Demonstrating Biomass Sustainability

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The Use of Wood Pellets from the US South in UK Power Generation



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Abstract

Current UK and EU regulations governing biomass sustainability and existing biomass certification schemes, do not fully address all potential negative impacts that may occur from using biomass supply chains in the US south; insufficient evidence is collected to ensure that the impact of forest derived biomass is either positive or neutral.

Data monitoring tools and technologies are available to track sustainability trends at a catchment area level and from individual harvesting sites. More detailed analysis, monitoring and collection of data is required to fully demonstrate the sustainability of biomass supply chains and genuinely contribute to emissions reduction targets.

Biomass Energy with Carbon Capture and Storage (BECCS) has been identified as an important tool for greenhouse gas (GHG) emission reduction; it forms a substantial component of IPCC modelling pathways for achieving climate change targets. It is also endorsed by the committee on climate change (CCC) in the UK as being an integral part of the UK's future energy generation portfolio. If BECCS is to be a substantial component of future energy generation in the UK, then improved sustainability requirements and more detailed evidence collection should be an integral part of any financial support mechanism to ensure a positive or neutral impact in the forest.

The use of biomass, in the form of wood pellets or any other forest derived feedstocks, has been challenged as unsustainable and leading to negative carbon and environmental impacts. Common challenges to the sustainability of wood pellet use include: deforestation; damage to sensitive sites and biodiversity; long-term loss of forest carbon; displacement of solid wood product markets; and changes in forest management practice leading to lower rates of carbon sequestration and storage.

A literature review has been carried out to identify the most relevant sustainability challenges for biomass use within the scope of this research. A process of gap analysis, against existing regulations and auditing standards, and consultation with biomass and forest industry experts, has been used to identify gaps in the current process of demonstrating biomass sustainability and to identify specific areas that require additional data and evidence. A case study was then used to test various tools and methodologies to address these gaps and identify suitable evidence. This showed that multiple options are available to improve biomass sustainability reporting and evidence gathering processes.

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List of Abbreviations

ABE	Amite Bioenergy
ASI	Assurance Services International
BECCS	Biomass Energy with Carbon Capture and Storage
BEIS	Department of Business, Energy and Industrial Strategy (UK Government)
BMP	Best Management Practice
BP	Biomass Producer
CAA	Catchment Area Analysis
CCC	Committee on Climate Change (UK Quango)
CCS	Carbon Capture and Storage
CDR	Carbon Dioxide Removal
COC	Chain of Custody
DBH	Diameter at Breast Height
DBI	Drax Biomass International
DUKES	Digest of UK Energy Statistics (UK Government)
Eurostat	Online database of European Commission data and statistics
EUTR	European Timber Regulations
FAO	Food and Agriculture Organisation (United Nations)
FAOSTAT	Online database of FAO land and forest data
FC	Forestry Commission (UK Government)
FIA	Forest Inventory and Assessment
FMU	Forest Management Unit
FR	Forest Research (part of UK Forestry Commission)
FRA	Forest Resource Assessment (FAO)
FSC	Forest Stewardship Council
GHG	Green House Gas
HCV	High Conservation Value
HWP	Harvested Wood Products
IEA	International Energy Association
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
ISAE	International Standard on Assurance Engagements

IUCN	Union for Conservation of Nature
JRC	Joint Research Centre of EC
LBE	La Salle Bioenergy
LEFT	Local Ecological Footprinting Tool
LIDAR	Light Detection and Ranging
LULUCF	Land Use, Land Use Change and Forestry
MBE	Morehouse Bioenergy
NFI	National Forest Inventory
NGO	Non-Governmental Organisation
NRDC	Natural Resources Defence Council
ODTs	Oven Dry Tonnes
ONS	Office of National Statistics (UK Government)
PEFC	Program for the Endorsement of Forest Certification
PFPI	Partnership for Policy Integrity
RED	Renewable Energy Directive
RO	Renewables Obligation
SBP	Sustainable Biomass Program
SDG	Sustainable Development Goals
SELC	Southern Environmental Law Centre
SFI	Sustainable Forests Initiative
SFM	Sustainable Forest Management
SRS	Southern Research Station (USFS)
SSP	Shared Socio-economic Pathways
TMS	Timber Mart-South
TPO	Timber Product Output Database (USFS)
TUP	Temporarily Unplanted
UNFCCC	United Nations Framework Convention on Climate Change
USDA	United States Department of Agriculture
US EPA	United States Environmental Protection Agency
USFS	United States Forest Service
USIPA	United States Industrial Pellet Association

Declaration and Copyright

I confirm that no part of the material presented in this thesis has previously been submitted for a degree in this or any other university. Where relevant, material from the work of others has been acknowledged.

Signed: A Dugan

Date: 10/02/23

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Chapter 1: UK Biomass Use, Sustainability and Challenges

1.0 BACKGROUND TO THE USE OF BIOMASS FOR INDUSTRIAL ENERGY

In 1997 the Kyoto Protocol set the first targets for a reduction in Greenhouse Gas (GHG) emissions relative to 1990 levels. The first commitment period began in 2005 with 37 industrialised countries and all European Union (EU) Member States committed to making reductions in emissions, with an initial EU combined target of 8% (United Nations Framework Convention on Climate Change - UNFCCC, 2008).

Under the Kyoto Protocol, each nation was responsible for creating its own mechanisms for change to achieve a target relative to the potential for renewable energy development in that country. The UK has historically had very low levels of renewable energy capacity and a heavy reliance on coal for power generation; 70% of the UK's electricity was generated from coal in 1990 (Department for Business, Energy and Industrial Strategy – BEIS, 2020). In 2004, the share of renewable energy in total energy consumption of the UK was at just 0.9%, which is low compared to the EU average of 8.5% (Eurostat, 2019).

To incentivise an increase in the production of renewable energy and begin a transition away from fossil fuels, the UK government introduced the Renewables Obligation (RO) in 2002. The RO provided financial incentives for energy generators to use biomass and other renewables to replace fossil fuels.

The prevalence of coal fired power generation in the UK provided the opportunity to substitute coal with biomass using the existing infrastructure, providing the potential for a large-scale increase in renewable generation, alongside the development of other renewable sources (Korhaliller, 2010). Initially, such a transition was achieved by co-firing biomass alongside coal, and ultimately by the full conversion of coal-fired boilers to biomass. The first conversions in the UK took place in 2013 and the use of biomass has increased substantially since that time (see section 1.1).

The use of renewables for all energy (heat and power) in the UK has increased to 11% of the total in 2018 compared to the EU average of 17.9% (Eurostat, 2019). In the UK power generation sector, renewables have increased from 3.5% in 2004 (predominantly hydro power) to 33% in 2018 (Digest of UK Energy Statistics – DUKES, 2019). The increase in power generation from renewables is primarily due to large-scale investment in onshore and offshore wind; the conversion of coal-fired power stations to biomass; and the more recent development of solar technology.

In 2021, renewable energy from wood and plant-based biomass made up 36% of all UK renewables, imported wood pellets represented 47% of this material and 17% of all renewable energy generation in the UK. Wind, solar and waste generation were the other major contributors to renewable generation. (Figure 1.1).

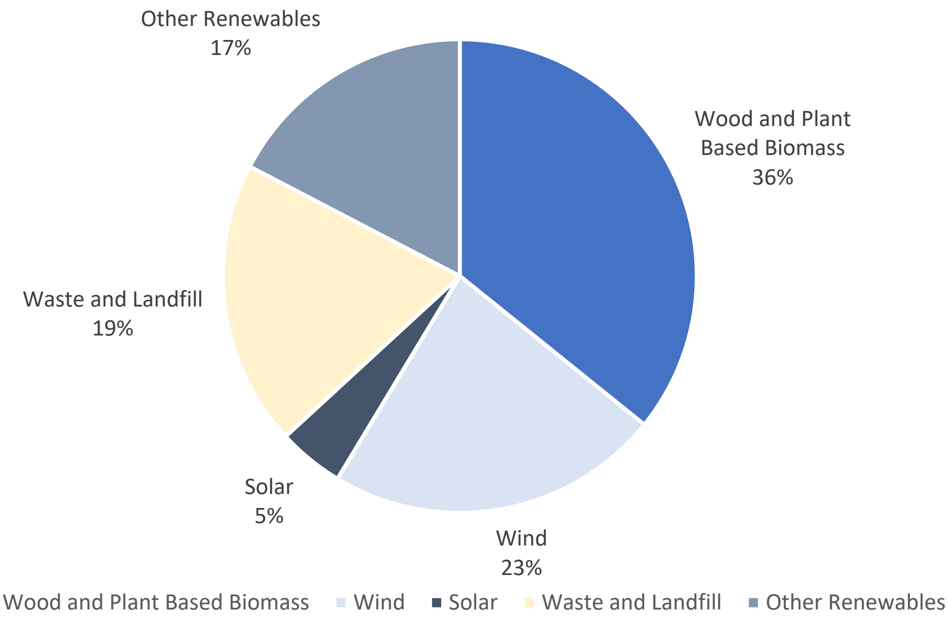


Figure 1.1: *The UK renewable energy generation mix 2021 (DUKES, 2022)*

1.1 THE USE OF INDUSTRIAL WOOD PELLETS IN THE UK

The use of wood pellets for large-scale energy generation in the UK began in 2009 with small scale experimental co-firing of pellets alongside coal in existing power stations. Co-firing was initially carried out on a trial basis, with relatively small quantities of imported pellets. Annual consumption increased up to 1.5 Mtonnes in 2012 (FAOSTAT, 2019), before further large-scale expansion began in 2013 (Figure 1.1).

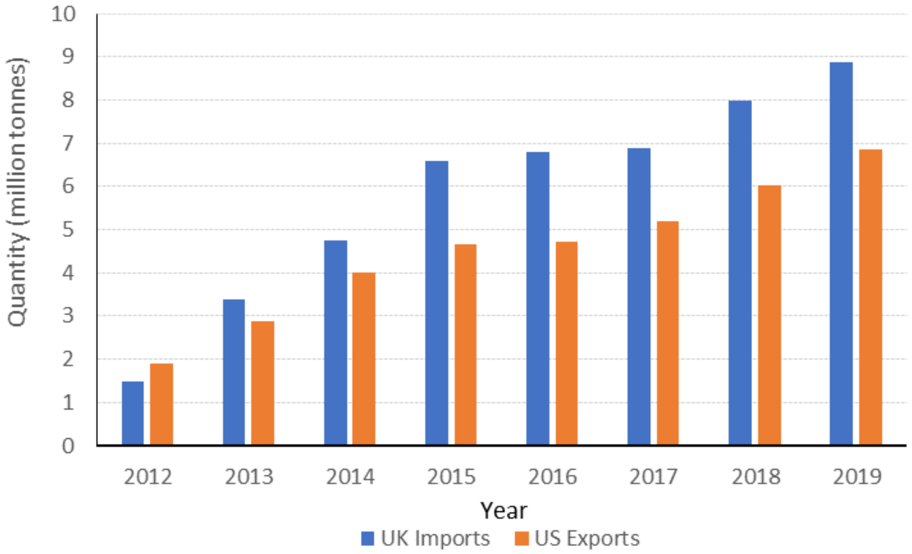


Figure 1.2: *UK imports and US export of wood pellets (FAOSTAT, 2019).*

Domestic biomass had been used at an industrial scale since around 2006, initially in Combined Heat and Power (CHP) plants (e.g. UPM's Shotton and Caledonian plants, later Wilton 10 and Iggesund CHP) and also in dedicated power plants (e.g. EON's Steven's Croft plant). The market for biomass arising from these biomass power plants was supplied by local surplus (e.g. forest and sawmill residues, waste wood and pulpwood) and whilst important in the context of the UK forest industry, these plants did not rely on imported biomass or operate at a scale that raised sustainability concerns. The major criticisms of the domestic biomass market at that time stemmed from competition for cheap feedstocks with the panel board sector and opposition groups argued for the cascading use of wood (Norbord, *2019*).

Drax power station, near Selby in North Yorkshire, became the largest consumer of wood fibre in the UK, converting 4 coal boilers to biomass between 2013 and 2015 with an annual demand of 7 Mtonnes of wood pellets (equivalent to 14 Mm^3 of wood fibre). Drax completed extensive research and development projects for a variety of biomass fuel types which lead to the commitment to use only compressed wood pellets for combustion in the converted boilers. The Drax research process demonstrated that conventional sources of biomass (e.g. wood chips derived from residues or pulpwood) can be extremely variable in their physical and chemical properties. The experience at Drax also showed that variability can be a challenge for use in a boiler designed to burn coal. Variations in moisture content, particle size or chemical composition can have a negative impact on the boiler both in terms of efficiency and damage leading to a major outage.

To produce wood pellets, the fibre must be ground down into fine particles, dried and then compressed (Drax, 2017); a process that is more expensive and energy intensive than making wood chips. Drax experimented with many forms of biomass prior to full conversion but ultimately opted to focus on wood pellet combustion due to several important advantages affecting the viability in its coal boiler conversions:

- Pellets have a more consistent and lower moisture content, typically around 4-8% compared to a range of 30-60% for wood chips, which has advantages for the efficiency of energy recovery, consistency of combustion rate and materials handling.
- Pellets can be easily ground into homogenous dust particles for injection into the boiler with existing infrastructure (e.g. in coal grinding mills) whereas wood chips require specialist processing equipment.
- Pellets are more cost effective and carbon efficient to transport over long distances due to improved bulk density and lower moisture content.

There has been a rapid increase in wood pellet imports to the UK since 2013 as co-firing and then conversion began to take place (Figure 1.1). The US emerged as the primary source of industrial wood pellets for UK biomass users due to a combination of positive factors. Firstly, there is a substantial area of forest and surplus of wood production in the US; there are 84 Mha of timberland (commercially productive forest) in the US South (United States Forest Service Forest Inventory and Analysis – USFS FIA, 2019) - around 30 times larger than the UK's commercial forest resource (Forestry Commission – FC, 2019). In addition, there is an average annual surplus of growth compared to removals (harvesting and other losses) of approximately 176 Mm^3 (USFS FIA, 2019). Other factors include a decline in traditional markets in the US South, excellent logistics and a relatively stable business environment all leading to the identification of the US South as the optimal place to source biomass and invest in wood pellet infrastructure (Stewart, 2015).

The UK has a very small forest area and relatively limited capacity for biomass production from existing forest resources. The current and historic level of pellet imports in comparison to the total production of roundwood for all markets in the UK is shown in Figure 1.2. In 2019, wood raw material imported in pellet form exceeded the total production of UK roundwood by 73% or 7.9 Mm^3 (FAOSTAT, 2020).

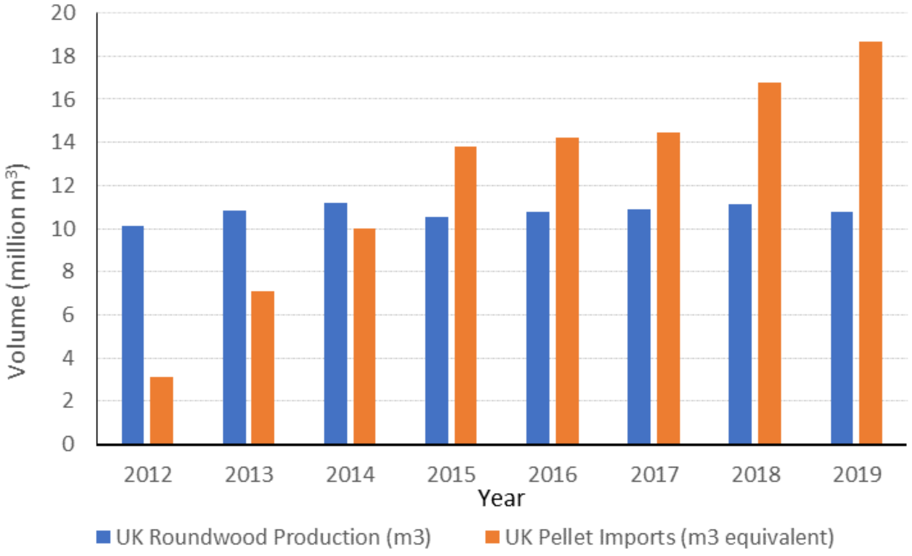


Figure 1.3: *UK imports of wood pellets compared to total roundwood production (FAOSTAT, 2020).*

Wood pellet exports from the US represent a very small proportion of the total US forest industry; in 2019 wood used for export pellets was equivalent to just 3.1% of the total US production of roundwood that year (Figure 1.3). Wood raw material demand for pellets is substantial in the context of UK energy and the UK forest industry, but not when compared to the scale of the entire forest industry in the US.

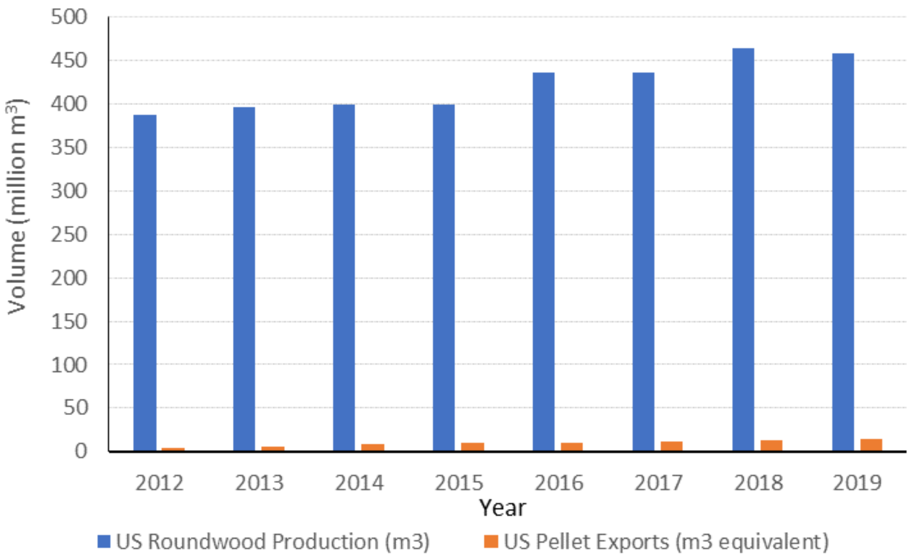


Figure 1.4: *US exports of wood pellets compared to total roundwood production (FAOSTAT,2020).*

In a global context, wood pellet utilisation is also small-scale relative to the use of wood fibre for other markets. Global wood pellet demand in 2020 is forecast at 41.9 Mtonnes for domestic heat & industrial use (Hawkins Wright, 2020), which is equivalent to around 88 Mm^3 of wood raw material which is small in comparison to the global production of wood fuel, primarily non-industrial, in 2018 of 1.9 billion m^3 and 2 billion m^3 of industrial roundwood (FAOSTAT, 2020), the total global wood pellet demand represents just 2.3% of the global harvest of wood products.

1.2 THE FUTURE USE OF BIOMASS

The use of biomass with Carbon Capture and Storage (BECCS) has been identified as one of the most viable options for Carbon Dioxide Removal (CDR). The future use of BECCS is considered to be one of the key pathways for reducing atmospheric concentrations of CO_2 and limiting the impact of global warming to 1.5 °C (Intergovernmental Panel on Climate Change – IPCC, 2018), see Figure 1.4.

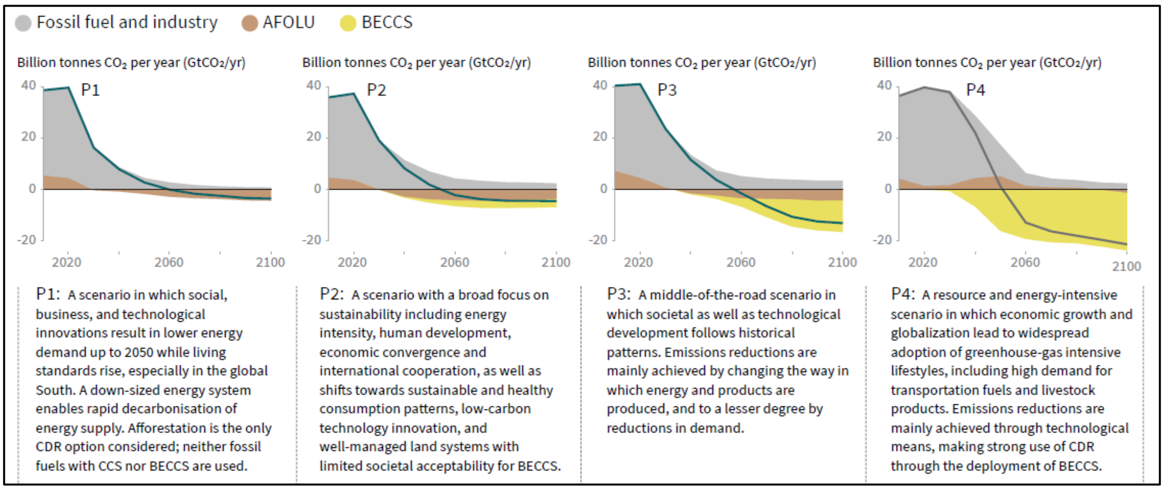


Figure 1.5: *IPCC modelling of future role of biomass in mitigation pathways (IPCC, 2018).*

The UK government has amended the 2008 Climate Change Act to create a legally binding target of zero net emissions by 2050. The change follows the Committee on Climate Change (CCC) recommendations in 2018 which included a call for an increase in the use of BECCS and a transition away from the use of biomass in transport, for heat and in power generation without CCS (CCC, 2018).

The role of biomass is also an integral part of the modelling work of Rogelj *et al*. (2018) looking at 6 integrated assessment models for limiting global mean temperature increases to below

1.5 ^{o}C. The Rogelj analysis was also considered in the work of Reid *et al*. (2019) which concluded that energy from biomass can make a significant contribution to reducing carbon emissions but, given the land intensive nature of biomass production and inherent limit on land availability, large-scale land intensive biomass should be transitional rather than permanent. The potential scale of future biomass use has raised some concerns over the sustainability of current and expanded future use of biomass, particularly in terms of land use change for energy crop development; the impact on food and water resources; and the impact on soil and biodiversity (Fajardy *et al*., 2019), these issues are explored further in the literature review in section 1.3.

1.3 BIOMASS SUSTAINABILITY, CRITICISM AND CHALLENGES - LITERATURE REVIEW

1.3.1 Methodology

A literature review has been completed to identify the range of sustainability related challenges associated with the use of wood pellets from the US South for bioenergy use in the UK. The search for relevant papers, reports, articles, modelling and analysis was restricted to wood pellet production in the US South for export to the UK. Only forest derived feedstocks were considered and only literature produced since 2009 were included, when pellet production for export began. The purpose of the review was to identify, collate and summarise the key themes and specific sustainability concerns relating to the use of biomass in the context described above. Literature was identified through a variety of search tools (including: web of science, science direct, research gate and google search - details of search terms are included in Appendix III); recommendations by industry experts and search of biomass and forestry related websites (e.g. USIPA, USFS, FC, IEA, Bioenergy Europe, NRDC, Dogwood Alliance, SELC, PFPI).

1.3.2 Anti-biomass campaign groups

Booth (2018), stated that wood pellets from the US South made from forest residues have a net emissions impact of 55%–79% at year 10 (in comparison to leaving this material to rot in the forest post-harvest), with net CO_2 emissions of 14–20 tonnes for every tonne of pellets. The paper also claims that net emissions may be ten times higher at year 40 if whole trees are harvested for feedstock and that the projected global pellet use would generate around 1% of world bioenergy with cumulative net emissions of 2 Gt of CO_2 by 2050. Booth (2018) founded an organisation called the Partnership for Policy Integrity (PFPI) which actively campaigns against the use of biomass for energy.

The Dogwood Alliance, based in North Carolina US, has had a long-standing campaign against the use of biomass and the production of wood pellets in particular. The Alliance has a campaign entitled: *our forest aren't fuel,* which claims that: burning wood as a heat source has been around since the time of cavemen; burning forests to fuel massive power plants is a climate and environmental disaster (Dogwood Alliance, 2021). This statement seems to suggest that the domestic use of wood fuel is acceptable but that industrial use is not. The data quoted in section 1.1 shows that global wood pellet utilisation is forecast at 88 Mm^3 in 2020 (Hawkins Wright, 2020) and total wood fuel consumption is at 1900 Mm^3 per year (FAOSTAT, 2020) – more than 21 times greater. The Dogwood statement also doesn't consider that the industrial wood pellet sector is formally regulated (as described in Chapter 2), whilst the domestic use of wood fuel globally has no formal governance or regulation; the Food and Agriculture Organisation (FAO) of the United Nations comments on the heavy reliance of the poor on wood fuel for their basic energy needs and the lack of robust policies and regulations on, and effective governance of, wood energy and wood fuel harvesting - in the context of domestic use in developing countries (FAO, 2016). The Dogwood campaign is also supported by the Natural Resources Defence Council (NRDC) and they claim that biomass harvesting in the US South is causing the destruction of sensitive protected forests such as bottomland hardwood forests.

In an article in the Environmental Journal in 2019, Ogden summarises the campaign against UK biomass utilisation citing the NRDC, the Dogwood Alliance and the Southern Environmental Law Centre (SELC) as having evidence that biomass demand is destroying US Forests this was based on a publication by these 3 activist groups entitled: Global Markets for Bioenergy are Devastating US Forests (2018). The evidence cited in the article is a series of photographs of harvesting sites where clear-cutting has taken place and a claim that whole trees have been used for biomass at a wood pellet plant. The article provides no further evidence to support the validity of the claim - the pellet plant owner claims that only low-grade material was used from the site and that all regulations and sustainability criteria were satisfied. Frost (2019) published an article for the Dogwood Alliance, in collaboration with the NRDC, Biofuelswatch and SELC, calling on the UK government to remove subsidies for the use of biomass as it encourages damaging logging practices that impact biodiversity and sensitive sites. The report does not mention the US pulp and paper industry or saw-timber mills which in 2019 consumed 20 times more fibre (374 Mm^3) than the wood pellet sector (18 Mm^3) according to FAOSTAT data (2020). These traditional forest industries are also not subject to the same sustainability regulations as the UK biomass sector, as described in section 2.1.

There is a robust and coordinated anti-biomass lobby centred around the organisations listed above and primarily active in the US South. The nature of campaigning tends to lead to emotive and sensationist statements to gain attention and support, as in some of the statements discussed above. Even where evidence is lacking, these claims should be taken seriously by the biomass sector and regulators and there should be a responsibility on the biomass producer to demonstrate that negative environmental impacts are not occurring as a result of their operations. Where these claims are supported in other literature, as discussed below, they are included in the scope of this research.

1.3.3 Papers and reports

In addition to the campaign groups discussed above, there are scientific papers and reports that challenge and question the use of biomass and the environmental impact of wood pellet demand. The European Academies Science Advisory Council (EASAC, 2019) raised concerns around biomass sustainability which were publicly countered by the International Energy Association Bioenergy Group (IEA) as including several errors, half-truths and generalisations, overlooking several important roles for bioenergy in climate change mitigation (IEA, 2019); this exchange demonstrates that within the scientific community the biomass sustainability debate is polarised and there can be limited common consensus on some issues. In 2012 the Royal Society for the Protection of Birds (RSPB), Greenpeace and Friends of the Earth produced a paper claiming that biomass is 'dirtier than coal' and calling for a change to carbon accounting methodologies. This short piece of work was followed up by much longer paper sponsored by Chatham House which also raised concerns over carbon accounting methodologies, the types of feedstocks being used for biomass, the forest types that could be affected and the impact on biodiversity (Brack, 2017).

Brack (2017), attempted to highlight some current and potential future negative impacts of biomass demand, recommending the following actions:

- Changes to carbon accounting rules to include changes in forest carbon stock
- More research into the full lifecycle GHG impacts of biomass
- Restricted use of biomass (including changes to subsidy), only permitting sawmill residues and post-consumer waste

These recommendations represent a way to avoid the complexities and variability of feedstock types, forest types and counterfactual use. Matthews *et al*. (2015) demonstrated that biomass feedstock and forest types are not universally good or bad in terms of their carbon impact; a combination of variables for each feedstock or forest type can lead to either good or bad outcomes. Therefore, restricting biomass feedstocks to only residues and wastes, as Brack (2017) suggests, could be considered a simplistic and ineffective conclusion. The use of sawmill residues could lead to negative climate and sustainability impacts if sourced inappropriately (e.g. where displacing a market for solid wood products), the use of roundwood from early thinnings can lead to a positive climate outcome and an increase in carbon stored in solid wood products (Matthews *et al.*, 2018).

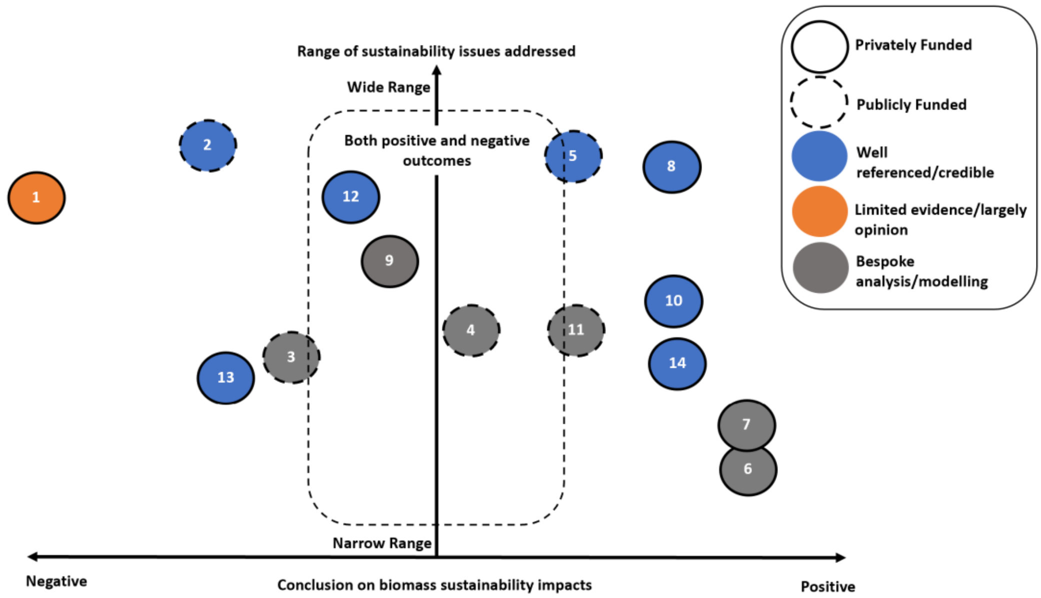
Some of the concerns raised by Brack (2017) are legitimate, as discussed in section 2.3, the use of some feedstocks and forest types could lead to poor climate impacts. The prevalence and likelihood of these outcomes requires more research. The Brack (2017) report has been publicly criticised by forestry and sustainability experts as lacking clear evidence and referencing, making multiple unsubstantiated declarative statements and expressing opinions that lack clarity and academic rigour (Dovetail Inc., 2018). A more complete piece of work, that also raises some potential concerns for biomass sustainability, was produced by Strange *et al*. (2015) for the European Commission (EC). It focused more on the range of potential future risks if biomass demand increased substantially without appropriate regulation. The Strange report for the EC focused on describing feedstocks that can lead to positive or negative climate impacts; forest types that could be threatened by biomass demand and the potential for competition with solid wood product markets.

Forsell *et al*. (2016) looked at the impact of an increase of future biomass demand on a range of sustainability issues. The report comments that a large-scale increase in biomass demand could intensify pressure on forest resources, leading to a loss of biodiversity and high competition with solid wood product markets. The modelling and analysis focused on feedstock types that might be used for biomass (e.g. the potential for saw-timber to be diverted into bio-energy markets) and the risk that sensitive forest types could become exploited by unregulated demand for biomass. One of the weaknesses of the Strange *et al*. (2015) report, is that the modelling is theoretical, rather than based on real life data and scenarios. The modelling is also limited as it does not include economic drivers and impacts or market dynamics, it assumes that demand will be maintained regardless of price trends, it also assumes that all feedstock types are fungible and could be readily used by a range of quite different markets.

In addition to reports that challenge the use of biomass, there are others that are supportive of biomass utilisation. Jefferies *et al.* (2017) uses USFS FIA data to show that the forest area of the US South has been increasing and not declining and that growing stock (the amount of carbon stored in the forest) has increased as a direct result of an increase in demand for wood products. The analysis finds that, in the period from 1953 to 2015, harvesting in the US South increased by 57%, largely driven by US economic growth and increased construction. Over the same period, annual wood growth increased by 112%, and inventory increased by 108% from 4 billion to 8.4 billion m^3. In total, annual growth exceeded annual removals by 38% on average.

1.3.4 Review and summary of most influential literature to this thesis

The studies that are considered to be the most influential and relevant to the scope of this research are summarised in Figure 1.5 below. Each piece of work has been scored according to the range of issues addressed, the conclusions reached on biomass sustainability - positive or negative - and according to its perceived credibility, based on the literature review.



1) Brack D, (2017). **2)** Strange et al., (2015). **3)** Stephenson et al., (2014). **4)** Matthews et al., (2015). **5)** Committee on Climate Change, (2018). **6)** Jefferies et al., (2017). **7)** Stewart P, (2015). **8)** Dale et al. (2017). **9)** Forsell, N. et al. (2016). **10)** Dale, V et al. (2017). **11)** Matthews et al. (2018). **12)** Fajardy et al. (2019). **13)** Searchinger et al., (2009). **14)** Lamers et al., (2013).

Figure 1.6: *Evaluation of the most influential reports and papers to the scope of this research on biomass sustainability in the US South.*

Following the literature review, the most commonly cited biomass sustainability issues have been collated and summarised in Table 1.1 with selected reports discussing each issue.

Table 1.1: *Summary of key sustainability issues identify across a range of studies.*

	Brack 2017	Strange et al. 2015	Stephenson et al. 2014	Matthews et al. 2018	Forsell et al. 2016	CCC 2018
Deforestation & degradation		✓ (blue)		✓ (blue)	✓ (blue)	✓ (blue)
Forest carbon, debt & payback	✓ (green)	✓ (green)	✓ (green)	✓ (green)	✓ (green)	✓ (green)
Use of whole trees and roundwood	✓ (orange)	✓ (orange)	✓ (orange)	✓ (orange)		
Negative impact on biodiversity	✓ (blue)	✓ (blue)		✓ (blue)	✓ (blue)	✓ (blue)
Diversion from other markets	✓ (orange)	✓ (orange)	✓ (orange)	✓ (orange)	✓ (orange)	
Use of old growth forest	✓ (blue)	✓ (blue)	✓ (blue)	✓ (blue)		✓ (blue)
Future increase in biomass use	✓ (orange)	✓ (orange)	✓ (orange)	✓ (orange)	✓ (orange)	✓ (orange)

Included in existing regulation ✓ (blue)   Partial inclusion ✓ (green)   Not currently included ✓ (orange)

The sustainability issues identified in the studies listed in Table 1.1 have been categorised according to their inclusion in existing biomass regulation. Despite the inclusion of forest carbon impacts in existing regulation, both Brack (2017) and Stephenson *et al.* (2015), have argued that current forest carbon accounting practices are not sufficiently accurate or robust. Matthews *et al*. (2018) also argued that some feedstock types can lead to negative impacts on forest carbon and that improved guidance and regulation is required to more clearly define biomass feedstocks that can have a positive impact.

1.4 AREAS OF CONCERN RELATING TO BIOMASS SUSTAINABILITY

The evidence of the literature review suggests that there are three critical fields of information that are central to understanding the sustainability and challenges of current and future biomass use, as described below:

1. <u>Feedstock types:</u> the type of wood raw material (or wood fibre) used for wood pellet production can vary considerably. Each of the following variables can have a major impact on whether biomass can be considered sustainable and whether the climate impact is positive or negative: species, growth rate, age, part of the tree, potential for use in alternative markets, counterfactual in the absence of biomass demand, impact on forest management.

2. Forest types: globally and within each country and region there can be a diverse range of forest types, from rapid growth plantations to slow growing high carbon primary forest. There are also commercial and productive forest areas and high biodiversity or designated protected areas. The forest type, management objectives and availability of opportunities can all have an influence on biomass sustainability and climate impacts.
3. Scale of future demand: the availability of sustainable biomass is finite, there are limitations. The concern over the future impact of biomass demand, and potential for land use change, is related to scale and appropriate regulation to avoid the many potentially negative impacts.

If biomass use is to be expanded, a clear understanding of the sustainability impacts is critical. Understanding which feedstocks, forest types and supply chain scenarios provide the best climate impacts is also required. The potential scale of expansion must be considered alongside the sustainability impacts, both for existing resources of woody biomass and the establishment of new biomass forests and crops.

1.5 AIMS AND THESIS LAYOUT

Given the review and discussion above the aims of this thesis were to:

- Identify a range of biomass feedstock and forest types, specific to the US South, that can be considered to provide biomass that has a positive or neutral climate impact. The feedstocks will be described through ***acceptable biomass pathways*** and specific criteria relating to the origin and impacts of the wood fibre being utilised.
- Review current regulatory reporting and sustainability evidence gathering processes to identify gaps between current evidence provision and the criteria necessary to demonstrate the use of good biomass.
- Develop a test methodology to demonstrate biomass sustainability; providing evidence that can address the gaps in the existing reporting process.
- Evaluate, through a case study, the effectiveness of the test methodology in demonstrating the sustainability of the recent use of biomass for pellet production in the US South.
- Consider the potential for expansion in the scale of future biomass use, explore the challenges associated with biomass availability forecasting and consider the potential for new dedicated biomass plantations to contribute to climate change mitigation.

The outline of this thesis is as follows:

Chapter 1: Introduction to Biomass Use, Sustainability and Challenges

Provides the background, context and purpose of the study.

Chapter 2: Identification of Sustainable Biomass Pathways

Details a review of current regulation, biomass research and informed opinion to understand the key sustainability challenges to the current use of biomass. The results of the review have been used to define a range of acceptable biomass supply chain pathways that can be considered to have a positive or neutral impact on climate and sustainability and to identify specific criteria to describe feedstocks that can lead to good and bad climate outcomes.

Chapter 3: Overview of Biomass Sustainability Reporting and Gap Analysis

Provides an overview of current sustainability reporting data and processes for the production of wood pellets in the US South. Gaps have been identified between current reporting data and processes and the criteria identified in Chapter 2. This chapter also describes a new methodology for additional evidence gathering to demonstrate biomass sustainability against the criteria and pathways developed in Chapter 2.

Chapter 4: Case Study of Additional Evidence Gathering Options

Presents data and evidence from a case study trialling the methodology developed in Chapter 3 for two pellet plants in the US South.

Chapter 5: Potential Scale of Future Biomass Utilisation

Considers the potential for large scale expansion of wood pellet use for energy generation based on the sustainability criteria and challenges discussed in this thesis and outlines the best available forecasts for sustainable biomass availability.

Chapter 6: Conclusion and Recommendations for Future Research and Action

Review of aims and objectives. Comments on results achieved and lessons learned. Recommendations for futures research and actions.

Chapter 2: Identification of Sustainable Biomass Pathways

2.0 INTRODUCTION

The purpose of Chapter 2 is to define a series of acceptable biomass pathways that can be used to determine whether a specific biomass supply chain can be considered to have a positive or neutral climate impact; or whether there is a risk of a negative climate impact. The pathways are intended to be used as a checklist for each forest, feedstock and supply chain type to determine whether the biomass can be considered to be good or bad in terms of the climate impact of utilisation and combustion. The pathway can also be used to indicate the type of evidence required to demonstrate compliance with each requirement.

2.1 METHODOLOGY

Each pathway was built on a series of criteria that are defined in Table 2.1. as being a requirement to demonstrate good biomass or to ensure that a negative outcome will not result from the use of biomass. These criteria were developed from the issues identified through the literature review in section 1.3 and the review of regulation detailed below in section 2.2; in addition to consultation with biomass industry experts (Drax sustainability team, Forest Research, Earthworm Foundation). To be comprehensive and representative of the identified sustainability risks and challenges, each pathway had to be based on current regulation and additional voluntary criteria that could satisfy any additional risks or concerns that were not currently included in regulation. To complete this process the following actions were taken:

1. Review current regulation, applicable to the use of biomass in the UK. Summarise specific requirements of the regulation that are relevant to the scope of this study. Details of applicable regulation were sourced from Ofgem, the UK government National Regulatory Authority for the gas and electricity sector. The specific requirements relating to biomass usage were reviewed and the key points that are relevant to the scope of this research are summarised in section 2.2 below; each of these requirements are included in the list of criteria detailed in Table 2.1.
2. Literature review of papers, reports, research and modelling relating to the sustainability of wood pellets from the US South (as described in section 1.3). Identification of sustainability issues and challenges and development of criteria that can address all issues specific to each forest and feedstock type (as detailed in Table 2.1).

2.2 REVIEW OF EXISTING REGULATION

There are 4 separate pieces of regulation that govern the sustainability of biomass use in the UK, these are:

- the UK Renewables Obligation - RO (2015),
- The Forest Europe Sustainable Forest Management Criteria - FE SFM (2015),
- The Renewable Energy Directive – RED (2018) and
- the European Union Timber Regulations – EUTR (2010).

Sections 2.1.1 to 2.1.4 below list the specific points in each piece of regulation that are relevant to the scope of this study.

2.2.1 UK Renewables Obligation (RO)

This is UK government legislation which sets out in schedule 3 of the Renewables Obligation Act the land criteria that must be met by any UK biomass user claiming subsidy. The criteria considered to be most relevant to the scope of this study, affecting forest land and sustainability, are:

- Supply chain Greenhouse Gas (GHG) levels must meet the UK government thresholds.
- Biomass must not be from land that, at any time during or after 2008, was primary forest, designated for nature protection purposes, highly biodiverse grassland, peatland, a former wetland area or a former continuously forested area.
- Biomass must be from a sustainable source (e.g. meeting the Forest Europe sustainable forest management (SFM) criteria, or other similar international SFM criteria).
- Harm to ecosystems must be minimised, including: soil and biodiversity maintained and protected; use of chemicals controlled and appropriate; disposal of waste to minimise negative impacts; adopting plans to deal with fires, pests and diseases.
- Biodiversity protected, including: rare and threatened species, key ecosystems, species of exceptional value.
- The productivity of the area must be maintained and the impact of harvesting on other land uses must be minimised.
- An adequate inventory of trees must be maintained to ensure that harvesting does not exceed the long-term capacity of the area to produce wood.
- Management must comply with local and national laws for health and safety.

The RO is regulated and enforced by Ofgem and each biomass user claiming subsidy must submit evidence to demonstrate compliance. The requirements listed above have been included in Table 2.1. to contribute to the definition of good and bad biomass.

2.2.2 Forest Europe sustainable forest management criteria (FE SFM)

These criteria define the concept of 'sustainable forest management' and underpin the objectives of the sustainable use of biomass. The criteria listed in Table 2.1, which relate to specific forest or feedstock types, are aimed at achieving these overarching objectives. The objectives are:

- Maintain the forest area and carbon stock;
- Encourage the production of forest products;
- Ensure soil and water protection is maintained;
- Maintain the forest ecosystem, health and vitality;
- Contribute socio-economic benefits; and
- Conserve and enhance biological diversity.

2.2.3 Renewable Energy Directive (RED)

The RED defines a series of sustainability criteria and GHG targets that are applied to the use of biomass and bioliquids within the EU. Forestry specific criteria for biomass, relevant to the scope of this study, are detailed below.

- Harvesting must be carried out legally and harvested sites regenerated.
- Maintenance of soil quality and bio-diversity.
- Harvesting maintains or improves the long-term production capacity of the forest.
- Carbon emissions from forestry and biomass are accounted for in a Nationally Determined Contribution (NDC) report, under United Nations Framework Convention on Climate Change (UNFCCC) rules, or there are local laws in place to conserve and enhance carbon stocks and sinks, reported through LULUCF (Land Use, Land Use Change and Forestry).

2.2.4 European Union Timber Regulations (EUTR)

The EUTR is legislation that aims to remove illegal timber from European supply chains. Any company importing wood products into the EU must be able to demonstrate compliance with EU and local (country of origin) laws, including due diligence to identify the appropriate legislation, supply chain traceability and transparency to evidence origin and specific criteria for the wood products.

2.3 THE IMPACT OF BIOMASS DEMAND ON FOREST CARBON

The largest area of contention identified through the literature review in section 1.3 were: the question of carbon neutrality; carbon reporting; and the impact of biomass use on both atmospheric carbon levels and forest carbon stocks. Booth (2018) and Brack (2017) both questioned the carbon impact of biomass, suggesting that it is having a negative rather than a positive impact. Stephenson *et al*. (2014) modelled scenarios that showed a possible negative impact for certain feedstock and forest types and Matthews *et al*. (2018) described a range of scenarios that can either lead to a positive or negative carbon impact depending on the forest type, feedstock type and the counterfactual usage. This section will discuss the range of debate around the carbon impact of biomass, giving an overview of differing views and opinions and explaining some of the questions that are required to be answered to demonstrate a positive or neutral impact from biomass use.

The use of biomass for energy has been considered by regulators to be carbon neutral, given that the CO_2 emissions from combustion are equal to the CO_2 absorbed during the growth of the biomass; an assumption originating from the national greenhouse gas inventories of the United Nations Framework Convention on Climate Change (UNFCCC). Supply chain GHG emissions (e.g. forest operations and transport) were not included in this debate as they are already accounted for in reporting to Ofgem and are not considered to be contentious.

Searchinger *et al*. (2009) challenged the carbon neutrality assumption on the basis that combustion emissions are not included in the accounting process. It was also argued that the counterfactual must be considered in any calculation of biomass emissions - the counterfactual describes the most likely alternative scenario in the absence of biomass demand (e.g. that harvesting might not take place, that the biomass would be used in other markets or that the biomass would be left on site to rot). The counterfactual debate has some validity, but it also introduces a considerable amount of uncertainty; for any given feedstock, forest type, ownership objective, or market scenario, there are multiple combinations of potential counterfactuals, even before considering the biological variables of each feedstock and forest type.

Another challenge to calculating the impact of biomass demand on forest carbon is the question of which baseline to use as the point of comparison. For an individual tree, or stand of trees, it could be at the point of planting (establishment), the point of harvesting or at another specific point in the rotation (e.g. at a point in time when the forest owner decides that the objective of management is wholly or partially for biomass production). Lamers *et* *al.* (2013) observed that from a forest owner perspective, the natural baseline is at the time of establishment, therefore all forests have accumulated a credit at the time of harvesting and no debt is incurred. The validity of the Lamers *et al*. (2013) approach depends on the forest owner's intentions and objectives of management at the time of establishment. A crop that has been specifically planted for biomass cannot incur a carbon debt, as the sequestration would not have occurred without the biomass demand.

The challenge for most biomass supply chains is the timescale of forest management activity and decision making. Forests can take many decades to grow, during which time markets and ownership objectives can change. In most cases, at the time of harvesting, the owner will have a range of options regarding whether to harvest and where to sell the timber, options that may not have been available at the time of planting. Each option can have a very different impact on forest carbon, future sequestration potential and carbon stored in solid wood products. Therefore, setting the baseline at the point of harvesting has become the most common basis for calculating the carbon impact of biomass demand, as this is the point at which the owner will make an irreversible decision. There is also the question of whether it is most accurate to consider the calculation of biomass impact on forest carbon for each individual tree, at a stand level or at a landscape level. The landscape level approach assumes a region or supply basin that has multiple stands of trees in a perpetual cycle of growth, harvesting and regeneration (either by planting or natural regeneration).

Determining the correct forest management reference level for an entire country has also been one of the greatest areas of contention in establishing the UNFCCC reporting basis. The forest resource, age class structure, management objectives, growth rates and market dynamics are different in every country. Therefore, agreeing a uniform baseline and compliance period against which every country must report can be a considerable challenge. Yet this is a key influencing factor in determining whether and when a bioenergy scenario becomes carbon beneficial (Lamers *et al.*, 2013).

In a report for the European Commission (Agostini *et al*., 2013) it was argued that the assumption of carbon neutrality is not valid since the harvest of wood for bioenergy causes a decrease in the forest carbon stock, which may not be recovered in a short time, leading to a temporary increase in atmospheric CO_2. This stand-based approach has been contested by many who argue that the impact on forest carbon should only be considered at a landscape level, for example the research by Jonkers (2012) and Matthews (2014) as discussed below.

Jonker *et al*. (2012) considered a landscape level approach in the US South and concluded that in some scenarios, where plantations already exist in multiple mixed age classes, carbon debt is non-existent. Jonker's view was supported by UK Forest Research (Matthews *et al*., 2014), suggesting that the growth of the remaining mid-rotation stands across the landscape will compensate for any short-term loss of carbon at the point of harvesting. Whilst theoretically true, the critical flaw in the landscape approach is the absence of counterfactual modelling. A comparison of what would have happened in the forest in the absence of biomass demand. Ter-Mikaelian *et al*. (2015) also supported the argument that the counterfactual should always be evaluated when considering the climate impacts of biomass and that it can lead to either positive or negative outcomes.

Stephenson & McKay (2014) attempted to model a range of counterfactuals and biomass supply scenarios in a study commissioned by the UK government. The model attempted to calculate the carbon payback times for a variety of biomass feedstock types and scenarios in North America, producing generally unfavourable results for the biomass sector, even when compared to coal combustion. The results were contentious, championed by the anti-biomass lobby and refuted by those in the forest industry and biomass sector. A follow up report was commissioned by the UK government (Howes *et al*., 2016) which included extensive stakeholder consultation on all sides of the debate. In conclusion, it was found that many of the scenarios and assumptions used in the original model were unlikely to occur in practice, and therefore the modelling results were entirely theoretical and not reflective of real-life scenarios in biomass supply chains. The model did show that where biomass demand influences forest management practice (e.g. changing rotation length, changing species or changing management objectives and the end use of timber), this can lead to negative climate outcomes. However, this form of modelling and analysis can only ever be theoretical and cannot genuinely reflect the real-life impact of biomass, the actual counterfactual in every biomass supply scenario can never be determined, therefore modelling will always be inherently flawed. The results of this work left regulators, stakeholders and those in the biomass sector in a difficult position, with uncertainty around the carbon implications of biomass use. There is a general acceptance that some types of biomass could lead to negative climate impacts (e.g. if sourcing biomass from high carbon primary forests). There is also agreement that some types of biomass can lead to immediate positive climate impacts (e.g. when the counterfactual is burned as waste with no energy recovery). Most feedstocks in current use do not fall into these extremes of the spectrum. Many feedstocks are from thinnings or low grade roundwood from commercial forests as a by-product of saw-timber production. Or they are mill residues from the processing of saw-timber (e.g. sawdust, wood chips, bark and off-cuts). These feedstocks could have both positive and negative climate impacts depending on a range of scenarios and assumptions.

To clarify these grey areas and model some scenarios that are more realistic to real life supply chains, Matthews *et al*. (2015) carried out extensive research and modelling for the European Commission. The aim was to predict the potential impact of biomass demand on the climate. The Matthews *et al*. (2015) modelling work also deliberately included a range of unrealistic scenarios to demonstrate the potential negative impacts that could occur from unregulated biomass demand. As a consequence of including such extreme examples in the modelling, the results of the analysis became difficult to interpret objectively. Each side of the debate could point to results that supported their case, especially in the absence of clear evidence detailing actual counterfactual scenarios and impacts from real life supply chains.

To bring greater clarity to the analysis and inform regulators with policy recommendations, Matthews *et al*. (2018) revisited the modelling analysis, once again including examples of both good and bad biomass but providing some clearer examples of the types of feedstocks and forest types that can lead to each pathway. The modelling included the identification of small or early thinnings as delivering a decrease in GHG emissions and a recommendation to strongly favour the supply of forest bioenergy as a by-product of wood harvesting for the supply of long-lived material wood products (e.g. saw-timber production).

Other academics have attempted similar modelling exercises. Sterman *et al*. (2018) produced a paper highlighting negative impacts from a selection of biomass scenarios. The main contribution of the Sterman *et al*. (2018) analysis was to demonstrate the complexity and variability of counterfactual modelling and that the output and results are entirely dependent on the input assumptions. Where these assumptions are invalid, or not representative of realistic scenarios, the results will be misrepresentative. It was not the intention of the study but the findings and assumption of the work have been widely challenged. Prisely *et al.* (2018) highlighted some of the weaknesses in the Sterman *et al*. (2018) report, especially the choice of unrealistic assumptions in the modelling. The Prisely paper was followed by further analysis by Rolls & Forster (2020) which challenged the validity of the original findings by questioning the choice of forest management assumptions and counterfactuals; and demonstrating that even a small difference in base assumptions can lead to a large difference in results.

Despite the substantial amount of research, debate, modelling and analysis into the carbon impact of biomass demand, there has been limited consensus and agreement. It is not practical to model every single biomass supply chain for every variable assumption, the combinations are too complex and often unknown. The counterfactual impact of any decision will always be uncertain, a decision of no harvest at one point in time, might be followed by a decision to harvest 6 months later if saw-timber markets or the personal circumstances of the forest owner change, therefore it is not valid to model a no harvest decision as the permanent retention of the carbon stock. Equally, the forest could then suffer a carbon loss as a result of natural disturbance (fires, wind, disease etc.). An original decision to harvest may have resulted in a much higher rate of sequestration and storage in the long term.

Starrs *et al*. (2018) demonstrated that the risk of wildfire was substantially higher in federally owned US reserved forest (where harvesting and management were restricted), compared to privately owned forests with active management. In California, the risk of wildfire in federal forest (2000-15) was almost double the risk in private forests where both had State firefighting resources. Starrs *et al.* (2018) found that the risk of fires in federal lands has increased by 93% since 1950-66 (from 1966 onwards), compared to only 33% in non-federal forests. The increased risk is due to a change in forest management practice which began in the 1970s which restricted harvesting practices in federal forests.

Harvesting, by definition, is the removal of carbon from the forest, leading to a reduction in forest carbon stock – this may be short term, medium term or permanent. Reducing forest carbon in this way can be a natural and necessary part of the forest cycle; management intervention emulating the natural cycle of climax, clearance and renewal in a more efficient and productive way. There are many circumstances where a combination of carbon storage in solid wood products, increased growth rates in replacement stands, and the use of by-products and residues to displace fossil fuels will lead to an overall better carbon balance, despite a lower carbon stock in the forest; as demonstrated by the work of Oliver et al (2014) and Favaro *et al*. (2020). The continual cycle of sequestration, storage in solid wood products, displacement of high carbon materials and regeneration of more productive replacement forest stands offers a better climate contribution than a static stand reaching senescence and emitting carbon through natural causes.

2.4 SUMMARY OF GOOD AND BAD BIOMASS CRITERIA

In this section, the criteria required to demonstrate the sustainability of biomass supply chains are detailed and explained, both in Table 2.1 and in the acceptable biomass pathways shown in section 2.5. The sustainability issues identified in section 1.3 and summarised in Table 1.1 have been incorporated into the acceptable biomass criteria and pathways described below, with the exception of the use of whole trees. This issue has been excluded as the term 'whole tree' is not a specific term for a forestry product or feedstock; it could refer to a small immature tree that is removed during thinning and is only suitable for biomass and pulpwood markets; or it could refer to a large mature tree of high value for saw-timber, therefore it is not accurate to discuss the use of whole trees rather than specific feedstock types. The criteria described in Table 2.1 refer to specific feedstocks and their potential impacts (e.g. saw-timber, low grade roundwood) rather than whole tree. One of the apparent concerns over the use of whole trees, as highlighted by Brack (2017) and other anti-biomass campaigners (Booth, 2018 and Frost, 2019) is to suggest deforestation or damage to high bio-diversity areas. These specific issues are addressed in the criteria in Table 2.1. The displacement of solid wood product markets or the use of saw-timber grade material for biomass could also be an issue if using larger diameter and higher quality feedstocks for biomass (Matthews *et al.*, 2018); this issue is also addressed in the criteria detailed in Table 2.1 below.

Table 2.1: *Summary of criteria to describe good and bad biomass. (NOTE: where the issue is currently partially covered by regulation, both blue and orange diamonds are indicated to show that some additional voluntary action is required to fully address the issue).*

Current regulatory requirement	🔷	**Carbon debt and payback**	**C**	**Regulatory requirement**	**R**
New voluntary requirement	🔶	**Deforestation and degradation**	**D**	**Market displacement**	**M**

	Examples of acceptable biomass:	**Explanatory text:**
C D R M 🔷 🔶	**Responsibly sourced sawmill residues.**	Sawmill residues that are compliant with both local and UK law; do not cause deforestation, degradation or displacement of solid wood products; compliant with UK GHG regulations.
C 🔶	**Forest residues from regions with high rates of decay, or where this material is extracted to roadside as part of standard harvesting practice.**	Research suggests that residues should not be specifically collected from the forest for biomass use in regions with slow rates of decay as this can lead to negative impacts (Matthew *et al.* 2018).
C 🔶	**Thinnings that improve the growth, quality or biodiversity value of forests.**	In most cases the objective of thinning is to improve the growth and quality of remaining trees for saw-timber production. Although it can also be appropriate to thin to improve bio-diversity value or to create space for new seedlings to develop. The purpose of thinning should be to improve the forest.
C D R 🔷 🔶	**Roundwood that helps to maintain or improve the growing stock, growth rate and productivity of forests.**	The use of roundwood should not reduce the long-term production capacity or carbon stock of the forest. Harvested sites must be replaced with an equal or better-quality area of forest after harvesting.

C D ◆	**Roundwood that helps to improve the health and quality of forests, for example by using storm, pest or fire damaged wood.**	Clearing diseased or damaged forest areas, to enable future regeneration of new forest, can be a suitable source of biomass even if the short-term carbon stock is reduced by the harvest (CCC, 2018). In some cases, clearing poor quality and low productivity stands in working forests, to establish a more productive and better-quality new stand, is also beneficial.
C M ◆	**Roundwood that is not merchantable to saw-timber markets.**	Saw-timber grade material, with access to a viable market, should not be used for biomass (Matthews *et al.* 2018). Biomass markets must not sustain elevated prices with the outcome of competing with and displacing otherwise viable solid wood product markets.
	Examples of bad biomass:	**Explanatory text**
C M ◆	**Biomass that drives harvesting decisions that would adversely affect the long-term potential of forests to store and sequester carbon.**	Biomass demand must not cause a change in management practice (e.g. shortening rotation lengths to produce less saw-timber and more biomass). It must not cause a reduction in carbon storage, sequestration or the production of solid wood products (CCC, 2018).
C D ◆	**Biomass that increases harvesting above the sustainable capacity of forests.**	As above, management should not be changed to produce more biomass and less saw-timber as this will reduce carbon stored in solid wood products (Matthews *et al.* 2018).
C M ◆	**Biomass that displaces solid wood product markets.**	Solid wood products can be effective at locking up carbon over the long-term (e.g. saw-timber for construction and furniture). This material displaces high GHG materials e.g. concrete, steel and bricks (CCC, 2018) and provides the most important revenue stream for forest owners. Biomass must be an additional and supplementary market.
C ◆	**Biomass that comes from stumps.**	The extraction of stumps, specifically for biomass use, can cause a large release of carbon from the soil and immediate emissions from the combustion of stumps (Matthews *et al.* 2018). There are some circumstances where the removal of stumps is necessary for pest and disease control, or for ground preparation prior to replanting. Stumps should not be extracted for biomass use.
	The use of biomass should avoid:	**Explanatory text**
C D R ◆	**Damage or disturbance to high carbon forests and soils.**	High carbon forests can be defined as primary forest, virgin forest, old growth forest, designated high bio-diversity forests. High carbon soils may include wetlands and peatlands. All the above are prohibited for biomass use under the Renewables Obligation (RO).
D R ◆	**Damage or negative impact to designated or known sensitive sites or identified high biodiversity areas.**	As above, also including identified protected sites within a forest area. This is included in existing regulation.

C D R ◆ ◆	**Deforestation or degradation of the forest resource.**	Biomass supply chain catchment areas must be monitored and evaluated to ensure that demand is not causing deforestation or degradation.
C D R M ◆ ◆	**Being the cause of direct or indirect land use change, which would lead to an adverse climate impact.**	Trends in forest cover and land use in biomass catchment areas must be monitored to ensure that biomass demand is not causing a negative climate impact as a result of land use change.
	The use of biomass must:	**Explanatory text**
D R ◆	**Maintain the protective functions of forests and ecosystem services, including following best practice for protection of water and soil quality.**	Biomass suppliers must adhere to local and UK regulation to protect water, soil and biodiversity. They must also follow Best Management Practice (BMP) as defined locally at the forest level. Minimising disturbance to ecosystems is one of the requirements of the RO.
C D R ◆ ◆	**Implement practices which help to reduce the risk of forest fires, pests and diseases.**	Active Sustainable Forest Management (SFM) should be encouraged, this includes thinning and clearing to reduce the risk of fire, pests and disease. Following the Forest Europe principles of SFM (or other similar criteria) is one of the requirements of the RO.
R ◆	**Promote and ensure respect for human rights through all levels of the supply chain, including safeguarding the labour rights of workers and not engaging in any form of discrimination, nor compulsory or child labour.**	This is included in existing local and UK legislation.
R ◆	**Verify that appropriate safeguards are in place to protect health and safety in the forest and at the pellet mill.**	This is included in existing local and UK legislation.
R ◆	**Verify that legal, customary and traditional tenure and use rights of indigenous people and local communities related to the forest, are identified, documented and respected.**	This is included in existing legislation (EUTR, RO) and also in the sustainable Biomass Program (SBP) certification Standard.
R ◆ ◆	**Verify that food and water supplies, or the subsistence needs of local communities, are not compromised due to forest biomass sourcing.**	The impact of biomass demand must be evaluated at a forest landscapes level. This includes looking at impacts on biodiversity, food, water and the socio-economic impacts on communities. These impacts must be monitored over time with appropriate intervention to resolve any negative issues.
◆	**Verify that biomass sourcing contributes to local prosperity.**	As above.
R ◆	**Ensure that all biomass used is fully compliant with international and local legislation.**	This is part of existing standard practice.

2.5 ACCEPTABLE BIOMASS PATHWAYS RESULTS

The criteria detailed in Table 2.1 above have been used to develop acceptable biomass pathways as detailed in the Figures 2.1 to 2.5 below. The pathways include all current regulatory requirements for forest and land sustainability and additional voluntary requirements that would be necessary to demonstrate a positive or neutral climate impact from the use of biomass. Considering the specific forest types that can be suitable for biomass use, the key factor is whether the forest is protected in any way; classified as high-carbon or designated as High Conservation Value (HCV). If the forest is not protected and commercial species are being used, as opposed to rare and protected species, then it can be suitable for biomass use providing that the other criteria are being met. Therefore, all pathways begin with the same general description of a suitable forest type.

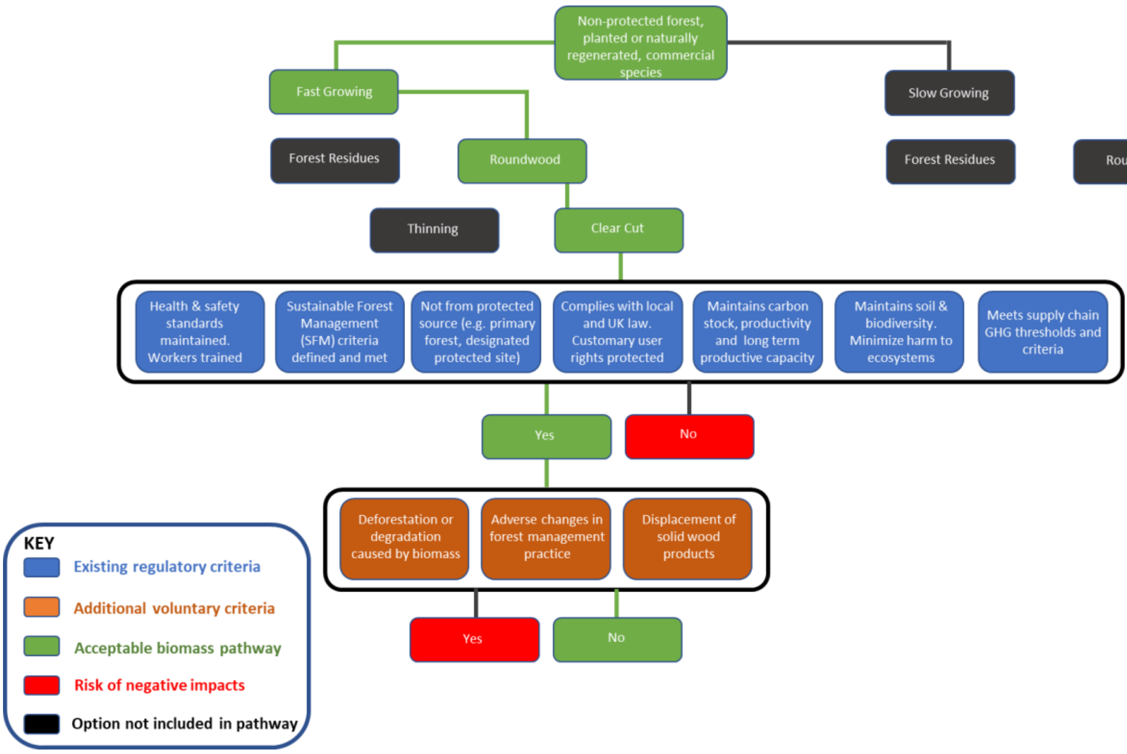


Figure 2.1: *Pathway 1, roundwood from clear cutting – fast growing forest.*

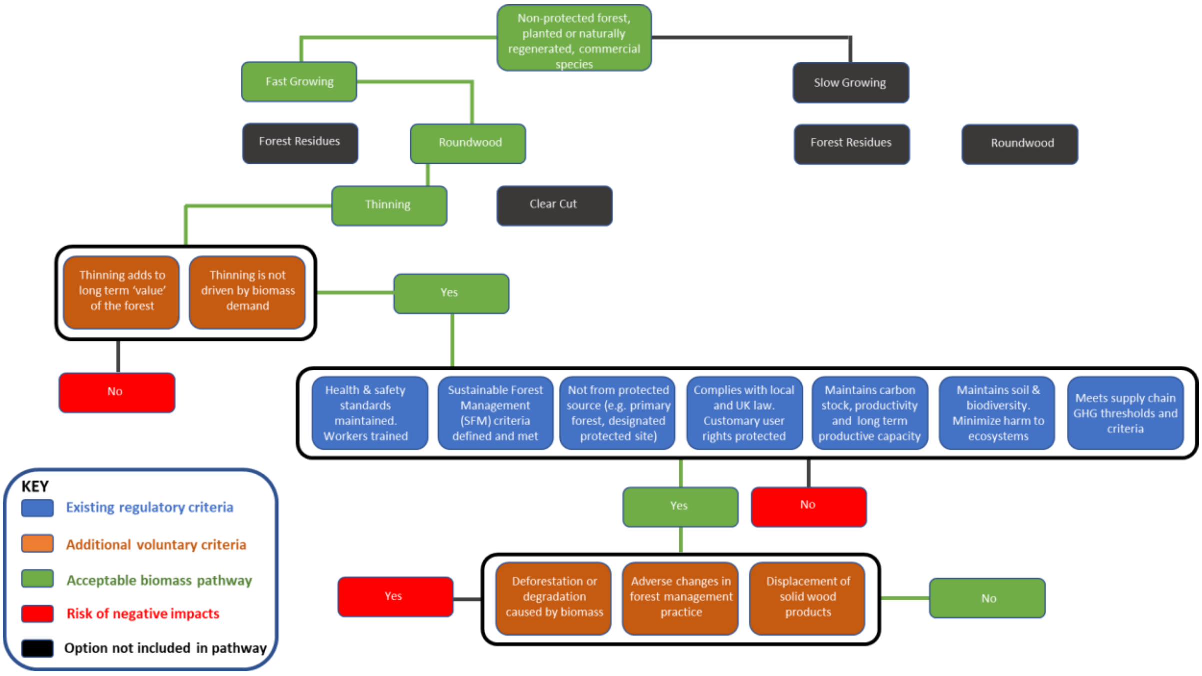


Figure 2.2: *Pathway 2, roundwood from thinning – fast growing forest.*

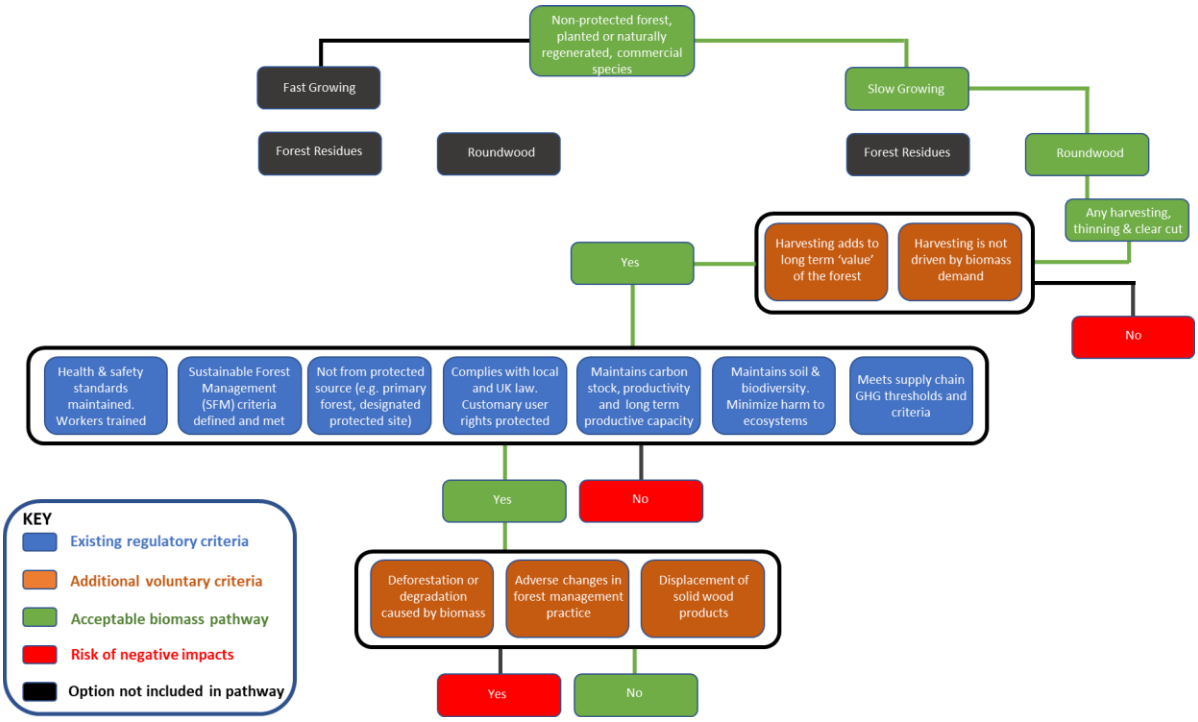


Figure 2.3: *Pathway 3, roundwood from clear cutting and thinning – slow growing forest.*

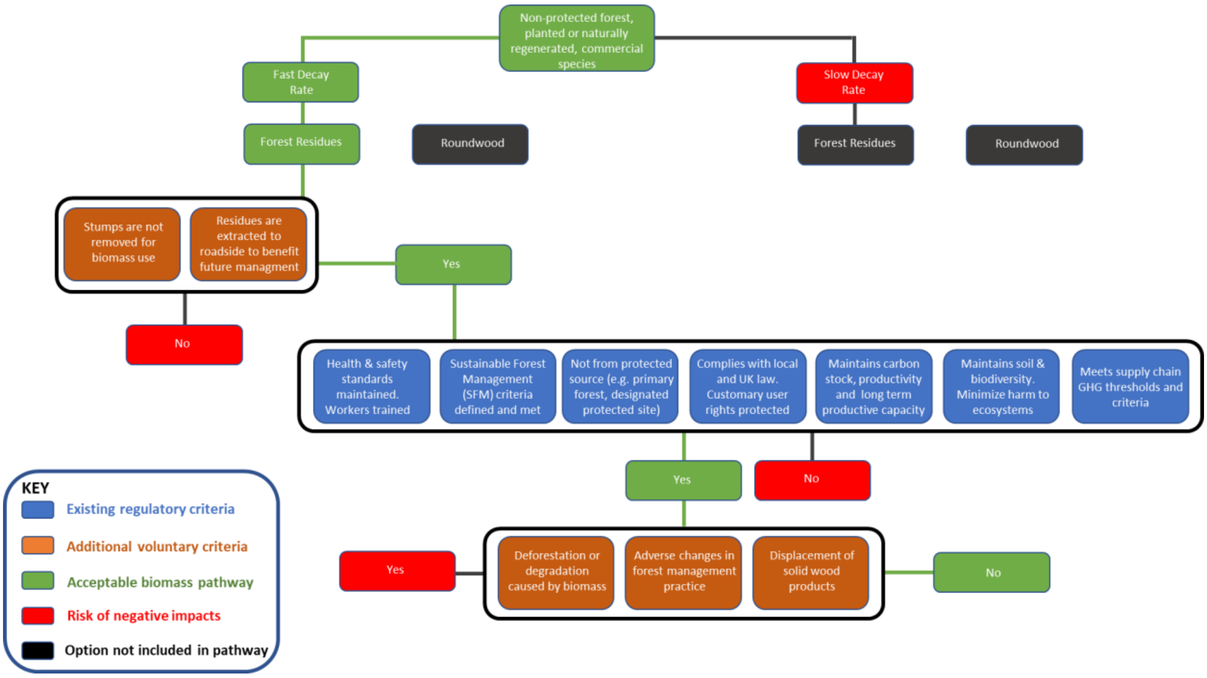


Figure 2.4: *Pathway 4, forest residues.*

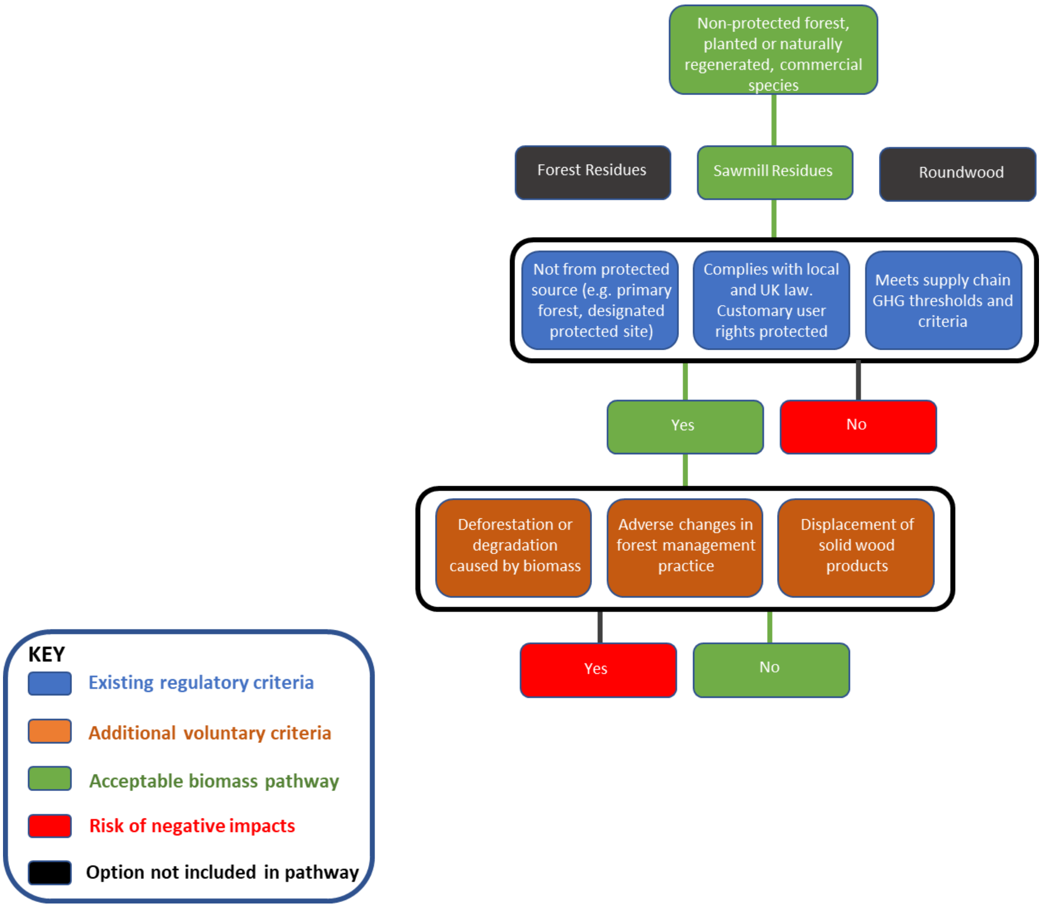


Figure 2.5: *Pathway 5, sawmill residues.*

2.6 DISCUSSION

A concern often cited when criticising the use of biomass, which is not addressed in these criteria or pathways, is the question of combustion emissions – that stack emissions from biomass combustion are higher than from coal. It is correct to suggest that the current use of biomass contributes to atmospheric levels of GHG when combustion emissions are directly released into the atmosphere. The energy density of biomass - as compared to coal - often means that emissions at the point of combustion can be higher per unit of energy generated than for fossil fuels. The differential in emissions can be as low as 3-4% (as at Drax power station), but it can be higher in less efficient generating units. These emissions are theoretically offset by the growth of the biomass; either prior to combustion in the form of a carbon credit; or post-combustion with a carbon debt that must be repaid by replacement biomass on the harvested land; the issue of carbon accounting is discussed in more detail in section 2.3. One option to resolve the combustion emissions issue is to ensure that any future use of new biomass is only permitted in combination with carbon capture and storage (CCS), as advocated by the Committee on Climate Change (Biomass in a Low Carbon Economy, CCC. 2018). Considering all of the evidence and focusing primarily on the sustainability of future biomass use, it is reasonable to support the CCC recommendation; if biomass is to be comparable with other renewables and a viable climate change solution, it must be capable of negative or genuinely neutral emissions. In practice this means CCS combined with improved sequestration at the forest level (e.g. through improved growth and better management practice).

The combination of criteria and pathways outlined in this chapter represent an aggregation of the best available knowledge and science on this issue into a workable tool for demonstrating biomass sustainability. If these sustainability criteria are combined with CCS, the future use of biomass should achieve a genuinely positive impact on climate change with increased sequestration and storage at forest level and zero emissions at the point of combustion. Biomass that can meet the criteria and pathways that have been developed in this chapter should have a positive or neutral impact on climate change and the environment; compliant with both current regulation and best available science. Demonstrating compliance to the new criteria is a challenge that will be addressed in Chapters 3 and 4.

Chapter 3: Overview of Biomass Sustainability Reporting and Gap Analysis

3.0 INTRODUCTION

The purpose of Chapter 3 is to review and summarise the current sustainability reporting process for UK biomass and to conduct a gap analysis of the existing process against the criteria identified in Table 2.1. The gaps identified in the first part of this chapter will be addressed by the additional evidence gathering processes described in section 3.11 and tested in the field in Chapter 4.

3.1 METHODOLOGY

Details of the current biomass sustainability reporting process, criteria and examples of evidence provision were obtained from Ofgem. These are described throughout this chapter and compared to the criteria described in Table 2.1. as a means of identifying any gaps. Information on biomass sustainability certification schemes, in particular the Sustainable Biomass Program (SBP), were obtained directly from SBP (publicly available on their website), from the current version of the standard and from examples of auditing reports that are in the public domain. Experts in biomass sustainability reporting and SBP certification were consulted for their opinion and the results of the gap analysis were reviewed and discussed with these experts to ensure it was accurate and reflective of genuine gaps in evidence at the time of review. The experts were Laura O'Brien and Richard Peberdy of the Drax sustainability team, they have been involved in reporting biomass sustainability since 2013 and have been involved with SBP since its inception. The review took place in December 2019.

3.2 DESCRIPTION OF SUSTAINABILITY DATA REPORTING PROCESS

The Ofgem reporting criteria have been reviewed as part of this analysis and summarised in Figure 3.1 below. A 5-step process is followed to determine the level of data required and the reporting methodology for biomass sustainability. The 5 steps, as defined by Ofgem, are detailed on the left-hand side of the graphic. On the right-hand side, next to each step, the criteria considered to be relevant to this study have been summarised following a review of the Ofgem guidelines, this summary has been produced following a review of relevant legislation, guidelines and reporting criteria as part of the research for this thesis.

Figure 3.1: *Summary of biomass sustainability reporting guidelines.*

3.3 REVIEW OF OFGEM PROFILING DATA

Large scale biomass users in the UK are required to submit annual profiling data to Ofgem using the Ofgem sustainability template. A modified version of this dataset is published on the Ofgem website. Comparing the published data to the requirements detailed in Table 2.1 shows that the published data does not provide sufficient detail about feedstocks and supply chains to clearly demonstrate sustainability compliance. It provides a summary of the volume of each consignment; the end user details; general information on species and forest type; and a public commitment that the RO land criteria have been met. The profiling data submitted to Ofgem could provide a good overview of the supply chain if reported at a tract level (each individual forest harvesting site). However, in the Ofgem dataset, supply chains are combined into country or regional level large consignments, or grouped as an entire feedstock type (e.g. all forest residues from the US). These consignments can include tens or hundreds of thousands of tonnes of biomass from many thousands of different forests or tracts, therefore it is not possible to demonstrate the compliance of one specific supply chain from forest to mill using this data. An example of the level of data provided by UK energy generators to Ofgem for reporting under the RO is shown in Table 3.1 below. The data has been extracted from the 2017-18 reporting data submitted by Drax to Ofgem. Each category amalgamates multiple sources of biomass, classified as either secondary residues or forest residues at a country level. Combining data in this way does not enable the sustainability criteria to be assessed at a tract or forest level, or even at a catchment area level for a specific pellet mill, therefore this profiling data is of limited use in demonstrating compliance with the RO sustainability criteria or any additional criteria, as described in Table 2.1.

Table 3.1: *Example of Annual Profiling Data.*

Fuel Name (as named on the Register)	Wood Pellets	Wood Pellets
Fuel Reference (as named on the Register)	Secondary Residues - USA	Forest Residues - USA
Fuel state	SOLID	SOLID
Fuel type	BIOMASS	BIOMASS
Quantity	590,540	1,896,548
Units	Tonne	Tonne
Density	N/A	N/A
Does the fuel meet the Land Criteria?	YES	YES
Does the fuel meet the GHG emissions criteria?	YES	YES
If "Yes" or No" to GHG emissions, please enter the gCO2eq/MJ of electricity	33.79	45.1
Does the fuel meet the definition of biomass?	YES	YES
The material from which the biomass was composed	Woody Biomass	Woody Biomass
The form of the biomass	Pellets	Pellets
Where the biomass was plant matter or derived from plant matter, the country where the plant matter was grown?	USA	USA
Is the biomass wood or derived from wood?	YES	YES
Name the forest or name the region of source at state/county level	US South	US South
Select forest type from the following:	MIX OF THE ABOVE	MIX OF THE ABOVE
Select harvesting system from the following:	MIX OF CLEARFELL & THINNING	MIX OF CLEARFELL & THINNING
Was the forest managed to supply energy and non-energy markets?	YES	YES-MAJORITY
Was the harvest made as part of a pest/disease control measure?	YES-MINORITY	YES-MINORITY
Intention for forest/land manager to retain forest cover, restock or encourage natural regeneration within 5 years of felling?	YES-MAJORITY	YES-MAJORITY
Indicate the proportion, by weight, of hardwood?	26-50%	26-50%
Indicate the proportion, by weight, of softwood?	51-75%	51-75%
Indicate the proportion, by weight, of wood that was likely to be protected or threatened species:	None	None
Indicate the proportion, by weight, of saw log (in accordance with definition in the Orders):	1-25%	1-25%

3.4 THIRD PARTY CERTIFICATION – SUSTAINABLE BIOMASS PROGRAM

Additional evidence, supplemental to the profiling data, has always been required to demonstrate regulatory compliance. UK energy generators initially used bespoke systems of data collection to give evidence of compliance, these systems were verified by auditing against International Standard on Assurance Engagements (ISAE) 3000. In 2013, the Sustainable Biomass Program (SBP) was co-founded by large-scale biomass using energy companies (including Drax, RWE, Hofor and Orsted) to standardise the sustainability reporting and evidence gathering process. The SBP builds upon existing forest certification programmes, such as the Sustainable Forest Initiative (SFI), Forest Stewardship Council (FSC) and the Programme for the Endorsement of Forest Certification (PEFC).

In 2015, Ofgem carried out a benchmarking exercise to determine the extent to which third party verification schemes are able to meet the regulatory sustainability criteria in the RO. The results are presented in the Renewables Obligation Sustainability Criteria (Ofgem, 2018). The results show that only SBP can meet all of the regulatory requirements to demonstrate biomass sustainability. The benchmarking process found that the pre-existing forest certification standards were focused primarily on forest management and lack some of the regulatory requirements necessary for biomass (e.g. the impact on ecosystems and forest productivity, maintenance of biodiversity and supply chain GHG data), this is detailed in Table 9 of the Ofgem report (2018). It is to be expected that SBP is the most appropriate standard as it was specifically created for the purpose of demonstrating biomass sustainability to achieve regulatory compliance. SBP is now a fully independent organisation; the role of the energy companies is now solely as stakeholders. The current structure is detailed in Figure 3.2.

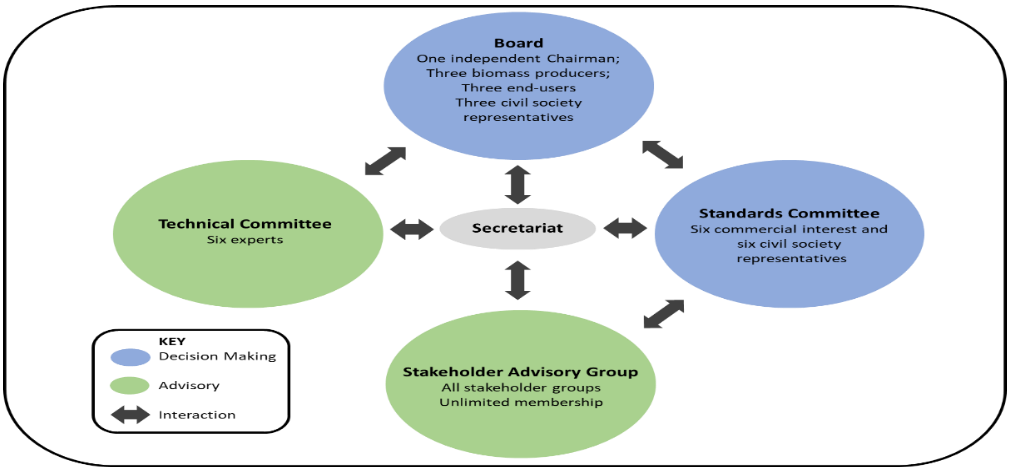


Figure 3.2: *Operational structure of SBP.*

Third party auditing is carried out against a set of principles and criteria as defined by the SBP Framework Standard (2015). Auditing is undertaken by international forest industry auditing companies (e.g. NEPCon, SCS, DNV, BV). A summary of these principles and criteria is shown in Table 3.2. The summary and the full guidance documents provided by SBP have been used for the gap analysis to evaluate the extent to which SBP can meet the 'good biomass' criteria described in Table 2.1.

Table 3.2: *Summary of SBP Principles and Criteria.*

Principle 1: Biomass feedstock is legally sourced	
Criterion 1.1	The Supply Base is defined
Criterion 1.2	The forest owner and manager hold legal use rights to the forest
Criterion 1.3	There is compliance with the requirements of local, national and applicable international laws, and the laws applicable to Forest Management
Criterion 1.4	All applicable royalties and taxes have been paid
Criterion 1.5	There is compliance with the requirements of CITES
Criterion 1.6	Harvesting does not violate traditional or civil rights
Principle 2: Biomass feedstock is sustainably sourced	
Criterion 2.1	Management of the forest ensures that features and species of outstanding or exceptional value are identified and protected
Criterion 2.2	Management of the forest ensures that ecosystem function is assessed and maintained through both the conservation/set-aside of key ecosystems or habitats in their natural state, and the maintenance of existing ecosystem functions throughout the forest
Criterion 2.3	Management of the forest ensures that productivity is maintained
Criterion 2.4	Management of the forest ensures that forest ecosystem health and vitality is maintained
Criterion 2.5	Management of the forest ensures that legal, customary and traditional tenure and use rights of indigenous peoples and local communities related to the forest, are identified, documented and respected
Criterion 2.6	Appropriate mechanisms are in place for resolving grievances and disputes, including those relating to tenure and use rights, to Forest Management practices, and to work
Criterion 2.7	The basic labour rights of forest workers are safeguarded
Criterion 2.8	Appropriate safeguards are in place to protect the health and safety of forest
Criterion 2.9	Regional carbon stocks are maintained or increased over the medium to long term
Criterion 2.10	Genetically modified trees are not used

SBP has been strongly criticised by some NGOs which claim that there are serious concerns about SBP's independence and ability to credibly evaluate the climate and ecological impacts of the biomass industry (NRDC, 2017). One of the key concerns is a lack of balanced governance, with a dominant representation from the biomass sector in the early years. The new structure shown in Figure 3.2 above may go some way to increasing the diversity of stakeholders. Critics also claim that forest carbon (Brack, 2017), sustainability and legality (NRDC, 2017) are not adequately addressed or independently verified. Brack (2017) also claimed that SBP does not set out precisely what evidence must be provided to demonstrate compliance within each indicator on the grounds that it will vary among different operations, and that the requirements for maintaining forest carbon stocks are too vague.

Third party certification relies on the credibility of the standard and of the auditing process; the rigour, integrity and experience of the auditor to ask the right questions and make appropriate judgment calls in determining if the level of evidence provided is sufficient to meet the standard. The process requires competent oversight and public transparency to build confidence, otherwise it is dependent on trust rather than evidence. To determine the capability of SBP to meet the criteria set out in Table 2.1, both the technical detail of the standard and the current level of evidence used by auditors must be considered. Gaps may be evident in the principles and criteria and the public transparency of evidence. However, given that the evidence will vary for each separate audit, supplier and scenario; it is not within the scope of this study to evaluate the SBP auditing process and quality of evidence provided, only whether the technical requirements in the standard are sufficient to demonstrate the criteria detailed in Table 2.1.

3.5 GAP ANALYSIS METHODOLOGY

A gap analysis has been carried out using SBP Framework Standard (2015). The gap analysis compares current regulation (as defined in the regulatory review conducted in chapter 2), the SBP principles and criteria and the sustainable biomass criteria defined in Table 2.1. The purpose of the analysis was to ascertain whether the SBP guidelines issued for auditing their criteria are sufficient to meet the definition of acceptable biomass outlined in Table 2.1; as detailed in the left-hand column of Table 3.3 below. The analysis was completed through discussion with biomass experts (as described in section 3.1) and comparison of examples of evidence for each criterion.

3.6 GAP ANALYSIS RESULTS

The gap analysis identified 13 instances where the current SBP Standard does not fully meet the ‘good biomass’ criteria defined in Table 2.1. The results of the gap analysis have been reviewed and confirmed as accurate by biomass sustainability experts familiar with the SBP process (Laura O’Brian and Richard Peberdy of the Drax sustainability team). The gap analysis shows that there are a number of areas where additional evidence will be required to demonstrate compliance against the criteria listed in Table 2.1. The current version of the SBP standard (at the time of writing) does not sufficiently address all of the sustainability criteria that can be considered necessary to demonstrate a positive or neutral impact.

Table 3.3: *Gap analysis of SBP criteria against 'good biomass' requirements.*

Examples of acceptable biomass:	Current regulation? (Y/N/Partial)	Included within SBP? (Y/N/Partial)	Relevant SBP criteria	Comment on current gaps with SBP principles and criteria	Additional evidence required? (Y/N)
Responsibly sourced sawmill residues.	Partial	Partial	All principles 1 & 2	Displacement of other markets not included	Yes
Forest residues from regions with high rates of decay, or where this material is extracted to roadside as part of standard harvesting practice.	No	No	None	Specific details on residue utilisation are not collected or reported	Yes
Thinnings that improve the growth, quality or biodiversity value of forests.	No	Partial	2.4.1	Does not specifically address thinnings	Yes
Roundwood that helps to maintain or improve the growing stock, growth rate and productivity of forests.	Partial	Yes	2.9	Only considered at a regional level, unclear on impact if regional trends are declining - vague criteria	Yes
Roundwood that helps to improve the health and quality of forests, for example by using storm, pest or fire damaged wood.	Partial	Partial	2.9	Only considers regional trends and status of the forest, not specific feedstocks - vague criteria	Yes
Roundwood that is not merchantable to saw-timber markets.	Partial	Partial	None	More detailed profiling data required	Yes
Examples of bad biomass:					
Biomass that drives harvesting decisions that would adversely affect the long-term potential of forests to store and sequester carbon.	No	Partial	2.3.1, 2.9.2	Only considers regional trends and status of the forest, does not look at management options	Yes
Biomass that increases harvesting above the sustainable capacity of forests.	No	Yes	2.3.1	Supply base assessment, not individual forest	No
Biomass that displaces solid wood product markets.	No	No	None	Not currently addressed	Yes
Biomass that comes from stumps.	No	Partial	2.2.1	Does not exclude stumps but requires controls	Yes
The use of biomass should avoid:					
Damage or disturbance to high carbon forests and soils.	Yes	Yes	2.2.2	Should currently include each site with procedures and inspections in place, in addition to regional level	No
Damage or negative impact to designated or known sensitive sites or identified high biodiversity areas.	Yes	Yes	1.5.1, 2.1.1, 2.1.2, 2.2.4		No
Deforestation or degradation of the forest resource.	Partial	Partial	2.3, 2.4.1	Does not address deforestation or degredation, only productivity	Yes
Being the cause of direct or indirect land use change, which would lead to an adverse climate impact.	Partial	partial	2.9.2	Does not specifcally address the causes of land use change, if necessary	Yes
The use of biomass must:					
Maintain the protective functions of forests and ecosystem services, including following best practice for protection of water and soil quality.	Yes	Yes	2.2		No
Implement practices which help to reduce the risk of forest fires, pests and diseases.	Yes	Yes	2.4.2		No
Promote and ensure respect for human rights through all levels of the supply chain, including safeguarding the labour rights of workers and not engaging in any form of discrimination, nor compulsory or child labour.	Yes	Yes	1.6.1, 2.7		No
Verify that appropriate safeguards are in place to protect health and safety in the forest and at the pellet mill.	Yes	Partial	2.8	Only covers forest workers, not at the pellet mill	Yes
Verify that legal, customary and traditional tenure and use rights of indigenous people and local communities related to the forest, are identified, documented and respected.	Yes	Yes	2.5.1		No
Verify that food and water supplies, or the subsistence needs of local communities, are not compromised due to forest biomass sourcing.	Partial	Yes	2.5.2		No
Verify that biomass sourcing contributes to local prosperity.	No	No	None	Not currently addressed	Yes
Ensure that all biomass used is fully compliant with international and local legislation.	Yes	Yes	1.3		No

3.7 SUMMARY CRITERIA WITH EVIDENCE GAPS

Table 3.4 summarises the criteria identified in table 2.1 which are not currently addressed by the SBP Standard. The right-hand column offers comments on nature of the gaps.

Table 3.4: *Summary of gaps in current evidence provision.*

Examples of acceptable biomass:	Examples and comment on current gaps against SBP criteria
Responsibly sourced sawmill residues.	Displacement of other markets not included
Forest residues from regions with high rates of decay, or where this material is extracted to roadside as part of standard harvesting practice.	Specific details on residue utilisation are not collected or reported
Thinnings that improve the growth, quality or biodiversity value of forests.	Does not specifically address thinnings
Roundwood that helps to maintain or improve the growing stock, growth rate and productivity of forests.	Only considered at a regional level, unclear on impact if regional trends are declining - vague criteria
Roundwood that helps to improve the health and quality of forests, for example by using storm, pest or fire damaged wood.	Only considers regional trends and status of the forest, not specific feedstocks - vague criteria
Roundwood that is not merchantable to saw-timber markets.	More detailed profiling data required
Examples of bad biomass:	
Biomass that drives harvesting decisions that would adversely affect the long-term potential of forests to store and sequester carbon.	Only considers regional trends and status of the forest, does not look at management options
Biomass that displaces solid wood product markets.	Not currently addressed
Biomass that comes from stumps.	Does not exclude stumps but requires controls
The use of biomass should avoid:	
Deforestation or degradation of the forest resource.	Does not address deforestation or degradation, only productivity
Being the cause of direct or indirect land use change, which would lead to an adverse climate impact.	Does not specifically address the causes of land use change, where necessary
The use of biomass must:	
Verify that appropriate safeguards are in place to protect health and safety in the forest and at the pellet mill.	Only covers forest workers, not at the pellet mill
Verify that biomass sourcing contributes to local prosperity.	Not currently addressed

3.8 METHODOLOGY FOR DEVELOPING EVIDENCE GATHERING TOOLS

The case study methodology and practical options for improving the degree of evidence available to demonstrate biomass sustainability have been developed as part of this chapter. The proposed methodology and data gathering approaches were developed by analysing the specific gaps in current evidence provision and considering the type of data and evidence that could be used to address each gap. Using an existing knowledge of available data sources and potential new data sources, and through discussion with biomass industry experts, a range of potential new approaches to gathering evidence were created and described in this chapter.

To address the gaps in Table 3.4, more detailed questioning of the type of biomass being used and the impact of biomass utilisation on the forest landscape are required. Some of these criteria need to be site specific, relating to every individual load of biomass procured (e.g. definition of feedstock type), others require a more high level view, looking at the trends in the forest landscape around the pellet mill, the catchment area from which the biomass is sourced (e.g. impact on other markets, trends in forest management practice). A summary of the type of additional evidence that could be collected for each criterion is given in Table 3.5.

Table 3.5: *Summary of additional evidence that could be collected to demonstrate sustainability.*

	Examples of good biomass:	Additional Requirements to Demonstrate Sustainability
1	**Responsibly sourced sawmill residues.**	SBP considers legal requirements for residues but does not consider displacement of other markets. Supply and demand and the impact of residue utilisation on other markets in the catchment area should be evaluated.
2	**Forest residues from regions with high rates of decay, or where this material is extracted to roadside as part of standard harvesting practice.**	The type and extent of forest residue utilisation should be considered, the site-specific impact and the regional decay rates that are typical in that catchment area.
3	**Thinnings that improve the growth, quality or biodiversity value of forests.**	The purpose of harvesting should be monitored (e.g. crop improvement, aesthetic/wildlife) and the impact of thinnings at a regional level and whether this is consistent with good practice.
4	**Roundwood that helps to maintain or improve the growing stock, growth rate and productivity of forests.**	Harvesting levels need to be monitored at a catchment area level, impacts and trend on the growing stock evaluated.
5	**Roundwood that helps to improve the health and quality of forests, for example by using storm, pest or fire damaged wood.**	Feedstock specific details required (e.g. what type of roundwood is used, the purpose of harvesting, the future plan for the forest).
6	**Roundwood that is not merchantable to saw-timber markets.**	Consider displacement of saw-timber markets, impact of biomass demand on the catchment area trends, monitor prices for biomass and other wood

		product grades to consider the incidence or risk of displacement.
	Examples of bad biomass:	
7	**Biomass that drives harvesting decisions that would adversely affect the long-term potential of forests to store and sequester carbon.**	Monitor forest management trends at a catchment area level, impact on forest carbon stocks, growth rates, forest management practice (e.g. changes in rotation length).
8	**Biomass that displaces solid wood product markets.**	Consider trends in the wider market and evaluate any potentially negative impacts.
9	**Biomass that comes from stumps.**	Feedstock classification and reporting.
	The use of biomass should avoid:	
10	**Deforestation or degradation of the forest resource.**	Monitor forest cover and forest quality at a catchment area level. Quality includes carbon stocks, species composition, rate of saw-timber production and any impact on bio-diversity.
11	**Being the cause of direct or indirect land use change, which would lead to an adverse climate impact.**	Identify any trends in land use change and the primary cause/drivers if relevant.
	The use of biomass must:	
12	**Verify that appropriate safeguards are in place to protect health and safety in the forest and at the pellet mill.**	SBP to widen the scope of audit to include both forest and pellet mill.
13	**Verify that biomass sourcing contributes to local prosperity.**	Evaluate the impact of biomass demand on the community around the pellet mill - socio-economic impact assessment.

3.9 GRANULARITY OF DATA COLLECTION

To understand what type of feedstock has been used, the purpose of harvesting and the future management plan for a particular site, it is necessary to have detail and information relating to that specific supply chain, rather than general information from across a catchment area. However, it would be extremely challenging to attempt to achieve this level of granularity for all criteria. A typical pellet mill of around 500000 tonnes/yr capacity will use more than 1 Mm^3 of feedstock each year. In the US south this is likely to be sourced from several hundred different forest harvesting sites. For example, in 2019 Drax Biomass International (DBI) sourced around 3 Mtonnes of wood fibre from 1180 different sites to supply it's 3 pellet mills in the US south (DBI, 2020). Given that each truck carries around 25 tonnes of product (as limited by local road traffic legislation), that equates to around 128000 deliveries of feedstock each year. It would not be practical or possible to evaluate every truck load, or every site, for all criteria. In addition, site specific information is not sufficient to determine the wider impact or influence of biomass demand on the catchment area. Therefore, a combination of multiple approaches will be required.

Every truck load can be logged on entry into the pellet mill for specific feedstock details, which would include: feedstock type, weight, source location, owner details etc. This level of information is standard practice and a minimum required to purchase and pay for feedstock and manage stock at the mill; it is not sufficient to adequately describe the biomass type or its impacts for the purpose of demonstrating sustainability. A more detailed analysis of the trends and impacts on forest management, forest inventory and forest markets at a catchment area level is required; in addition to granular data about each load of feedstock.

3.10 APPROACH TO EVIDENCE COLLECTION - DEVELOPING A METHODOLOGY

Based upon the gap analysis (the review of the current evidence; and the criteria required to demonstrate biomass sustainability - Figure 3.3), a 5-step methodology was developed. The process outlined below includes evidence gathering, analysis, evaluation, monitoring, review and revision. Each step is explained in more detail in section 3.11 and specific activities are described as a proposed method of fulfilling each requirement. These activities will be trialled in the case study presented in Chapter 4.

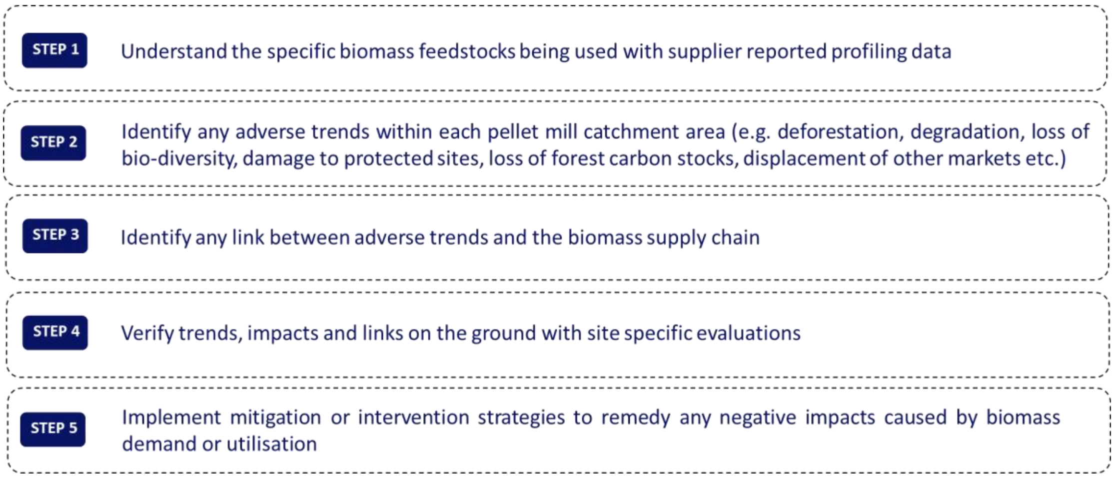


Figure 3.3: *Methodology for additional data and evidence gathering.*

3.11 EVIDENCE COLLECTION PROCESS

3.11.1 Step 1: profiling data

Collect additional information for each truck load of fibre to provide more specific details about each harvesting site for each truck load, including:

- Type or purpose of harvest (e.g. thinning, clear cut, aesthetic/wildlife)
- Species being supplied
- Total area of harvesting site
- Total tonnage of harvesting site

- Owner's plan for future management (e.g. re-plant, natural regeneration, convert to other use)
- Location coordinates of the site

These details can only be collected from forest derived biomass (e.g. roundwood from thinning and clear cutting, in-woods chips and harvesting residues). Sawmill residues are from a secondary supplier and it is currently not possible to trace the forest origin of each load of sawdust, shavings or sawmill chips. Sawmills buy logs from multiple sources and multiple forest sites, these logs are then stored together in a yard or storage area at the mill; sometimes unsegregated but often segregated by species, size and quality rather than by site of origin. The mill will operate by producing a certain specification of end product within any given work period; typically requiring the use of logs of similar size, quality and species; a mixture of raw material from multiple sites. As a consequence, the by-product of this process (chips, sawdust, shavings and off-cuts) will be produced from material derived from multiple sites within the sawmill catchment area; it is not possible to differentiate one site from another once the logs have been mixed and processed. These residues will often be sold to multiple users (e.g. animal bedding markets, panel and pulp mills or for biomass). The sawmill is able to demonstrate the source of its feedstock in total but it cannot match each load of processing residues to a specific forest site. When considering the impact of biomass demand as it relates to sawmill residues, criteria must be limited to legality and market displacement and the more general sustainability performance of a particular supplier. These aspects are covered in the SBP audit, with the exception of the impact on other markets, address in step 2.

3.11.2 Step 2: catchment area data collection

High level evidence (as opposed to site specific evidence) should be collected and evaluated to understand the relevant trends occurring within the catchment area of each pellet mill, prior to its operation and up to present day - subject to data availability. Evidence can be in the form of publicly available data (e.g. National Forest Inventory (NFI) databases), bespoke consultancy data (e.g. market price data, market production data, forecasts of future trends), or it can be anecdotal (e.g. interviews with forest owners, contractors and forest managers). The potential for remote sensing data (e.g. satellite imagery or LIDAR) to be used to demonstrate some metrics should also be investigated. For example, evidence of land use change or deforestation. Two specific pieces of work will be trialled in Chapter 4 to evaluate the viability of multiple approaches and data sources for gathering evidence at a catchment area level, these are:

Catchment area analysis (CAA): evaluation of forest inventory, market and management trends in a pellet mill fibre supply basket. Detailed analysis of growth rates, harvesting trends, carbon stock, market dynamics, wood price trends and changes in forest management practice.

Remote sensing of key metrics: A trial process to test the use of remote sensing technology to evaluate key metrics in pellet mill catchment areas at a high level. Satellite imagery will be used to evaluate changes in land use and forest cover. Remote sensing data will be used to monitor bio-diversity changes through identification of habitat changes for key species.

The purpose of these two approaches is to more clearly understand the impacts of biomass demand in the forest landscape around a pellet mill and to evaluate the viability of various data sources and methodologies for demonstrating compliance with the sustainability criteria detailed in Table 2.1. The data gathering exercise will be undertaken by specialist consultants in each field of expertise (e.g. local professional foresters for forest management and market insights in CAA, bio-diversity experts and remote sensing specialists). Analysis of the data, a summary of findings and a review of the process is included in Chapter 5.

3.11.3 Step 3: data analysis

Context and interpretation will be required to draw conclusions from the data gathered in step 2; therefore, each specialist consultant will be required to provide a professional opinion following a review the data to determine the extent to which an identified trend can be considered positive or negative and the extent to which biomass demand has been an influencing factor in the formation of the trend. For the case study, consultants with extensive local knowledge of each catchment area have been engaged to gather the data and form an expert opinion on the impact of biomass demand in the forest landscape. If this case study is successful in providing greater insight into sustainability trends and the impact of biomass demand, then future use of this approach would also require a qualified local expert to gather and evaluate the data.

3.11.4 Step 4: verification post harvest

A process of 'ground truthing' should be used for evidence identified through each of steps 1 to 3 to verify and validate the data and findings; either through physical inspection of sites on the ground, by the use of remote sensing technology and through the use of a sense-check cross-comparison of multiple data sources. One option that will be investigated in Chapter 5 is the use of post-harvest evaluations; revisiting individual harvesting sites that have been used to supply biomass to ensure that the future quality of the forest has been maintained and that data provided are accurate.

3.11.5 Step 5: review, revise, mitigate

To complete the process for the biomass user, action must be taken to remedy or mitigate any negative trends identified through steps 1 to 4. The process must be an ongoing cycle of continual monitoring, evaluation and modification of the sustainability criteria as necessary. For example, if a pattern of deforestation is identified, and a link to biomass demand is evident, then the biomass user must take action to modify their procurement process to ensure that forest owners retain and maintain forest in the long-term. There might also be a requirement for the biomass user to facilitate or fund the planting of new forest areas to mitigate against a loss of forest as a result of biomass demand.

3.12 SUMMARY OF SUSTAINABILITY DATA COLLECTION PROCESS

The proposed methodology, detailed above, involves additional voluntary criteria and data collection processes to the existing regulatory reporting and certification systems as described in Figure 3.4. The voluntary criteria can complement current sustainability processes and fit alongside a biomass user's current requirements for sustainability compliance.

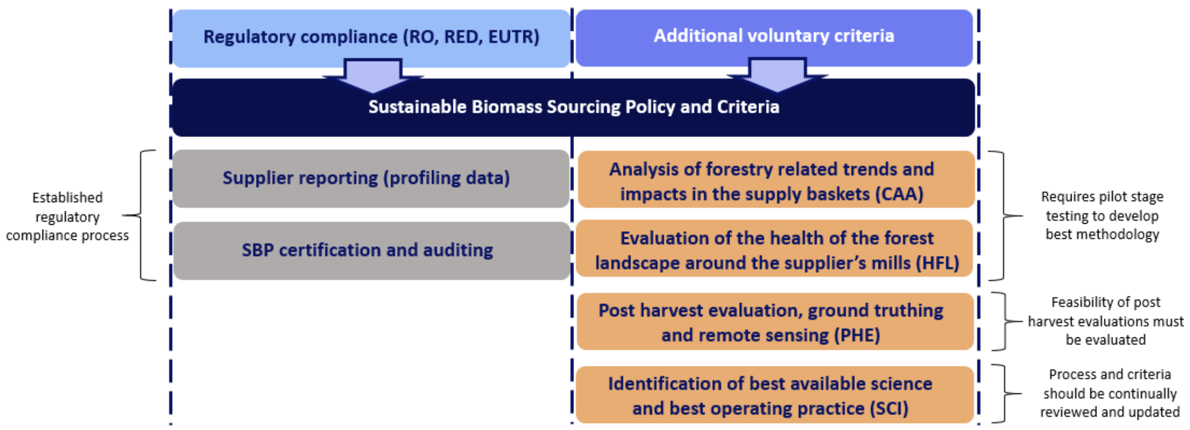


Figure 3.4: *Summary of sustainability evidence gathering process.*

It is proposed to use a range of tools and processes to improve the understanding of sustainability performance and monitoring of the impact of biomass demand in the supply chain. In combination, these tools can contribute to a more robust body of evidence to demonstrate biomass sustainability. Figure 3.5 below shows how these various tools relate to the gaps identified in the current process of audit and regulation.

	Examples of good biomass:		
1	Responsibly sourced sawmill residues.	SBP	CAA
2	Forest residues from regions with high rates of decay, or where this material is extracted to roadside as part of standard harvesting practice.	PRD	SCI
3	Thinnings that improve the growth, quality or biodiversity value of forests.	CAA	PHE
4	Roundwood that helps to maintain or improve the growing stock, growth rate and productivity of forests.	CAA	PHE
5	Roundwood that helps to improve the health and quality of forests, for example by using storm, pest or fire damaged wood.	CAA	PRD
6	Roundwood that is not merchantable to saw-timber markets.	CAA	PRD
	Examples of bad biomass:		
7	Biomass that drives harvesting decisions that would adversely affect the long-term potential of forests to store and sequester carbon.	CAA	PHE
8	Biomass that displaces solid wood product markets.	CAA	
9	Biomass that comes from stumps.	PRD	
	The use of biomass should avoid:		
10	Deforestation or degradation of the forest resource.	CAA	RSD
11	Being the cause of direct or indirect land use change, which would lead to an adverse climate impact.	CAA	RSD
	The use of biomass must:		
12	Verify that appropriate safeguards are in place to protect health and safety in the forest and at the pellet mill.	SBP	
13	Verify that biomass sourcing contributes to local prosperity.	RSD	

SBP	Sustainable Biomass Program
CAA	Catchment Area Analysis
SCI	Science Monitoring
PRD	Profiling Data
RSD	Remote Sensing Data
PHE	Post Harvest Evaluation

Figure 3.5: *Additional evidence gathering options and role in meeting sustainability criteria. (NOTE: these codes reflect the minimum required use of information sources or tools to address the issue, in most cases multiple sources are required to fully address an existing gap).*

SBP: Ongoing auditing against the SBP standard, this is the primary evidence tool for legal and regulatory requirements.

CAA: Data gathering, interpretation and analysis of forest inventory and market trends in the pellet mill catchment area, primarily focused on the forest carbon impacts of biomass demand.

SCI: An ongoing programme aimed at monitoring scientific evidence and debate as it develops to ensure that the criteria and focus of evidence gathering remains relevant and appropriate.

PRD: The biomass user must ensure that the range of data and information collected prior to harvest is appropriate and accurate and sufficient to categorise the biomass feedstock and forest type.

RSD: Trial the use of satellite imagery and remote data sensing methodologies to monitor high level sustainability metrics (e.g. forest cover, land use, carbon and bio-diversity).

PHE: Explore a range of options to monitor and evaluate forest sites in the years subsequent to harvesting to ensure that the long-term production capacity and 'value' of the site is maintained.

3.13 SUMMARY

This chapter has identified a range of gaps in the current process of evaluating and demonstrating biomass sustainability against the 'good biomass' criteria developed in Table 2.1. Detailed above are six potential tools that can be used in combination to build a portfolio of evidence that can be used to assess and demonstrate whether biomass supply chains are meeting the required sustainability criteria. Two of these tools are established in the biomass sector, SBP certification and monitoring scientific developments and debate. The other four tools are either new of less commonly used, or not utilised in the way described in this thesis. These four tools and approaches to evidence gathering will be trialled in a case study detailed in Chapter 4.

3.14 DISCUSSION

The criteria, gaps and challenges, associated with demonstrating biomass sustainability, cannot be described as definitive, they are dynamic and evolving. Therefore, the findings presented in this chapter are a snapshot view based on the best available data and interpretations at the time of review and analysis. The general understanding of sustainability values and impacts will continue to develop and evolve with further research and experience within the biomass sector; future challenges and requirement may be different to those identified during this research. Government pressures and priorities can change, impacting regulatory requirements and changing the type and degree of data required for compliance. Forest industry certification is also an evolving tool; the most effective schemes targeting continual improvement. The gaps identified in this chapter and the tools and methodologies to be trialled in the case study, should be considered a starting point towards better understanding rather than a definitive solution to demonstrating biomass sustainability.

Chapter 4: Case Study of Additional Evidence Gathering Options

4.0 INTRODUCTION

The results of the research included in Chapters 1 to 3 of this thesis suggest that additional evidence is required, supplemental to existing regulatory compliance, to be able to demonstrate the sustainability of biomass feedstocks and supply chains; addressing gaps in current regulatory requirements and to monitor some of the potential impacts of biomass demand that are not currently included in the provision of biomass sustainability evidence. In Chapter 3, several potential data gathering and analysis methodologies were suggested. In Chapter 4, some of these approaches have been trialled to test the availability of data and the potential of the approach to improve the evidence base for demonstrating biomass sustainability. The purpose of gathering additional evidence is to be able to answer the questions posed in the acceptable biomass pathways described in Figures 2.2 to 2.6. Particularly the criteria that are not currently included in regulation and certification schemes.

4.1 APPROACH AND METHODOLOGY

This case study was used to test 4 additional evidence gathering tools identified and discussed in section 3.11. Each tool is intended to provide a more detailed description of the forest resource, pellet mill feedstocks, relevant trends, and specific evidence to address the gaps identified in table 3.4. This chapter describes the data and evidence gathered for each of the 4 tools as described below.

1. **Profiling data:** 2 pellet mills were identified in the US South and information has been gathered to describe the type of feedstocks, forest types and harvesting activity that have been used to supply biomass. This information forms the base from which other sustainability issues can be addressed; the data can be used to answer some of the questions posed in the acceptable biomass pathways; and to determine which pathway is the most appropriate for each supply chain. Data has been gathered directly from the pellet mill owners during a field trip.
2. **Catchment area analysis:** information and data has been gathered regarding local forest inventory, forest management and market data to identify trends occurring in the fibre baskets (catchment areas) around wood pellet mills in the US South. The data is intended to demonstrate if any negative trends are occurring (e.g. reduction

in forest area, reduction in forest carbon, distortion of wood product markets). Data has been gathered by local forest industry experts working as consultants in the US South (Hood Consulting at ABE, Forisk at MBE). The data has been analysed as part of this research but the consultants have been asked to provide a professional opinion on the results and the impact of biomass demand on local trends.

3. **Remote sensing of key metrics:** the potential of remote sensing technology to monitor key metrics (forest cover and biodiversity) in the forest landscape surrounding a wood pellet mill has been tested and evaluated. The forest landscape is defined as the same geographic area as the catchment area; the forest area in which a pellet mill is likely to have an impact or influence. To facilitate this process, experts in the use of remote sensing (Hatfield Consulting) and biodiversity monitoring (Department of Zoology, Oxford University) have been used to test the methodology and to provide a summary of results. The purpose of inclusion in this thesis is to determine whether this approach is a viable option for addressing some of the gaps identified in Table 2.1.
4. **Post-harvest evaluation:** The purpose of PHE is to monitoring the ongoing quality and state of the forests after biomass use. The options available for post-harvest evaluation are reviewed and discussed, a remote sensing tool has been used as part of the case study to evaluate one of the option, further option were evaluated during a field trip to the US South to visit the case study catchment areas.

Two typical pellet mill catchment areas were identified in the US South. Each area includes an operational pellet mill supplying the UK with wood pellets for energy generation. The mills are of sufficient scale to be typical of the industry in the US South, and they both use a range of feedstocks that are representative of the current biomass sector. The catchment area has been defined as the zone around each mill from which biomass is regularly sourced; calculated by plotting historical deliveries of feedstocks (see section 4.3.1).

Additional data has been gathered from within the catchment areas to address the gaps identified in Table 3.3. The following data sources were used:

- Feedstock, forest type and site-specific data provided by the pellet mill owner
- Publicly available data sets (e.g. forest inventory data, land classification)
- Wood pricing and market trend analysis (available from consultants)
- Anecdotal evidence from forest managers, land owners and contractors

4.2 IDENTIFICATION OF CASE STUDY AREAS

To identify suitable mills for the case study analysis a field trip to the US South was undertaken in March 2020. The field trip was organised with the intention of visiting two pellet mill clusters, one in the southern United States owned and operated by Drax Biomass International (DBI) and another in the Chesapeake region on the east coast, owned and operated by Enviva Biomass. The purpose of the visit was to select 2 suitable mills (from a total of 6 across both clusters) that were typical and representative of the forest and feedstock types currently utilised in the US South for export pellet production. In the first week of the field trip, meetings with DBI staff were able to proceed as planned. However, the escalation of the Covid-19 outbreak during the visit forced the curtailment of the second week and the visit to the east coast cluster. Therefore, the case study pellet mills were selected from the DBI catchment areas as described below. The DBI cluster of 3 mills are located along the Mississippi river on the cross-section of the states of Louisiana (LA), Mississippi (MS) and Arkansas (AR). The mills have a combined production capacity of around 1.5 Mtonnes wood pellets /yr equivalent to more than 3 Mm^3 of wood raw material. All of the DBI production is transferred to the port of Baton Rouge by rail and truck and then shipped to the UK.

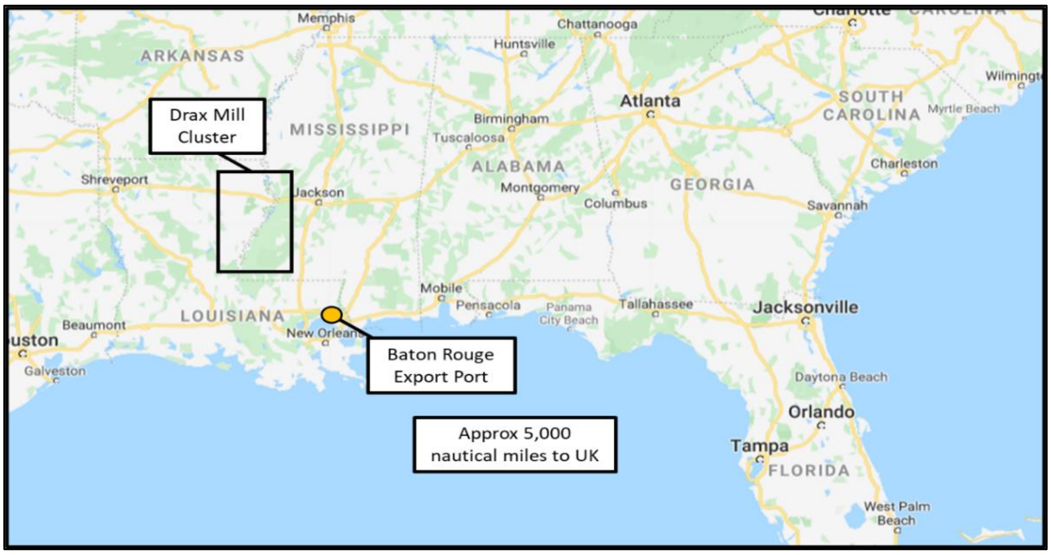


***Figure 4.1**: Location of Drax pellet mill cluster (Google Maps).*

The 3 mills visited were: Amite Bioenergy (ABE), located in Gloster, MS; Morehouse Bio-energy (MBE), located on the LA/AR border north of Bastrop; and La Salle Bioenergy (LBE), located in northern LA.

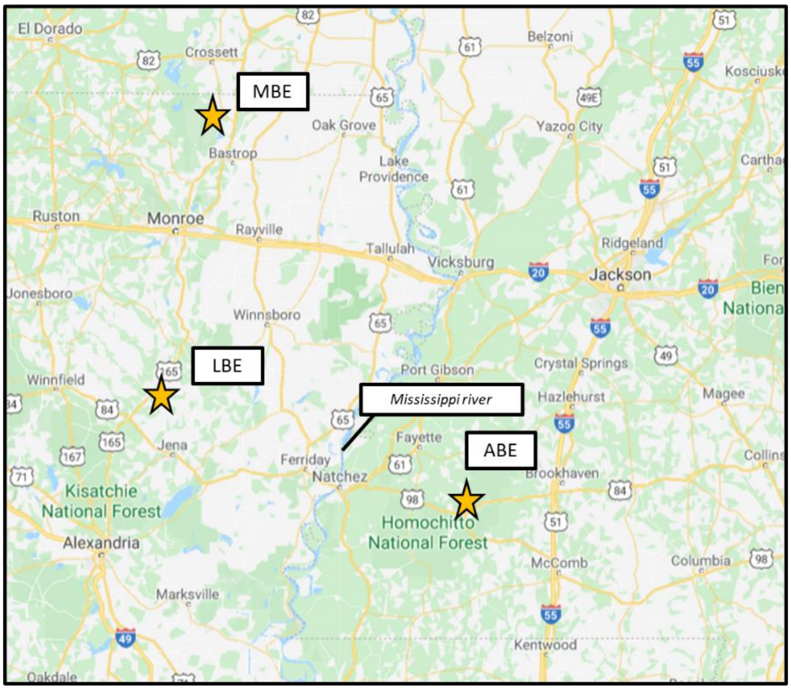


__Figure 4.2:__ Location of the three Drax pellet mills (Google Maps).

__Figure 4.3:__ DBI facilities in the southern US (Drax Group).

The mills are relatively close, with some overlap in catchment area between LBE and MBE. ABE is approximately 220 km (around 2.5 hours' drive) from LBE and around 235 miles (2.75 hours' drive) from MBE. All 3 mills were included in the initial phase of gathering profiling data, specifically the recent feedstock mix, section 4.3.1. However, LBE was then excluded and MBE and ABE chosen as the case study mills as they are located further apart; they have greater variation in forest ownership and forest type; they have a longer history of continual operation; and therefore, more data availability and more time for any impacts to become apparent.

4.3 TOOL 1: PROFILING DATA

During the field visit with DBI in March 2020, and in subsequent communications, the range of data described in section 3.11.1 was collected, as far as possible, for biomass feedstock sourcing at ABE and MBE in 2019.

4.3.1 Biomass feedstock mix

The changing mix of feedstock types at each mill from 2017-19 is shown in Figures 4.4 to 4.6. The data shows that LBE used a higher proportion of roundwood in 2018-19 but has been gradually transitioning to a higher proportion of residue use; the mill is co-located next to a sawmill and will use more mill residuals in the future. LBE is a recent acquisition for DBI, initially constructed by German Pellets and sold to Drax in 2017. Following acquisition, a number of upgrades took place which have affected production and the feedstock mix in 2017 and early 2018. The ABE and MBE mills were both constructed by DBI and have been in operation since 2014. The feedstocks are shown in 4 categories; the first 3 are used as raw material or 'furnish' to make the pellets, the 4th (hogfuel) is a lower grade of fibre and is used in the boiler for drying the wet wood prior to pelletisation. Pulpwood and in-woods chips are both derived directly from forest harvesting; mill residuals are by-products sourced from mills producing saw-timber. Each mill uses around 1 Mtonnes of wood fibre /yr.

	Sawmill Residues	Pulpwood	In-woods Chips	Hogfuel	TOTAL
Amite BioEnergy	120,543	698,929	38,972	53,206	911,650
La Salle BioEnergy	0	45,960	409	5,259	51,628
Morehouse BioEnergy	53,624	675,440	186,711	74,658	990,434
Total	**174,167**	**1,420,329**	**226,092**	**133,123**	**1,953,712**

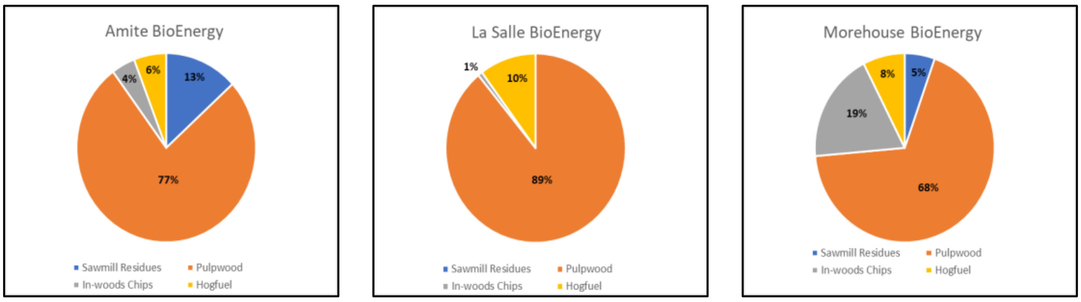


Figure 4.4: *2017 Feedstock DBI mills (tonnes).*

	Sawmill Residues	Pulpwood	In-woods Chips	Hogfuel	TOTAL
Amite BioEnergy	254,744	524,534	192,907	65,084	1,037,270
La Salle BioEnergy	21,876	722,812	101,466	42,835	888,988
Morehouse BioEnergy	232,927	495,148	244,019	81,169	1,053,264
Total	**509,547**	**1,742,494**	**538,392**	**189,088**	**2,979,522**

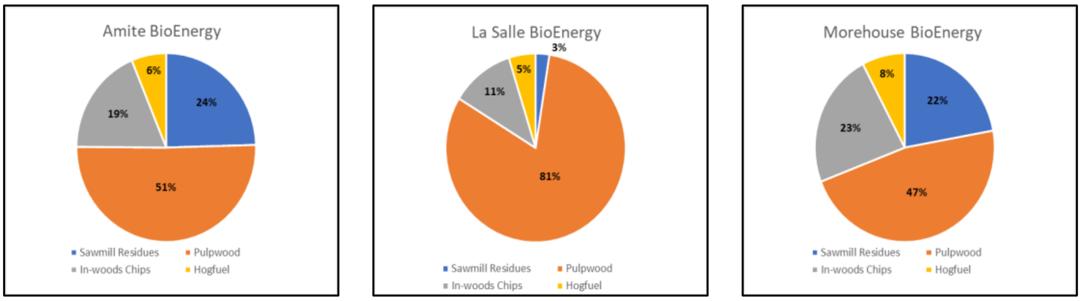


Figure 4.5: *2018 Feedstock DBI mills (tonnes).*

	Sawmill Residues	Pulpwood	In-woods Chips	Hogfuel	TOTAL
Amite BioEnergy	310,441	453,114	261,277	71,507	1,096,340
La Salle BioEnergy	200,073	605,355	167,740	45,311	1,018,480
Morehouse BioEnergy	231,125	356,029	365,889	72,420	1,025,464
Total	**741,640**	**1,414,499**	**794,906**	**189,238**	**3,140,283**

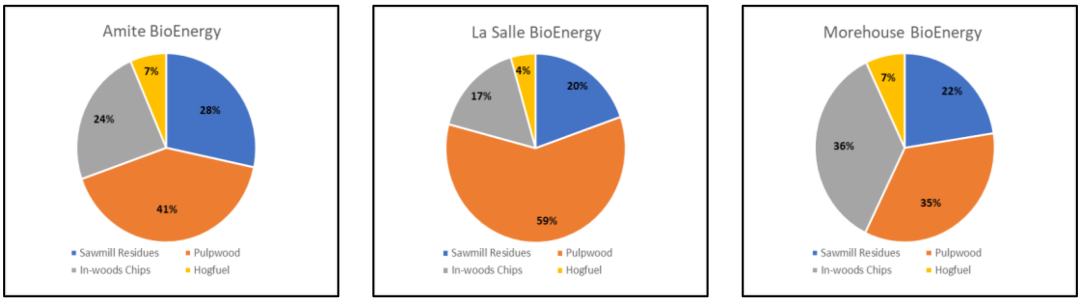


Figure 4.6: *2019 Feedstock DBI mills (tonnes).*

There are differences in forest ownership structure between the ABE and MBE catchment areas that can impact forest management decisions. There are more corporate forest owners around the MBE mill compared to ABE, which has more family or smaller scale private owners (Bretta Palmer, DBI, 2020). The USFS National Woodland Owner Survey – NWOS (2018) demonstrates that different ownership types can lead to a difference in management objectives, investment and management practice. In addition to the NWOS, evidence from site visits and discussions with forest owners in the US South suggest that, corporate forest owners are more likely to plant seedlings with adapted stock; as opposed to letting natural regeneration 'self-seed' any harvested areas. The corporate owner is also more likely to fertilise, control weeds and thin the crop to maximise the production of saw-timber and therefore revenue generation. These operations require capital expenditure which some family owners are less inclined or less able to invest (Bretta Palmer, 2020). The result is that corporate owners tend to have more pure stands of fast-growing pine with a high proportion of saw-timber and a shorter rotation length; family owners tend to have more mixed stands (as natural regeneration allows both hardwood and softwood seeds to germinate), lower timber quality and slower growth rate due to lack of investment in management and care (NWOS, 2018). Family owners tend to manage for multiple objectives, rather than only for a return on investment, their primary objective is often to produce wildlife habitat for hunting, with timber sales a secondary and periodical objective (Bretta Palmer, 2020).

The proportion of softwood, hardwood and mixed species has remained the same over the 3-year period at around 82%, 4% and 14% respectively (DBI data, 2020). The mix is driven by the forest type in the catchment area, most of the actively managed forest is pine, but also by the technical specification of the mills which require a high proportion of pine rather than hardwood.

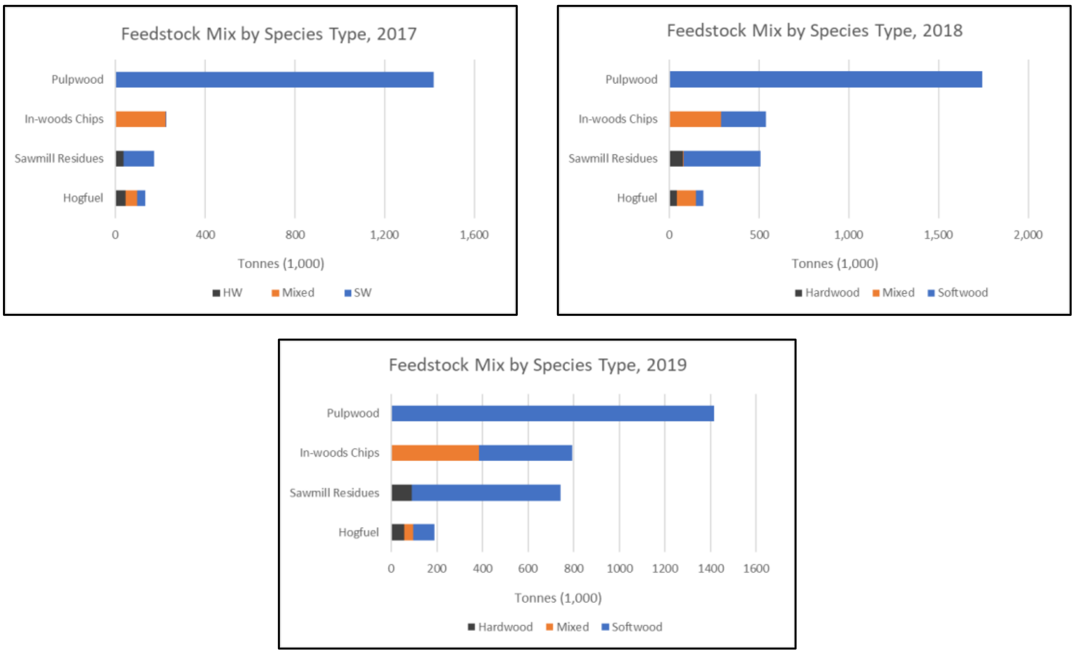


Figure 4.7: *DBI Feedstock Mix by Species Type 2017-19.*

4.3.2 Description of case study catchment areas

The catchment areas for ABE and MBE have been defined by DBI (Figure 4.8). The higher-level green areas indicate the location of the highest concentration of fibre sourcing by volume. These catchment areas were used as the basis for analysis of available data and forest management trends.

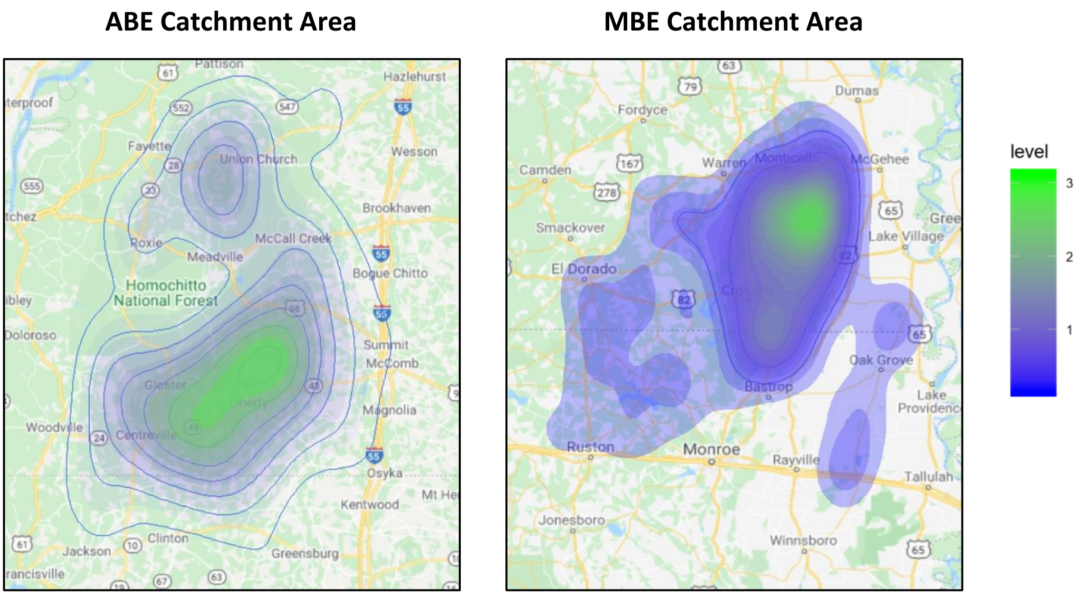


Figure 4.8: *DBI roundwood fibre sourcing heat maps 2017-19.*

All wood using mills will aim to source fibre from as close to the mill as possible: to reduce transport costs. Therefore, the shape of a catchment area tends to be determined by the location and concentration of suitable forests (those at the appropriate age for thinning or clear cutting) and the proximity of other markets. Pellet mills typically have the lowest wood paying capacity of any market in the US South (Pöyry, 2015) and cannot compete with pulp and panel mills for raw material. In some cases, mill residuals are sourced from a wider area as this feedstock is typically lower cost and transport distances can be extended where surplus material is available.

4.3.3 Overview of forest types

The catchment areas around MBE and ABE have 4 typical forest types (Figure 4.9). Three of these can be described as typical 'working forests' or forests that are actively managed either for timber production, recreation or amenity. The exception is Bottomland hardwood forests which can be more ecologically sensitive; management and intervention in these areas needs to be undertaken with greater care; in some cases, it may not be appropriate to manage or harvest these areas at all (US EPA, 2021). Within the ABE and MBE catchment areas this forest type is rare, naturally located along the Mississippi river valley on the boundary of the fibre sourcing catchment area. The ABE and MBE mills utilised only around 4% of pure hardwood species, at the time of data collection, and all of this fibre was sourced as secondary residues from sawmills and as bark for hogfuel. The primary source of fibre is from the other 3 forest types, pure pine stands (either planted or naturally regenerated) and stands of mixed pine and hardwoods.

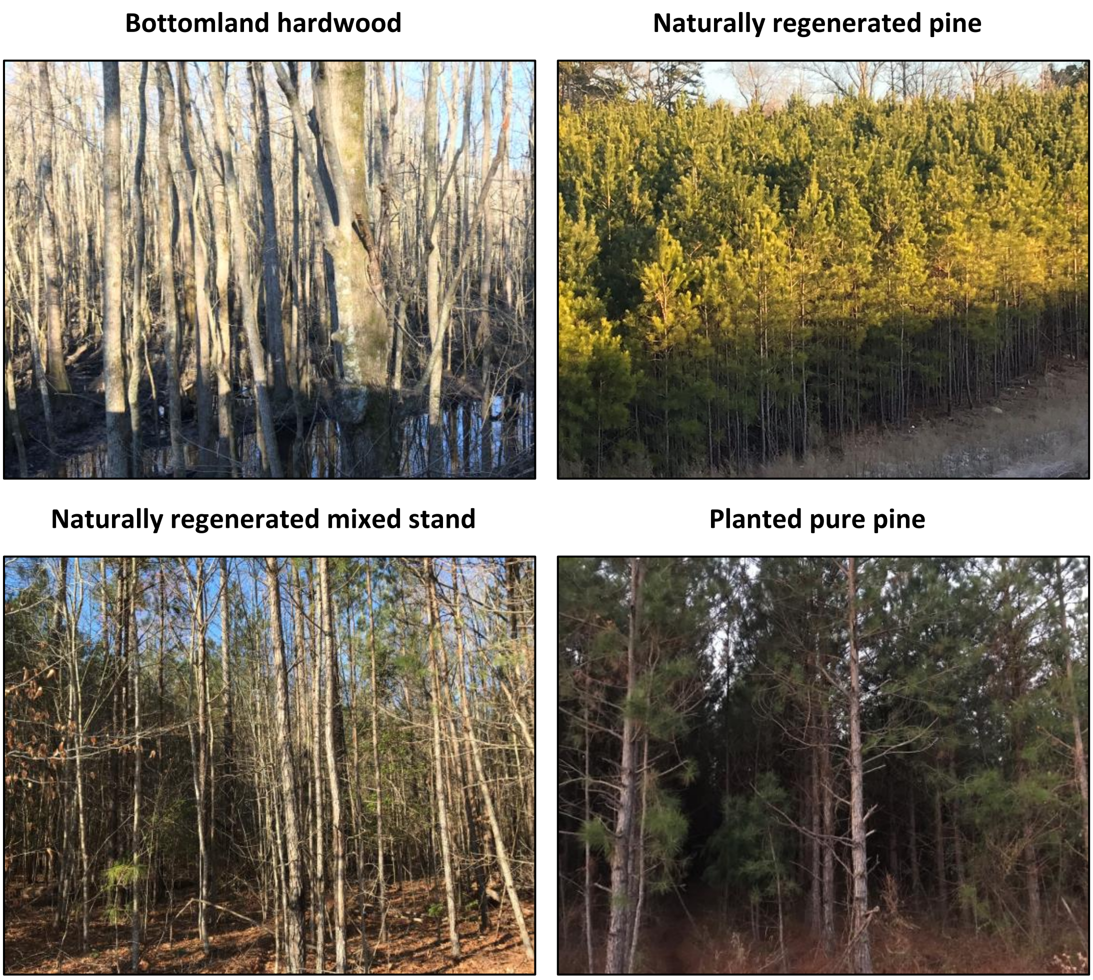


Figure 4.9: *Forest types in the DBI catchment area.*

4.3.4 Description of forest derived feedstock types

The DBI mills use 2 types of forest derived feedstocks: pulpwood and in-woods chips. Pulpwood is stemwood that is not of sufficient size or quality to be utilised in higher value markets (e.g. saw-timber production). Pulpwood can be whole trees, in the case of thinning operations to remove small and undesirable trees from a crop, or it can be the tops of larger trees left behind once the sawlog portion of the stem has been removed. Pulpwood does not include branches and the green tops of the trees, only solid wood fibre. In the US, pulpwood is transported in the longest possible length (as opposed to the European short-wood system) as this can increase the efficiency of loading and unloading the timber wagons (Figure 4.10).

Figure 4.10: *Roundwood used in DBI mills a) Pulpwood-roundwood, derived from thinnings and clear cuts b) Pulpwood-roundwood, derived from thinnings and clear cuts.*

In-woods chips will include some of the same material as pulpwood but instead of being transported whole to the mill, it will be chipped in the forest directly into the back of a container lorry. It can be more efficient for haulage but it also increases the utilisation of feedstock from the forest. Tops and branches can be included and misshapen trees, that would be difficult to transport whole, can be processed in the forest rather than being left to rot on-site.

An in-woods chipping operation in the US South is shown in Figure 4.11 below. A mix of low-quality hardwood and pine trees are being cleared and processed on site for utilisation at the pellet mill. Low quality, small or crooked stems and branches can be difficult to transport without on-site processing and it is not of sufficient quality to access higher value markets. In-woods chipping allows the land owner to clear the site and generate revenue to re-invest in a better-quality future forest. Figure 4.11 also shows large dimension material from another site that has been cut and left to rot. These large, irregular shaped, pieces of residue are not suitable for saw-timber markets and not viable to transport unprocessed; in many cases this type of material is left on site. There are pros and cons to leaving the material on site, from a carbon perspective it may take many years to rot and release the stored carbon, therefore providing a slower release of CO_2 than if used for pellets. Rotting wood can also provide habitat for some insect and animal species and it is common 'best management practice' to leave a proportion of deadwood habitat on site after harvesting. Conversely, if too much deadwood and residue material is left on site it can restrict or impede the establishment of the next generation of trees, reducing the quality of future forest; reducing revenue to the forest owner and increasing operational costs. It can also increase the risk of wildfire and spread diseases and insect pests (USFS, 2022).

Figure 4.11: *Forest residues a) Chipping of 'whole tree' harvesting residues, b) Large debris left on site, could be utilised as harvesting residues.*

4.3.5 Management data 2019

During 2019, additional data was collected by DBI from forest owners to describe the purpose of harvesting (e.g. thinning, clear cut, aesthetic/wildlife), and the owner's intentions for future use of the land. In 2019, the proportion of forest derived feedstock (as opposed to sawmill residuals) that came from clear cutting at ABE was 340000 tonnes or 48% of the total harvesting, the remainder of the supply came from various types of thinning (Figure 4.12).

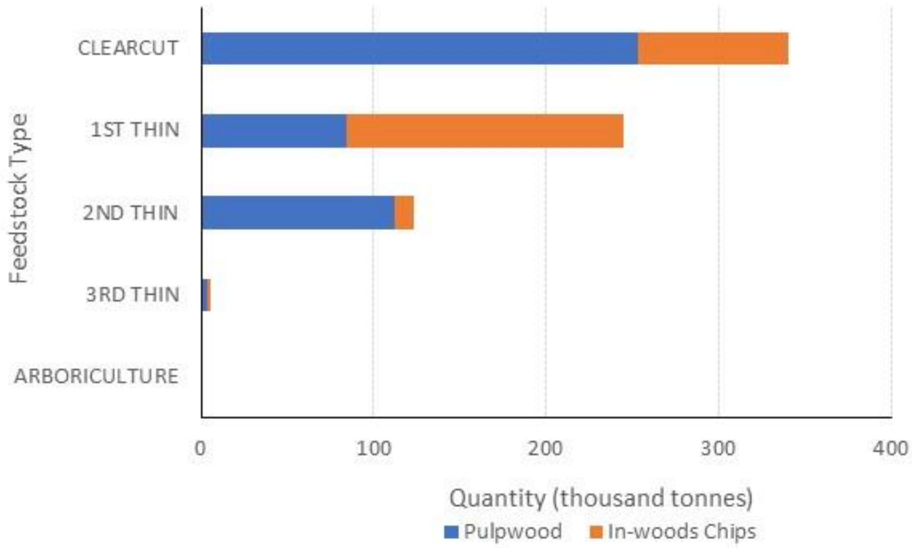


Figure 4.12: *ABE 2019 feedstocks by harvest and regeneration type.*

At MBE, in 2019, only 180000 tonnes or 25% of the forest derived feedstock came from clear cutting, more than 480000 tonnes or 66% came from first thinning operations and around 61% of this quantity was in the form of in-woods chips.

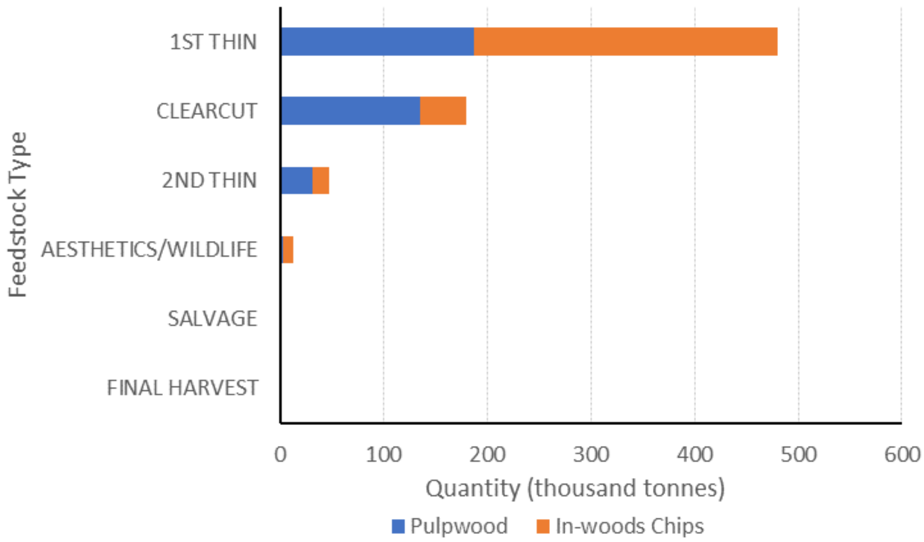


Figure 4.13: *MBE 2019 feedstocks by harvest and regeneration type.*

The landowners plan for future use of the forest is shown in Figure 4.14, reflecting the relative proportions of thinning and clear cut shown in Figures 4.12 and 4.13. DBI will not source fibre from areas that will be converted to non-forest, and therefore, all fibre sources should have a plan to maintain the forest area in future. The data for 2019 shows that most owners of sites where clear cutting took place intend to actively replant rather than allowing natural regeneration, this should ensure a better-quality future forest.

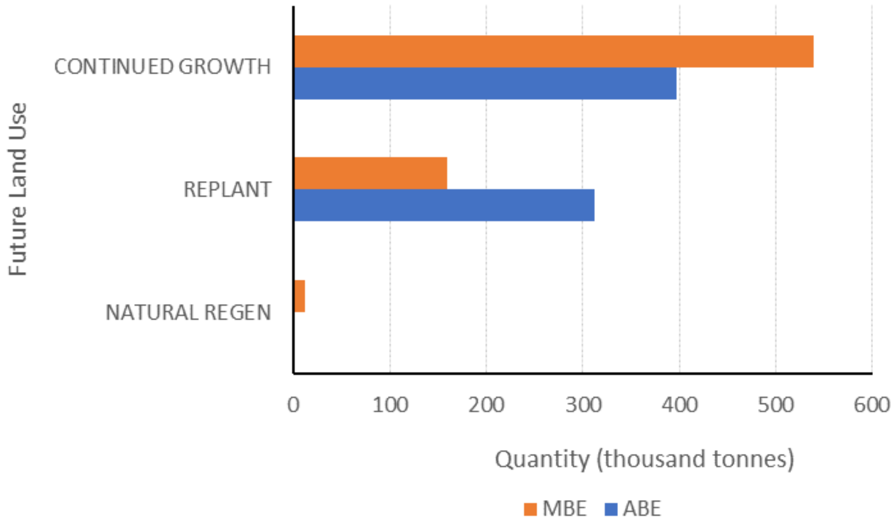


Figure 4.14: *DBI 2019 feedstocks by future use of forest land.*

As discussed in section 3.9, DBI sourced from 1180 separate sites in 2019. Each of these sites has a specific geo-reference and can be mapped (Figure 4.15). Each reference point can include specific details about the forest type and harvesting operation.

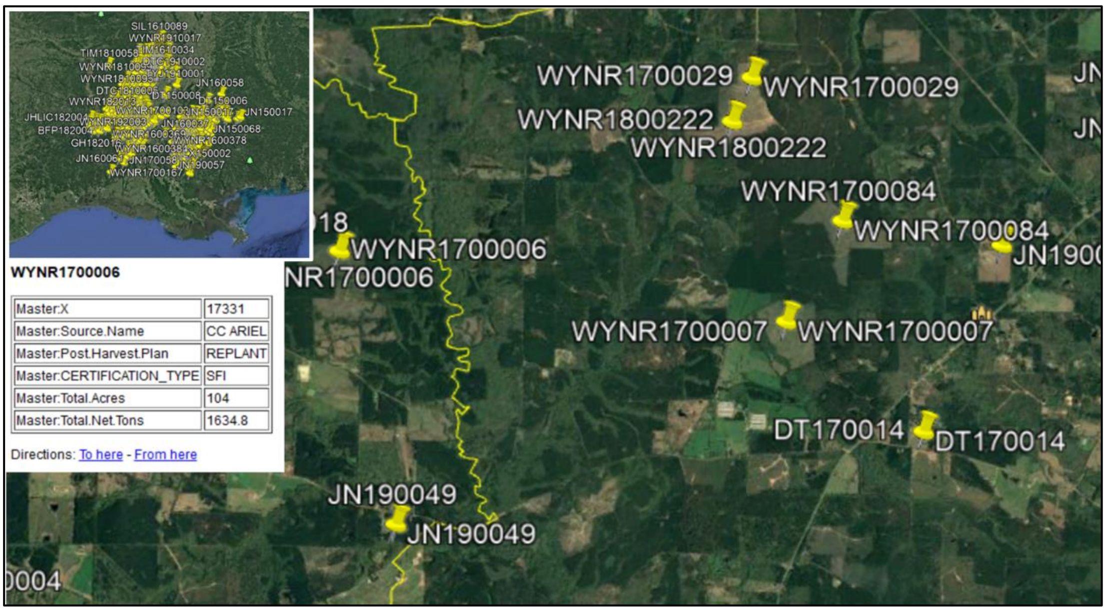


Figure 4.15: *DBI 2019 feedstocks by site location and harvesting site detail.*

4.4 TOOL 2: CATCHMENT AREA ANALYSIS

The objective of the catchment area analysis (CAA) was to evaluate the impact or influence of the pellet mill sector on forest inventory, markets and trends in local fibre baskets. The boundary of the analysis area will vary according to each specific mill, its sourcing practices and the proximity to other pellet mills. The analysis areas were selected to encompass the landscape catchment from which the wood demand of a pellet mill has been, or is likely to be, sourced. The boundary includes all land where pellet mills source primary feedstock (i.e. direct from the forest) and land from which sawmill residuals (described as secondary feedstock) originate. Where catchment areas for multiple mills overlap (with a combined procurement plan) then the entire fibre basket for all mills can be considered as one unit for analysis, although this is not the case with ABE and MBE. In some cases, a degree of rationalisation is required, if a small quantity of short-term feedstocks have been sourced from outside of the normal supply boundary, then it can be excluded from the analysis area if it does not form part of the core supply basket. Consequently, the impact of the pellet mill or mill clusters, can be more clearly evaluated as the analysis area is focused only on the core supplies. The catchment area definition is very specific to the individual market trends and sourcing patterns of a particular mill or cluster, and will therefore vary in size and shape in each instance. For this piece of analysis, the catchment areas were as defined in section 4.3.2 based on the 'heat map' of historical fibre sourcing at ABE and MBE. The ABE catchment area (Figure 4.16) includes 11 counties totalling 0.66 Mha of land (US Census Bureau), with 554 thousand ha of timberland (84%) in 2017.

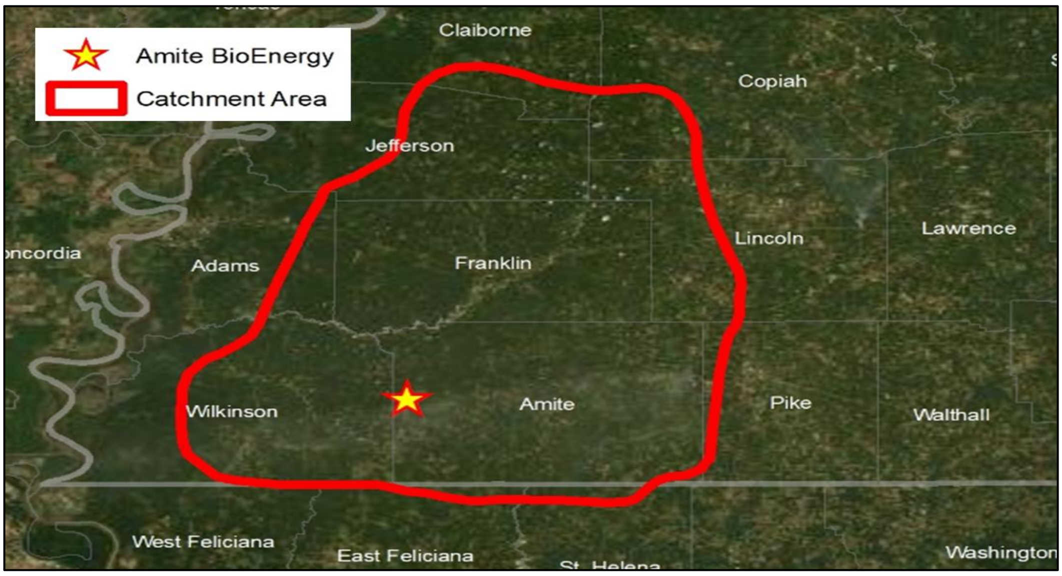


Figure 4.16: *ABE catchment Area for data analysis (Hood Consulting)****.***

The MBE catchment area is less compact and is defined in 2 segments: the primary market where roundwood is procured and the secondary market where residues are sourced, these areas are shown on Figure 4.17 below. The primary market has 8 counties and 1.62 Mha of total land (US Census Bureau), 1.03 Mha of timberland in 2017. In total the catchment area has 23 counties and 4.3 Mha of land (US Census Bureau) and 2.8 Mha of timberland. The data in section 4.4 below are presented for the total catchment areas including both the primary and secondary market.

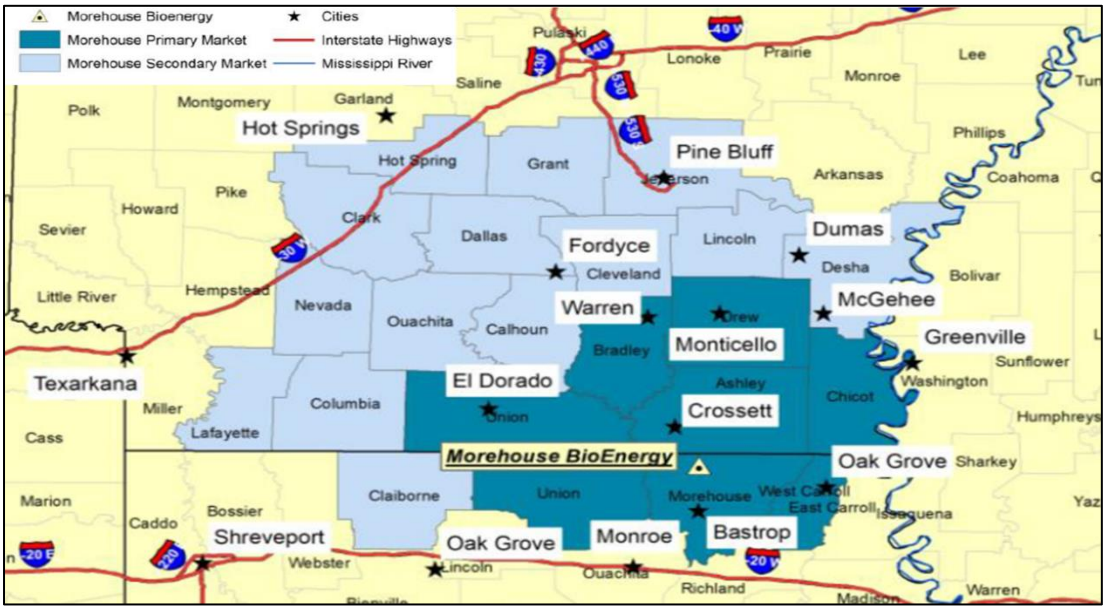


Figure 4.17: *MBE catchment Area for data analysis (Forisk Consulting).*

The purpose of collecting data about the forest resource and market trends within the catchment area was to find evidence that can be used to demonstrate whether the sustainable biomass criteria identified in Chapter 2 of this study are being met, specifically addressing the gaps in current evidence provision. These criteria have been translated into questions that can be addressed by data points and trends, with reference to each specific catchment area, as detailed in Table 4.1. For each question, the overall trend in the catchment area must first be identified. The scale and context of wood pellet production and its impact on the overall trend can then be considered. In some cases, determining the impact of the biomass plant can be highly subjective or based on anecdotal evidence; proving cause and effect for one specific market, especially if it is a small component of the total market in the catchment area, can be challenging and impractical. The alternative outcome, with a theoretical change in feedstock sourcing, cannot be conclusively determined; timber markets can be unpredictable and affected by a range of volatile factors (e.g. weather events, macro-economic trends, micro-market trends, local labour or cost issues, forest resource impacts –

age class, species, quality, disease or pest infestation). Isolating one individual factor is not always possible and requires expert local knowledge and a degree of subjectivity.

Using expert local knowledge to make this assessment and reach a conclusion for each question is an essential part of the process. For example, the data may show that saw-timber production has decreased and wood pellet production has increased within the catchment area. It is important to understand the drivers for each change and the circumstances under which one trend is related to or caused by the other. The analysis must determine whether saw-timber production has decreased as a result of a decline in end product demand (or another mill-specific reason), or through a lack of raw material due to competition from the wood pellet sector. If wood pellet demand is responsible for a decline in saw-timber production then it can have a negative carbon impact as saw-timber typically locks up carbon over the medium to long-term whereas pellets lead to an immediate release; therefore, pellet production should not replace saw-timber production, it must be additional and complimentary to achieve a positive climate impact (as described in Chapter 2 of this thesis). The available data can be used to understand the relationship between these two markets in the following ways:

- Surplus of fibre for each product category can be calculated from the National Forest Inventory (NFI); the surplus can demonstrate that there is no shortage of fibre and that both markets have ample supply.
- Feedstock usage for the pellet markets can be monitored to determine what categories are being utilised and if these feedstocks could be used in sawmills.
- Price trends for each product can be monitored to see if there is an abnormal change in prices (e.g. if a pellet mill is suddenly paying more for fibre than the sawmill, driving the price upwards).
- End product markets can be monitored to see if saw-timber demand and prices have declined and local knowledge about specific mills and markets can be used to clarify any changes and trends.

Specific examples of this process relating to ABE and MBE and the local expert interpretation of the data are discussed in more detail in section 4.4.6 of this thesis.

Table 4.1: *CAA questions and potential data sources.*

Is there evidence that bioenergy demand has caused:	
Deforestation?	Data on the change in land use, forest area and forest composition can be found in National Forest Inventories (NFI) and national land surveys. Remote sensing, using satellite data, is also a potential option to monitor this criterion. Reasons for changing trends may require local knowledge or anecdotal evidence.
A change in management practices (rotation lengths, thinnings, conversion from hardwood to pine)?	Conversion can be monitored through NFI data. Harvesting data is also available for thinnings and age class distribution can be used to determine whether rotation lengths are changing, although this requires longer term monitoring and in the short-term anecdotal evidence will be required.
Diversion from other markets (such that those markets were forced to reduce production)?	Production volume can be monitored for each market. Price trends for each product category can also be monitored and the surplus of available feedstock is available from the NFI.
An abnormal increase in wood prices?	Price trends are available from subscription services in most geographies, in the US South this can be sourced at county level to form an aggregate for the entire catchment area.
A reduction in the growing stock of timber?	NFI data is available to monitor this metric: change in total forest inventory.
An abnormal reduction in the sequestration rate of carbon (overall growth rate)?	NFI data is available to monitor this metric: average annual growth. It must be analysed in the context of the age class of the forest resource, as forests mature the rate of growth declines and therefore sequestration rates also decline. The decline is a normal part of the forest cycle and not a negative impact of bio-energy. A negative impact may result from a change in management practice (rotation length, species, management regime etc.).
An increase in harvesting above the sustainable yield capacity of the forest area?	NFI data can show the average annual growth compared to removals within the catchment area. Age class distribution must also be considered to determine the long-term sustainable yield capacity.

In addition to answering the questions in Table 4.1 the local expert carrying out the catchment area analysis should provide a considered professional opinion (based on the data trends, local knowledge and anecdotal evidence) for the criteria described in Table 4.2 below.

Table 4.2: *CAA subjective summary and conclusions.*

Define the impact of bio-energy demand (positive/neutral/negative) on:	
• growing stock • growth rates • forest area • wood prices • markets for solid wood products	The overall trend for each of these categories will be evident in the data, however the role of the wood pellet market in influencing this trend is not directly evident. Therefore, a professional judgement is required to determine the extent of influence and if there is any evidence of a direct link between the dominant trend and the operations of the pellet mill.

The local expert review is discussed in section 4.4.6. The local expert engaged for ABE is Hood Consulting and for MBE Forisk Consulting. The raw data presented in this section has been provided by each consultant and analysed as part of the research for this thesis.

4.4.1 National Forest Inventory (NFI) Data

The approach to producing and maintaining a National Forest Inventory is different in each country and is usually in the control of the government forestry or land use department. Full inventories are commonly carried out at intervals of between 5, 10 and 20 years depending on the country's level of financial commitment to managing the forest resource: the scale, risk and sensitivity of the forest resource. Field measurement is the most accurate form of assessment, although some remote sensing is used, particularly interpretation of aerial photography supported by ground truthing. There is a degree of error associated with any sampling process; however, in most cases the nationally available database is the most accurate large-scale data source for forest area and growth metrics. Corporate forest owners typically have more detailed and accurate information on their forest areas, although it is not usually available in the public domain. If looking at a specific individual forest or stand, then using bespoke data would be most accurate. Private owners have a varying degree of data, from detailed inventories and mapping, to no data at all; depending on the scale of the resource, the management objectives and the owners' commitment to detailed management. Again, this data is not usually available in the public domain. When considering larger areas with multiple ownerships, as with the catchment area analysis, then NFI databases are the most appropriate, accessible and accurate resource. The potential role of remote sensing as an alternative tool for forest cover monitoring is discussed in section 4.5.

In the US South, the NFI is produced and maintained by the US Forest Service (USFS), a part of the US Department of Agriculture (USDA). The inventory database is the called Forest Inventory and Analysis (FIA) database. An understanding of the database, as described below, is taken from the USFS online guidance documents. The database is constructed and updated based on field measurements from random sample plots located in each State. The exact location of each sample plot is not published, so as to avoid biased management and to protect the privacy of land owners; plots are distributed across all forest and ownership types. Measurement is carried out on a rolling 5-year programme where 20% of plots are measured each year, creating an annual partial update. Therefore, a full update only occurs every 5 years but there is a continual rolling average. An annual forecast is made for the entire area based on the data collected during annual sampling. The degree of accuracy can vary depending on the scale of data retrieval. In general, the larger the area considered in the analysis, the more accurate the data is likely to be (USFS, pers. comm.). At forest level, or for very small areas, there is likely to be a higher degree of error.

4.4.2 Forest area data

At the time of this study, 2017 was the latest available inventory year for Mississippi and the ABE pellet plant. Pellet production began in 2014, and therefore data were taken from 2010 to show a period prior to and after commencement of operations at the plant. For consistency, the same time period was used for both ABE and MBE; the data are shown for 2010-2017 (Figure 4.18), all data below are from the USFS FIA database unless otherwise stated.

The ABE data shows that there has been an annual change in total timberland area with an increasing trend. There is no evidence of a corelation in this data and it does not reflect a clear trend. The result can be expected given the limited sample size and annual variability. Overall, the timberland area increased by 399000 ha from 2010 to 2017 (Figure 4.18).

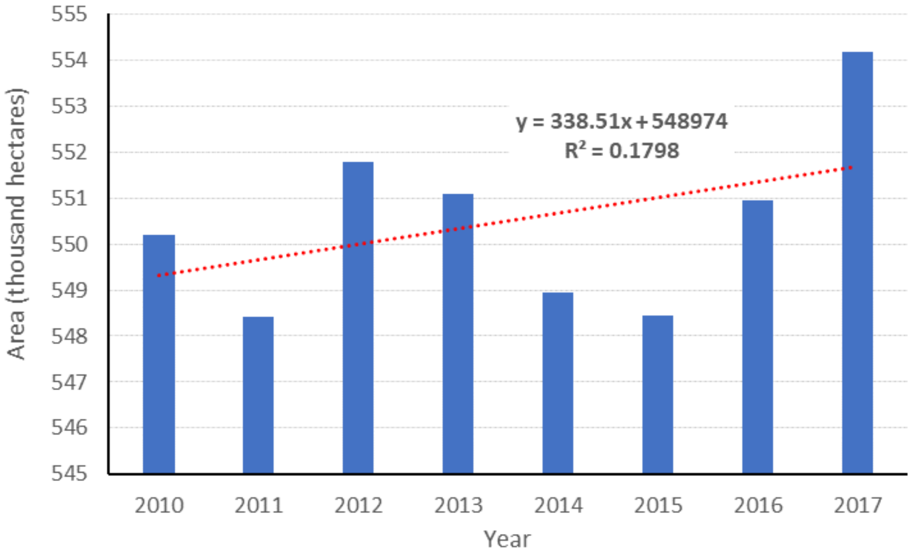


Figure 4.18: *ABE annual change in timberland area (USFS FIA, 2019).*

The species and forest type has also changed over this period, with an increase in planted pine of 153000 ha and a decrease in naturally regenerated pine and both planted and regenerated hardwood, as shown in Figure 4.19 and Table 4.3.

Table 4.3: *ABE, change in forest area 2010-17.*

	Planted Pine	Natural Pine	Mixed Pine	Planted Hardwood	Natural Hardwood	TOTAL
2010-17 Change (ha)	15,305	-4,521	1,498	-809	-7,481	3,992

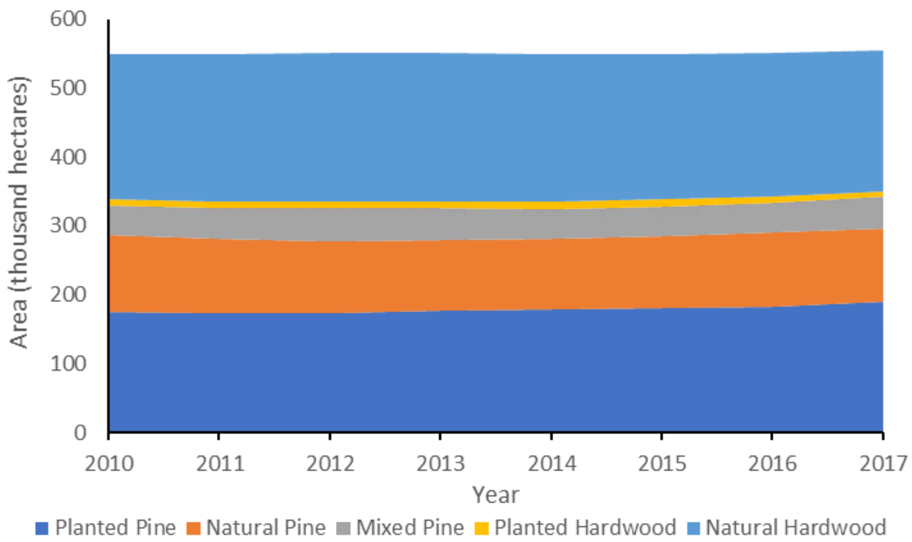


Figure 4.19: *ABE timberland area by forest type (USFS FIA, 2019).*

The MBE forest area data (Figure 4.20) also shows an increase in overall timberland area, with some annual fluctuations, a total net increase over this period of 593000 ha. R^2 = 0.71, demonstrating a stronger positive correlation than at ABE.

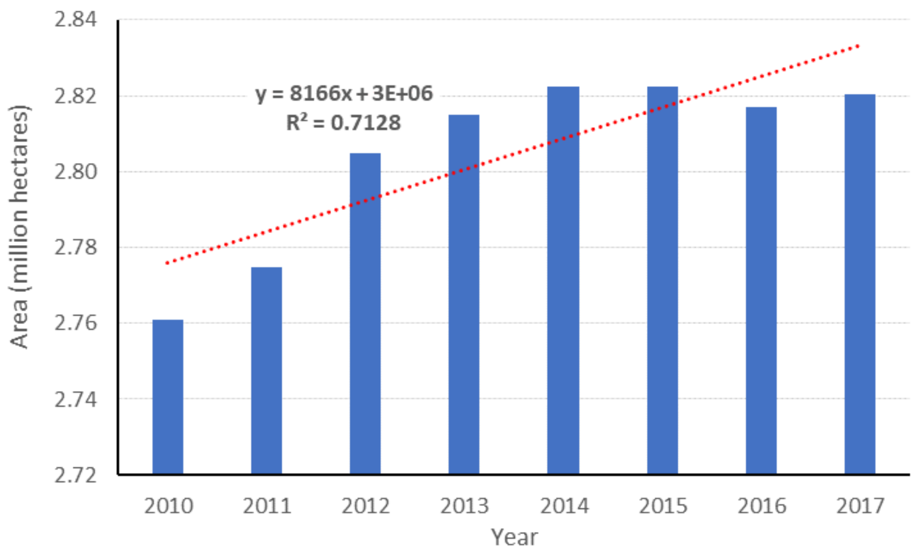


Figure 4.20: *MBE - annual change in timberland area (USFS FIA, 2019).*

As with ABE the trend has been for an increase in the area of planted pine and a decrease in naturally regenerated pine and mixed stands. The data also shows a loss of natural hardwood and an increase in planted hardwood.

Table 4.4: *MBE, change in forest area 2010-17.*

	Planted Pine	Natural Pine	Mixed Pine	Planted Hardwood	Natural Hardwood	TOTAL
2010-17 Change (ha)	135,093	36,371	-79,988	-27,755	-4,449	59,271

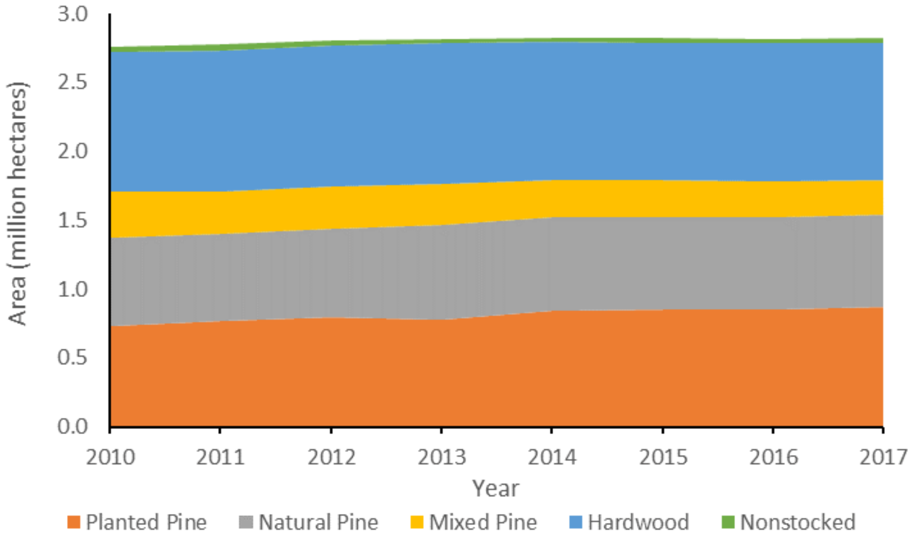


Figure 4.21: *MBE timberland area by forest type (USFS, FIA 2019).*

4.4.3 Markets and pricing

An important metric to consider when looking at the potential for market distortion or displacement is the variation in the production of wood products. There has been a change in the production of major wood categories (Figure 4.22) in the ABE area from 2010-17. There has been a substantial increase in demand of 2.3 Mtonnes (93% from 2010-17) with an increase of 1.2 Mtonnes in softwood sawlog production and 0.97 Mtonnes in softwood pulpwood production since 2010. Hardwood sawlog production has declined and hardwood pulpwood increased by 211 Ktonnes, this demand has been driven by the recovery of markets post-recession alongside new demand from ABE.

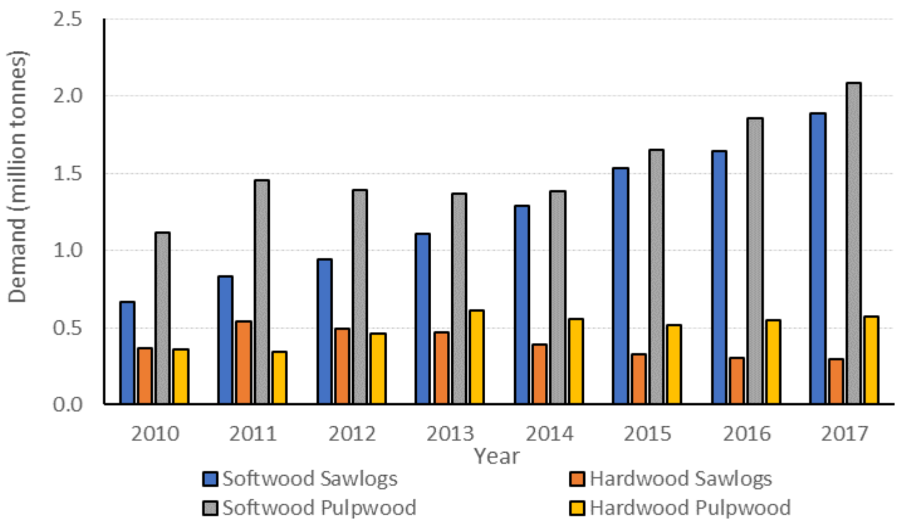


Figure 4.22: *ABE demand for timber products (USFS TPO 2019).*

The data below for the MBE catchment is from the USFS Timber Product Output (TPO) database. The data (Figure 4.23) is presented bi-annually and shows the change in demand over a longer timeframe, incorporating the peak of the US housing boom in the mid-2000s and the subsequent crash and early stages of the recovery. In the period from 2009 up to Q4 2018 cumulative demand only increased by 575 ktonnes.

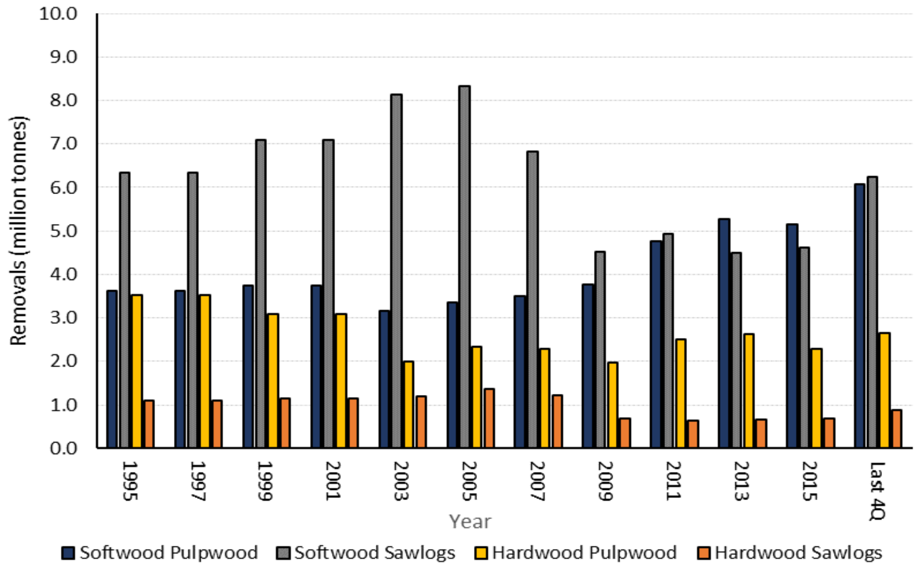


Figure 4.23: *MBE demand for timber products (USFS TPO 2019).*

There has been a decline in pine saw-timber and pine pulpwood prices of $6.68 per tonne (19% change) and $4.60 per tonne (39% change) respectively from 2010 to 2018 at ABE (Figure 4.24). Hardwood prices have increased by $14.05 per tonne (43% change) for sawlogs and $0.90 per tonne (8% change) for pulpwood over the same period.

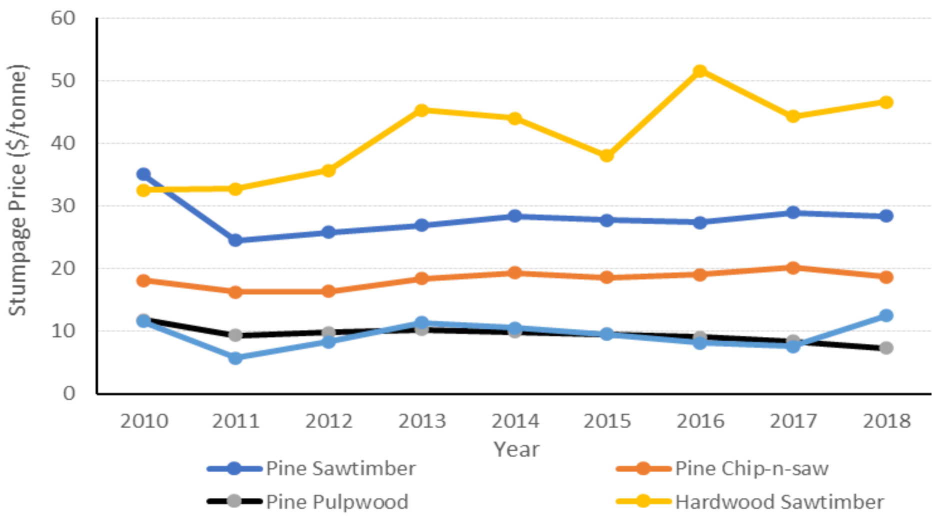


Figure 4.24: *ABE stumpage price trends (Timber-Mart South 2019).*

The catchment area price data for MBE (Figure 4.25) shows that almost all prices have declined since the pellet mill began operation in 2014, with the exception of chip 'n' saw which has increased by $0.46 /tonnes. MBE's primary feedstock is pine pulpwood and it has declined by $2.32 per tonne (23%) since 2014 and by $5.69 per tonne (44%) from 2010 to 2018.

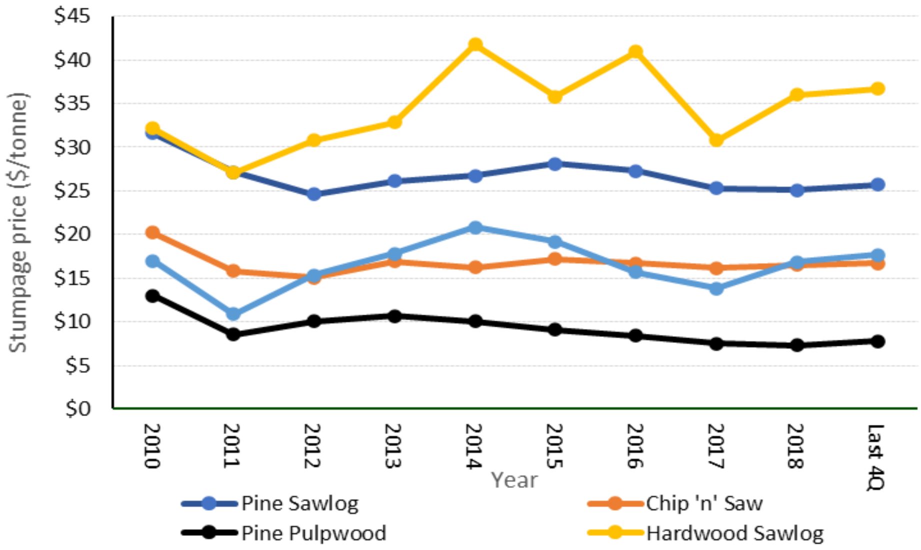


Figure 4.25: *MBE stumpage price trends (Timber-Mart South 2019).*

4.4.4 Carbon, growth rates and inventory

In the ABE catchment area, the volume of timber on private lands (typically the more actively managed areas) increased by 12.6 Mm^3 (21%) whereas the volume on publicly owned forest (e.g. National Forest areas) declined by 1.5 Mm^3 (8%) in the period from 2010-2017 (Figure 4.26).

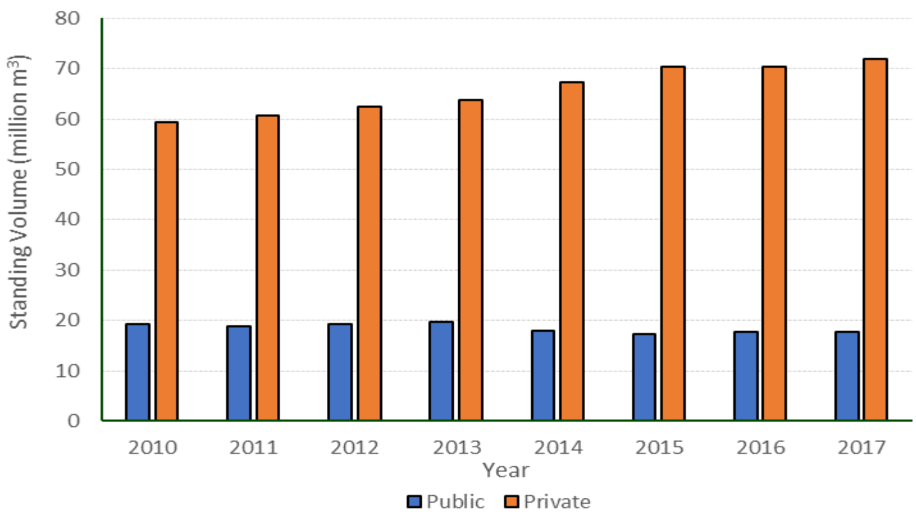


Figure 4.26: *ABE timber inventory by ownership (USFS FIA 2019).*

The MBE catchment area data also shows an increase in the growing stock of timber year on year, the private forest area increased by 47.8 Mtonnes (17%) between 2010 and 2017, whereas the publicly owned forest increased by 2.4 Mtonnes (19% -Figure 4.27).

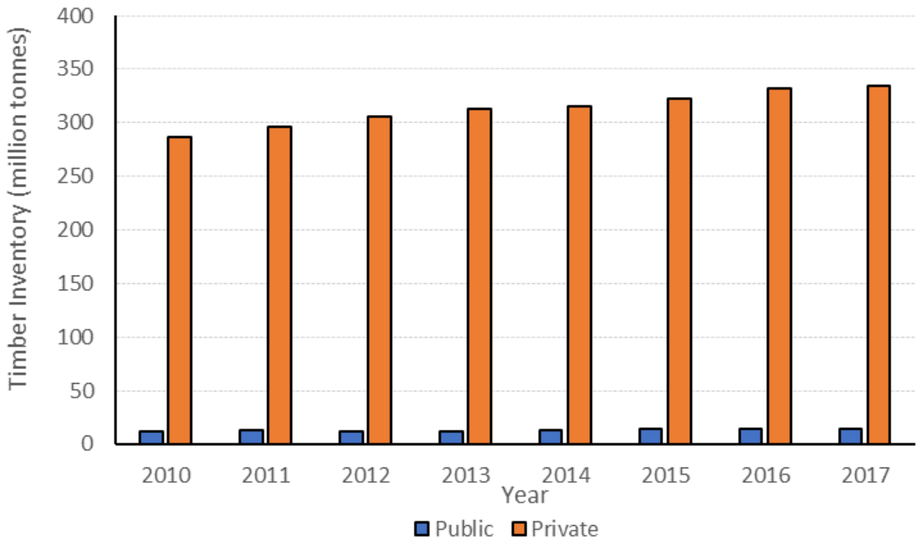


Figure 4.27: *MBE timber inventory by ownership (USFS FIA 2019).*

The annual change in volume for each diameter class in the ABE catchment area indicates an increasing size class, the volume in the larger diameter classes increasing annually (Figure 4.28); suggesting a maturing forest resource with an increasing average tree size and a higher proportion of forest approaching the point at which harvesting is viable and necessary. The largest increases over the period were in the 25 cm and 30 cm classes which increased by 2.9 Mm^3 (29.5%) and 3 Mm^3 (33.5%) respectively.

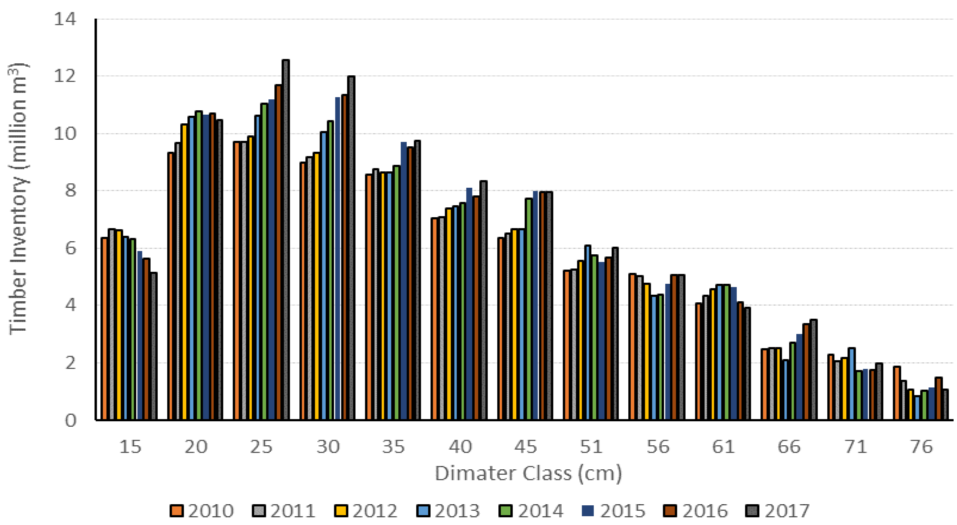


Figure 4.28: *ABE timber inventory by diameter class (cm) (USFS FIA 2019).*

A clear increasing trend is evident in the MBE catchment area (Figure 4.29) with the annual increase in the mid-range diameter classes more pronounced; the 20 cm size class increased by 12.4 Mtonnes (61%) from 2010-17 and the 25 cm class increased by 11.9 Mtonnes (53%). The higher rate of growth is partially due to the MBE data specifically looking at pine growth whereas the ABE data included both pine and hardwood.

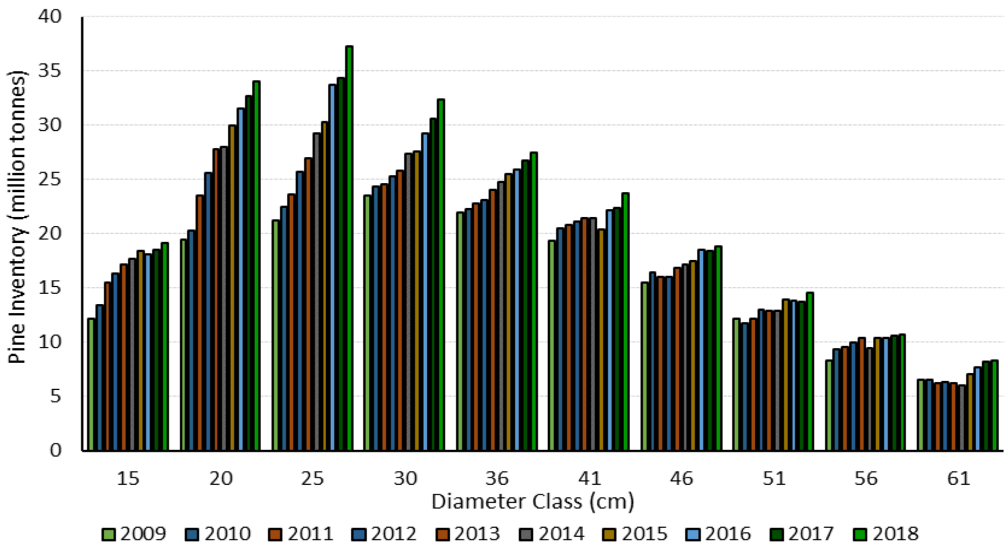


Figure 4.29: *MBE timber inventory by diameter class (cm) (USFS FIA 2019).*

The average annual surplus of growth compared to harvesting removals for pine sawtimber and pulpwood at ABE was 2.6 Mm^3 (Figure 4.30).

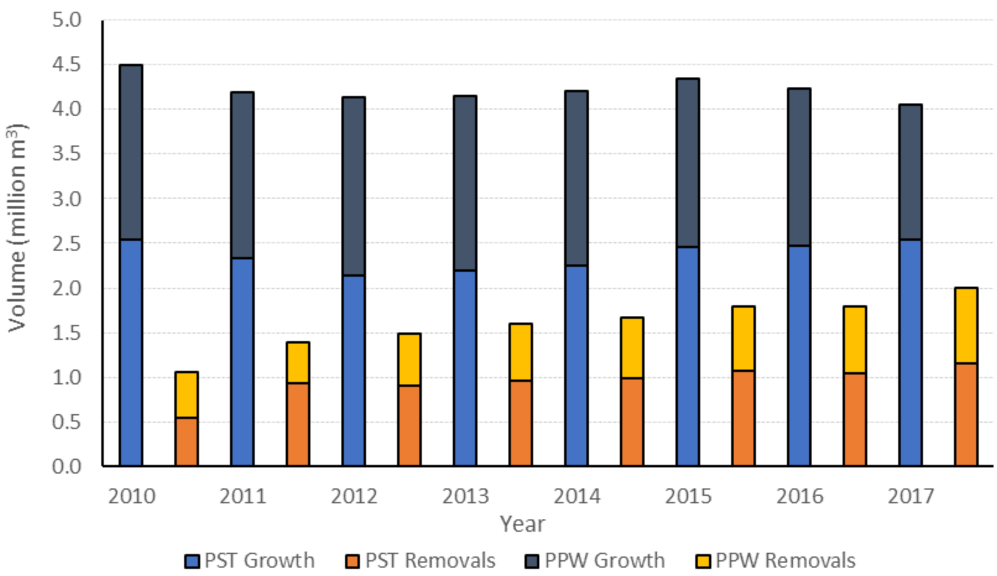


Figure 4.30: *ABE annual growth and removals comparison - pine (USFS FIA 2019).*

The annual growth and removals comparison for hardwood in the ABE catchment area (Figure 4.31) shows the annual average surplus from 2010 to 2017 was 0.89 Mm^3.

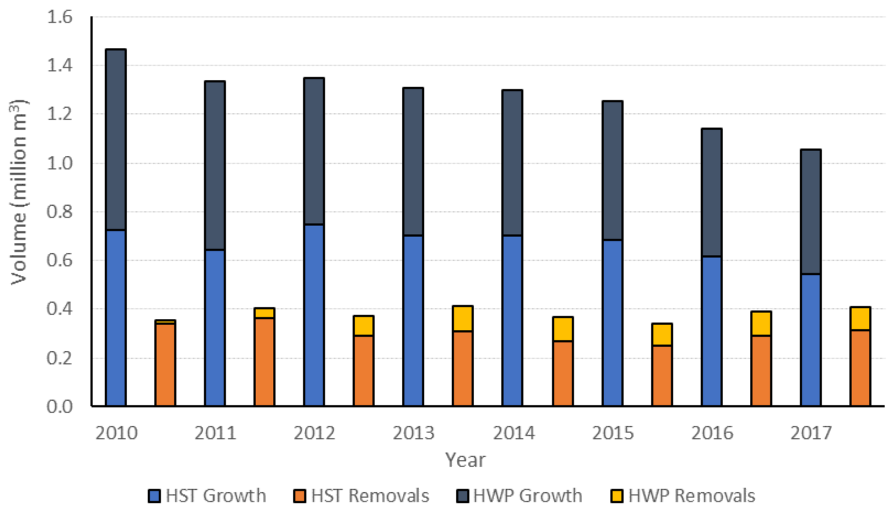


Figure 4.31: *ABE annual growth and removals comparison - hardwood (USFS FIA 2019).*

In the MBE catchment area (Figure 4.32) the average annual surplus of growth was 5.7 Mtonnes in the pine species.

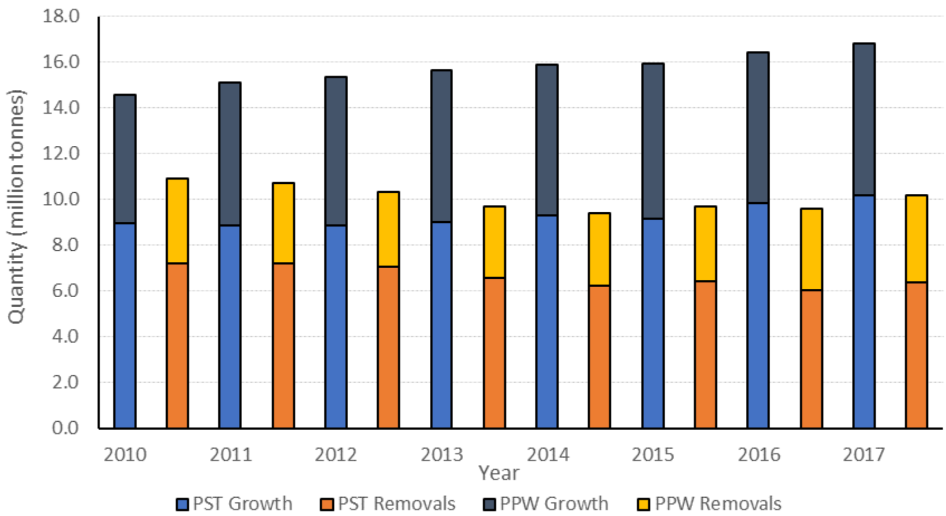


Figure 4.32: *MBE annual growth and removals comparison - pine (USFS FIA 2019).*

The average hardwood surplus in the MBE area was 0.27 Mtonnes /yr from 2010 to 2017 (Figure 4.33) and actually reached a deficit in 2016. Harvesting levels exceeding the annual growth in the short term do not necessarily equate to unsustainable practice, it depends on a range of other factors, including the age class distribution – it could be a predominantly mature forest area ready for harvesting. If the harvested area is replaced with an equivalent new forest, then the long-term sustainable capacity of the forest area will be maintained.

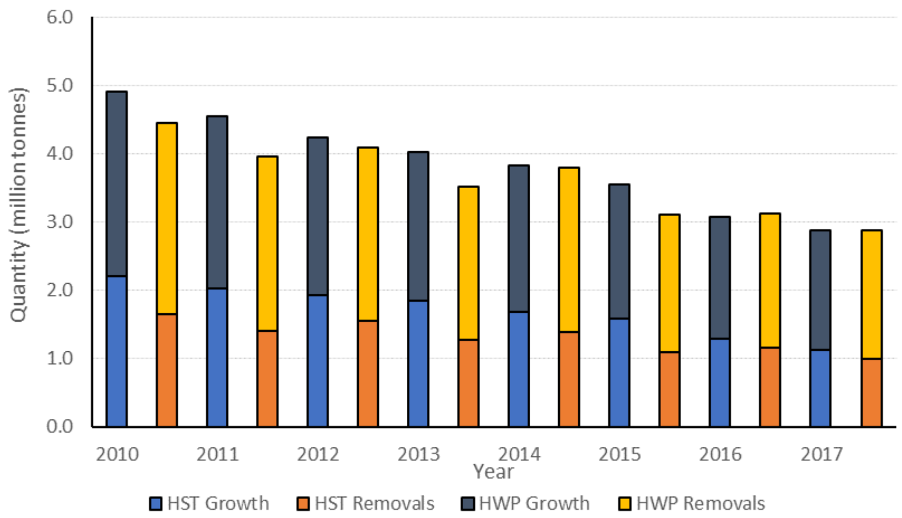


Figure 4.33: *MBE annual growth and removals comparison - hardwood (USFS FIA 2019).*

The data in Figures 4.30 to 4.33 can be an indicator of sustainable harvesting levels, where an annual surplus of growth is maintained, although this depends on having a balanced age class distribution. In practice, there are likely to be periods of substantial surplus growth where the age class is skewed towards younger rapidly growing forests; or periods of deficit, where the age class is skewed toward mature forests which grow at a slower rate and are ready for harvesting.

Average growth rates per hectare are also an indicator of sequestration rate, which can be a factor of age class (younger and mid-rotation stands growing at a faster rate than mature stands) but it can also be an indicator of improved management and overall increase in sequestration rate. The change in pine growth rate over time is shown in Figure 4.34, comparing planted pine with naturally regenerated pine. The data show that planted pine is consistently much faster growing than natural regeneration, due to better seed material and more active management (ground preparation, weeding, fertilisation, pest control etc.).

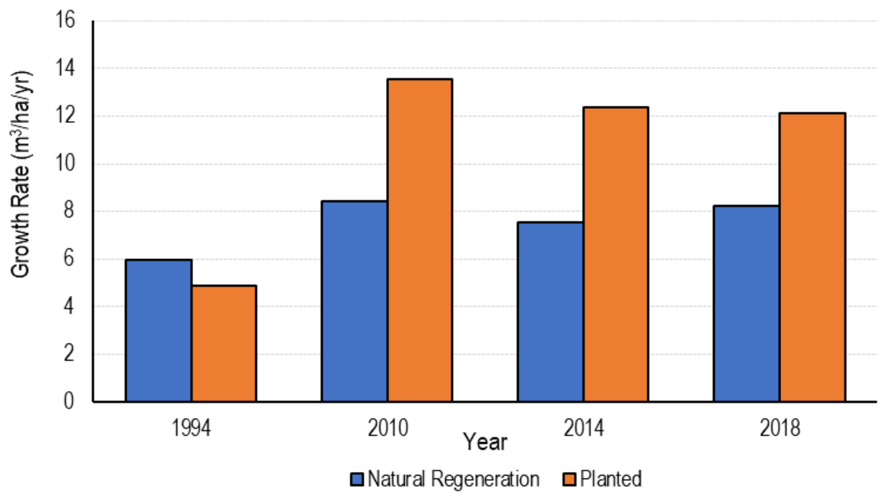


Figure 4.34: *ABE average annual growth per hectare /yr – pine timberland (USFS FIA 2019).*

At MBE, growth rates on private land are higher than those on public land (Figure 4.35), indicating that more active management leads to a higher rate of carbon sequestration.

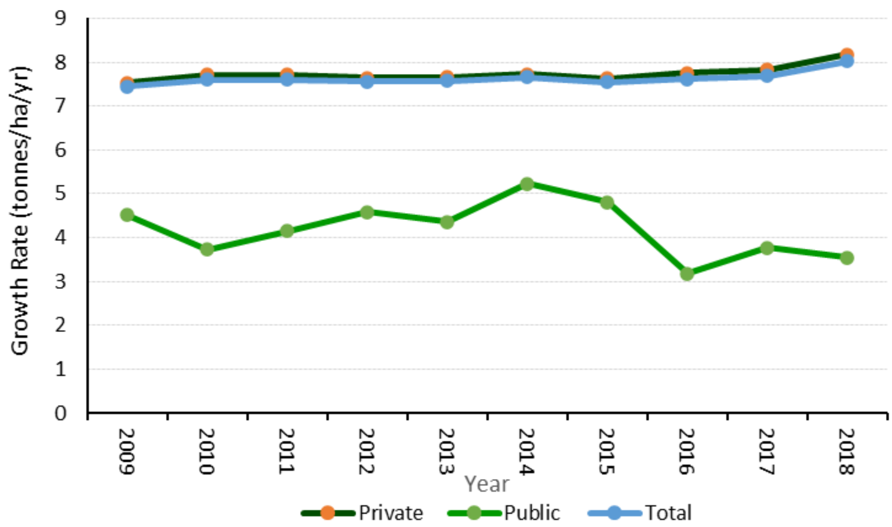


Figure 4.35: *MBE average annual growth per hectare /yr by ownership category (USFS FIA 2019).*

The impact of management options on carbon storage and sequestration in Mississippi State are shown in Figures 4.36 & 4.37. In publicly owned forest there is limited or no harvesting taking place (as described in section 2.3). In the privately owned forest, active management for timber production is widespread. The results of the comparison show that, in the short term, the total volume of timber stored per ha is higher where no harvesting occurs, this result is to be expected as the forest will keep growing until it reaches its climax point and succumbs to fire, pest or disease. Standing volume in the private sector, where active management occurs, is the lowest as timber is removed for use in solid wood products.

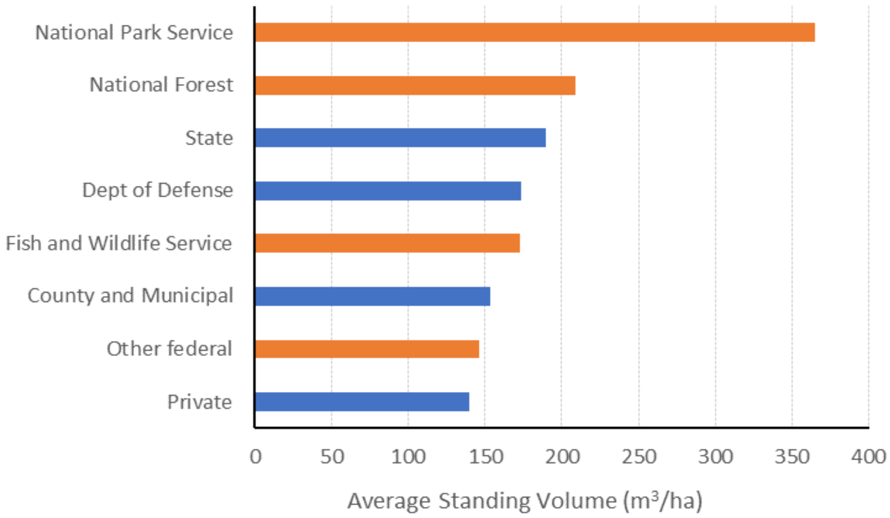


Figure 4.36: *average standing volume per acre by ownership class, Mississippi (USFS FIA 2109).*

Comparing the average annual growth rates across all forest types in Mississippi (Figure 4.37), the annual growth in the private sector is almost double that in the unharvested public forest; more carbon is sequestered with potential to be stored in harvested wood products.

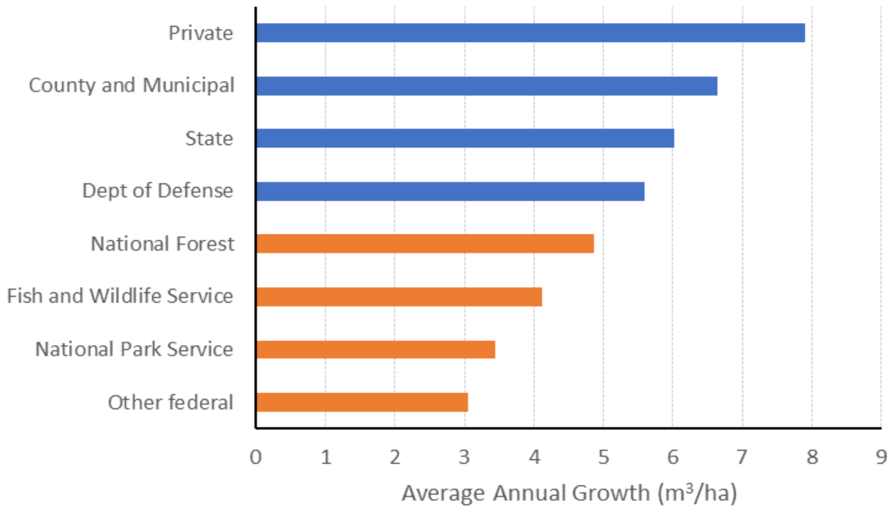


Figure 4.37: *average growth rates per acre by ownership class, Mississippi (USFS 2019).*

4.4.5 Change in management practice

In the ABE market, the volume thinned as a percentage of the total reported sale volume trended downwards from 43% in 2010 to 26% in 2016 (and increasing slightly to 30% in 2018). The overall decrease in thinning volume (as a percentage of total sale volume) is in line with what typically occurs when markets are weak; loggers tend to reduce the amount of thinnings they conduct because the profitability associated with thinnings is lower than that associated with clear-cut harvests (Hood Consulting - Figures 4.38 & 4.39).

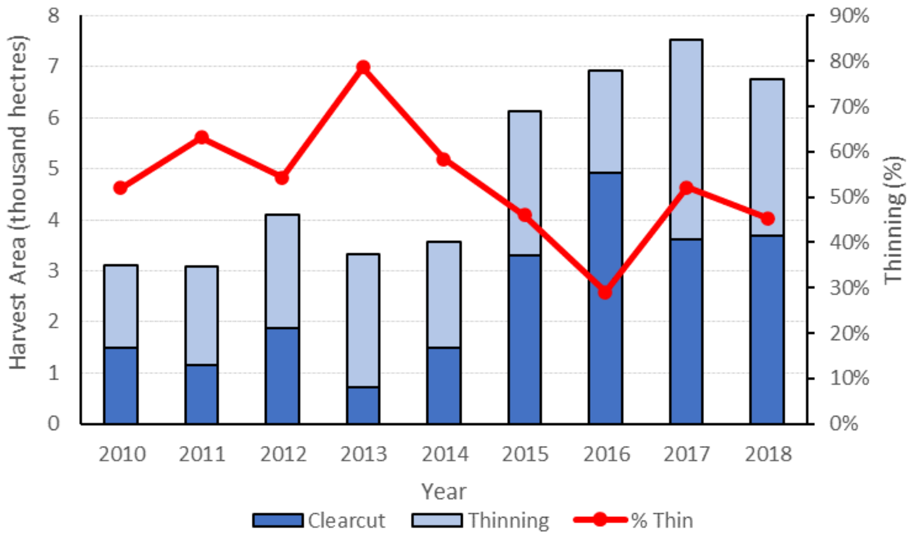


Figure 4.38: *ABE total harvesting area by operation type (Timber-Mart South 2019).*

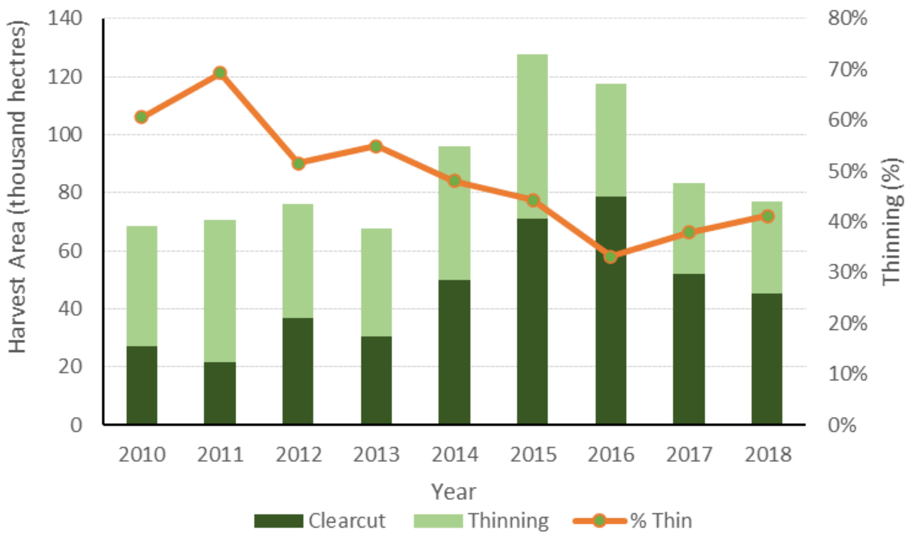


Figure 4.39: *TMS South-wide, total harvesting area by operation type (Timber-Mart South 2019).*

Average sale size in the ABE market has averaged 41 ha since 2010. Thinnings have averaged 28% larger (+10 hectares) than clear-cuts (Figure 4.40), with thinnings averaging 46 hectares in size compared to 36 hectares for clear-cutting. (Hood Consulting).

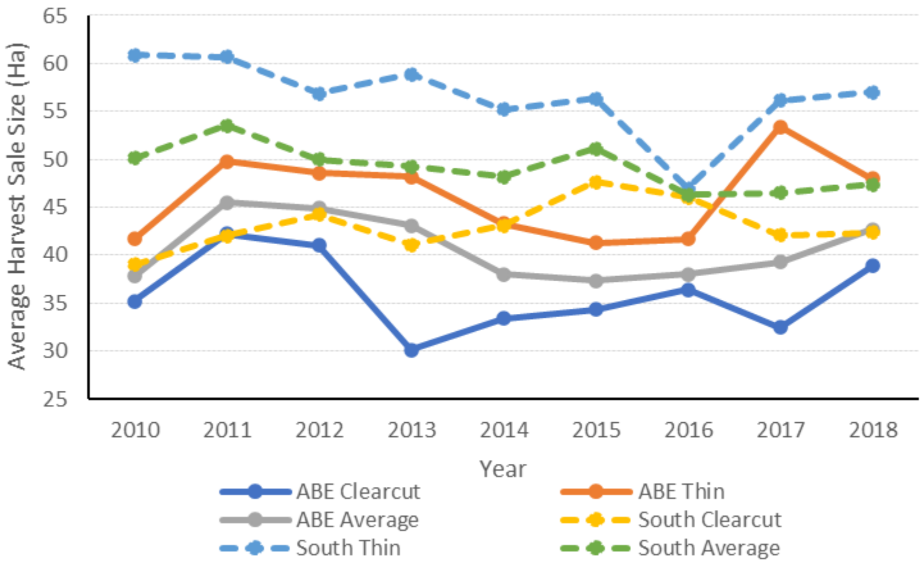


Figure 4.40: *ABE average harvesting area by operation type (Timber-Mart South 2019).*

The age class data (Figure 4.41) indicates that a typical pine rotation period at ABE is 25-30 years; the area of pine in the older classes declines after this point. Hardwood rotation length is much longer, typically up to 70 years. The change in this distribution can be monitored over time to determine if any widespread changes are occurring in management regime.

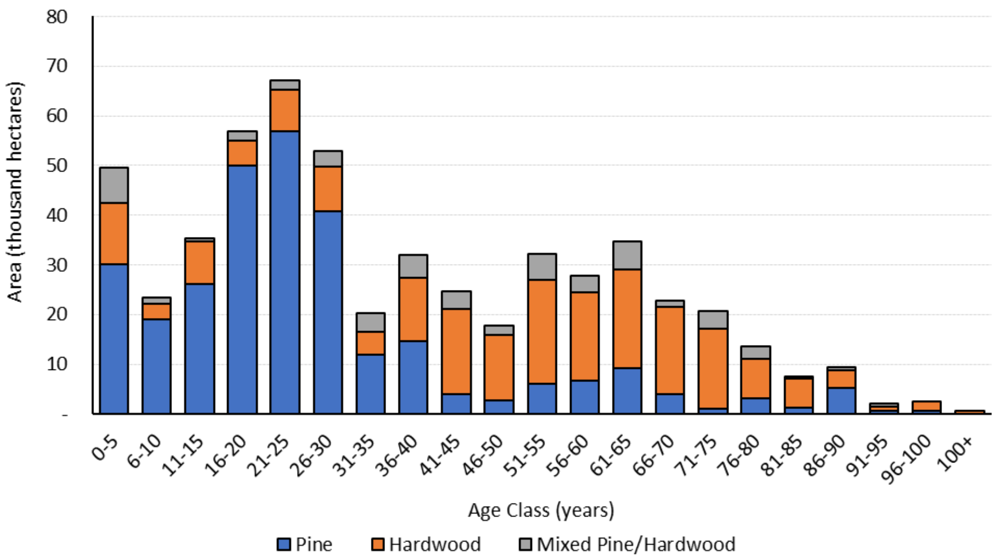


Figure 4.41: *ABE age class distribution by area (USFS FIA 2019).*

The data for the MBE catchment area (Figure 4.42) indicates a decline of around 1 Mtonnes in thinning and a slight increase of 70 ktonnes in clear-cutting since 2010.

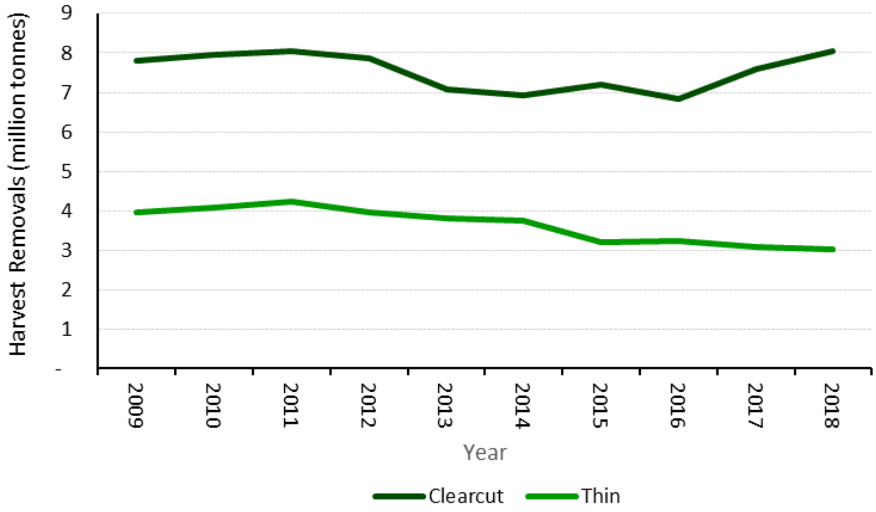


Figure 4.42: *MBE harvest removals by operation type (USFS FIA 2019).*

The age class distribution at MBE (Figure 4.43) shows that planted pine has a much shorter rotation, with the area declining after around 25 years of age; reflecting the proportion of intensively managed corporate owned forest. The natural pine is distributed over a much wider range of age classes and has a large area of very mature stands of over 50 years of age; reflecting the smaller private owners that tend to retain stands as a banked asset or for other purposes (e.g. hunting) rather than actively managing on multiple short rotations.

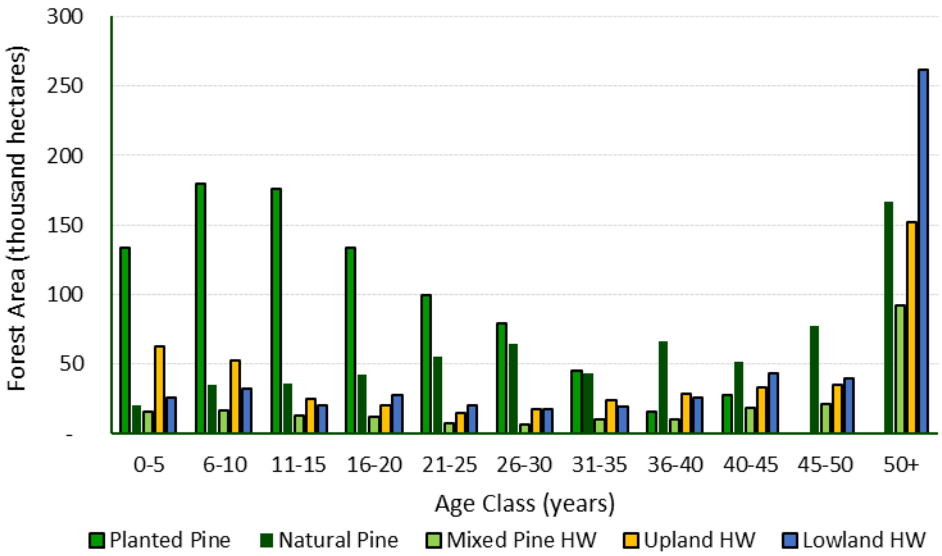


Figure 4.43: *MBE age class distribution by area and forest type (USFS FIA 2019).*

4.4.6 Data analysis

Tables 4.5 through to 4.8 summarise the data findings and professional opinions of the local experts carrying out the catchment area analysis at ABE and MBE. The comments included in these tables are the local expert opinions and conclusions based on the data findings.

Table 4.5: *ABE CAA, summary of data trends and analysis for key metrics (Hood Consulting).*

Is there evidence that bioenergy demand has caused:	
Deforestation?	**No.** US Forest Service data shows that the total timberland area has increased by more than 5,200 ha since the pellet mill began operation in 2014.
A change in management practices (rotation lengths, thinnings, conversion from hardwood to pine)?	**No / Inconclusive.** Changes in management practices have occurred in the catchment area over the last 5-10 years, but there is little evidence to suggest bioenergy demand has caused these changes. Market research shows thinnings have declined in this catchment area since 2014 (when ABE commenced production). However, local loggers identify poor market conditions for the decrease in thinnings, not increased bioenergy demand. The primary focus of timber management in this area is the production of sawtimber and rotation lengths of managed forests have remained unchanged (between 25-35 years of age) despite increases in bioenergy demand. Increased bioenergy demand, however, has benefited landowners in this catchment area, providing additional outlets for pulpwood removed from thinnings.
Diversion from other markets (such that those markets were forced to reduce production)?	**No.** Since 2014, softwood pulpwood demand not attributed to bioenergy has increased 8% while demand for softwood sawtimber and hardwood pulpwood has increased 53% and 5%, respectively.
An abnormal increase in wood prices?	**No.** Prices for delivered pine pulpwood (the primary raw material consumed by Amite Bioenergy) have decreased 12% since the pellet mill commenced production in 2014.
A reduction in the growing stock of timber?	**No / Inconclusive.** Total growing stock inventory in the catchment area increased 5% from 2014 through 2017 (the latest available data). Specifically, pine sawtimber inventory increased 13%, pine chip-n-saw inventory increased 24%, and pine pulpwood inventory decreased 12% over this period. The change is indicative of an aging forest.
An abnormal reduction in the sequestration rate of carbon (overall growth rate)?	**No.** US Forest Service data shows the average annual growth rate of growing stock timber has decreased slightly since 2014, and a slower timber growth rate essentially represents a reduction in the sequestration rate of carbon. However, the reduced growth rate and subsequent reduction in the sequestration rate of carbon is due to the aging of the forest (changes in timber age class distribution), not to increases in bioenergy demand. As trees get older the growth rate slows down.
An increase in harvesting above the sustainable yield capacity of the forest area?	**No.** Growth-to-removals ratios, which compare annual timber growth to annual harvests, provides a measure of market demand relative to supply as well as a gauge of market sustainability. In 2017, the latest available, the growth-to-removals ratio for pine pulpwood equalled 1.80 (a value greater than 1.0 indicates sustainable harvest levels). Even with the increased harvesting required to satisfy bioenergy demand, harvest levels remain well below the sustainable yield capacity of the catchment forest area.

***Table 4.6:** ABE CAA, consultant's professional overview on key issues (Hood Consulting).*

Is there evidence that bioenergy demand has caused:	
Timber growing stock inventory	**Neutral.** Total wood demand (from biomass and other solid wood products) is up more than 35% compared to 2014 levels. Intuitively, increased demand means more timber is harvested, which reduces total growing stock inventory. However, in this catchment area, inventories are so substantial that increases in demand from bioenergy, as well as from other sources, have not been great enough to offset annual timber growth, and, as such, total growing stock inventory has continued to increase – an average of 2% per year since 2014 (when Amite Bioenergy commenced production).
Timber growth rates	**Neutral.** Timber growth rates have declined since 2014; however, evidence suggests the reduction in growth rates is more a product of an aging forest and not due to changes in bioenergy demand. Additionally, young planted pine stands are actually growing at a faster rate than ever before – due to the continued improvement of seedling genetics. And, as timber is harvested and these stands are replanted in pine (as has historically occurred in the catchment area), over the long term, the average timber growth rate is likely to increase.
Forest area	**Positive / Neutral.** Total forest (timberland) area in the catchment area increased more than 5,200 hectares from 2014 through 2017, the latest available. And while our analysis of biomass demand and forest area found a moderately strong relationship between the two, findings are inconclusive as to whether the increase in timberland acreage can be attributed to increases in biomass demand.
Wood Prices	**Neutral.** Despite the additional wood demand placed on this market by Amite Bioenergy, since 2014, prices for delivered pine pulpwood (the primary raw material consumed by Amite Bioenergy) have decreased 12% in the catchment area. Prices for pine sawmill residuals and in-woods chips (the other two raw materials consumed by Amite Bioenergy) have also declined over the last several years – down 3% since 2016 for pine sawmill residuals and down 3% since 2015 for in-woods chips.
Markets for solid wood products	**Positive / Neutral.** In the Amite Bioenergy catchment area, demand for softwood sawtimber to produce lumber has increased more than 50% since 2014. A biproduct of the sawmilling process is sawmill residuals – a material utilized by Amite Bioenergy to produce wood pellets. Not only has Amite Bioenergy benefited from the greater availability of this biproduct, but lumber producers have also benefited, as Amite Bioenergy has provided an additional outlet for these biproducts.

Table 4.7: *MBE CAA, summary of data trends and analysis for key metrics (Forisk Consulting).*

Is there evidence that bioenergy demand has caused:	
Deforestation?	**No.** Timberland area in the MBE market has increased by 3% since 2006. Conversion of natural and mixed pine stands to planted pine has occurred; hectares of planted pine increased 56%, while natural and mixed pine stands declined 25% and 51%, respectively.
A change in management practices (rotation lengths, thinnings, conversion from hardwood to pine)?	**No.** Overall, bioenergy markets have not directly impacted forest management activities or forest supplies in the MBE market. Pellet producers use 6% of the roundwood used by the forest products industry in the MBE market; Drax uses 4% of the roundwood in the market. Roundwood pulpwood consumption is concentrated in the pulp and paper sector, which represents 75% of pulpwood demand.
Diversion from other markets (such that those markets were forced to reduce production)?	**Possibly.** Bioenergy plants compete with pulp/paper and OSB mills for pulpwood and residual feedstocks. There is no evidence that these facilities reduced production as a result of bioenergy markets, however.
An abnormal increase in wood prices?	**No.** There is no evidence that bioenergy demand increased stumpage prices in the market. Stumpage prices for all pine products have declined since 2010. Pulpwood also remained above its ten-year low but was down over 40% from 2010. Ample pine supplies in the market softened prices.
A reduction in the growing stock of timber?	**No.** Inventory has increased 22% since 2009, with pine volumes rising by 39%.
An abnormal reduction in the sequestration rate of carbon (overall growth rate)?	**No.** Timberland productivity has increased in the MBE market. The annual growth per hectare, which increased 8% from 2009, reached 8.0 metric tons per hectare in 2018. These gains were attributable to private landowners as productivity on public land decreased. Timberland across the South and in the MBE market gained productivity from genetic improvements and silvicultural practices (including site preparation, fertilization, and competition control), particularly on actively managed private timberlands.
An increase in harvesting above the sustainable yield capacity of the forest area?	**No.** Since 2010, growth-to-drain (GTD) ratios have remained above one, averaging 1.45, with total growth exceeding removals. Net growth, growth minus removals, has averaged 6.0 million metric tons annually and increased 68% since 2010.

Table 4.8: *MBE CAA, consultant's professional overview on key issues (Forisk Consulting).*

Is there evidence that bioenergy demand has caused:	
Timber growing stock inventory	**Neutral.**
Timber growth rates	**Neutral.**
Forest area	**Neutral.**
Wood Prices	**Neutral.** Bioenergy markets benefit timberland owners by adding outlets for wood in the region. However, the scale of demand at MBE (just 4% of the market) means that it is unlikely to have any major impact on key issues at the catchment area level.
Markets for solid wood products	**Neutral / Positive.** Access to viable residual markets benefits users of solid wood (i.e. lumber producers).

4.5 TOOL 3: REMOTE SENSING OF KEY METRICS

4.5.1 Analysis of forest area

The use of NFI data and field sampling is a well-established and widespread methodology for assessing forest area and forest inventory (see section 4.4.1). However, the increase in the availability of satellite data and imagery provides the potential to look at other methodologies for monitoring trends in forest metrics at a catchment area level. A pilot study was carried out using the ABE catchment area to assess the viability of using remote sensing for monitoring any change in forest area and forest composition. Hatfield Consulting was engaged to use the methodology described in Figure 4.44 to assess forest area at ABE.

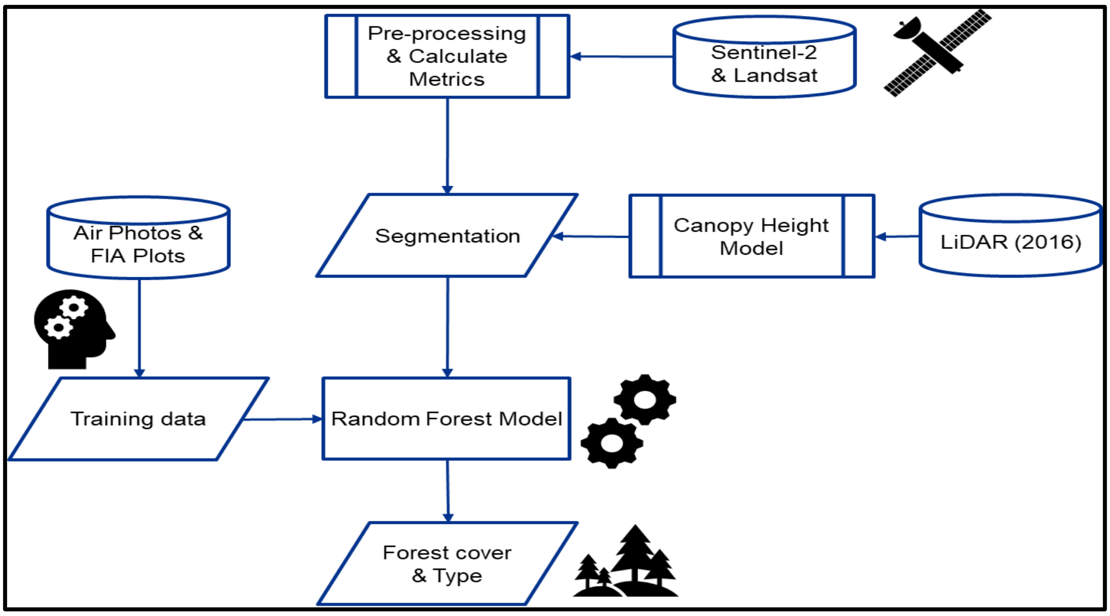


Figure 4.44: *forest cover analysis methodology (Hatfield Consulting, 2019).*

The range of available 'open' data sources are listed in Table 4.9. LiDAR and aerial photographs require a bespoke survey of the target area and are therefore more expensive unless pre-existing and openly accessible. For the ABE catchment area LiDAR was available for 2016. Landsat and Sentinel satellite images are available for the study period (2010-19) however, the quality and detail for each option is variable and only the more recent data sources (e.g. Sentinel-2) offer sufficient granularity to decipher variations in canopy composition (Hatfield, 2020).

Table 4.9: *availability of satellite data sources for ABE (Hatfield Consulting, 2020).*

Dataset	Source	Availability	Description	Forest Cover	Forest Carbon
LiDAR	USGS	2016	Derive vegetation metrics (e.g. canopy height)	Y	Y
Aerial Photos	MCCRSGIS; NAIP	2016, 2018	Reference data to interpret and validate forest cover	Y	
Sentinel-2	ESA	2015-present	Imagery to derive spectral metrics to classify tree and shrub cover and other basic land cover classes	Y	Y
Landsat-8	USGS	2013-present			
Landsat-7	USGS	1999-present			
Landsat-5	USGS	2010-2013			
Forest Inventory	US FIA	Present	NFI plots and allometric equations		Y
Protected Area Database	USGS	Present	National database for biodiversity conservation	Y	Y

Where Sentinel-2 data are available, post 2016, it has been used in the analysis. Prior to 2016, Landsat was the best available source of satellite imagery, see Table 4.10. Earlier data sources (pre-2016) were more susceptible to image clarity problems due to cloud cover, smoke or other factors obscuring the image due to a lower resolution.

Table 4.10: *satellite data sources selected ABE study (Hatfield Consulting, 2020).*

Year	Data	Sensor	Cloud Cover %	Comments
2008	Nov 9th	Landsat-5	0	
2009	Nov 12th	Landsat-5	0	
2010	Oct 30th	Landsat-5	0	Smoke plume
2011	Nov 2nd	Landsat-5	0	
2012	Oct 11th	Landsat-7	0	SLC error
2013	Nov 7th	Landsat-8	10	Cirrus clouds
2014	Nov 26th	Landsat-8	0	
2015	Oct 28th	Landsat-8	25	Cirrocumulus clouds
2016	Nov 12th	Sentinel-2	0	Co-incident LiDAR
2017	Nov 17th/22nd	Sentinel-2	0	
2018	Nov 22nd	Sentinel-2	0	

Satellite image availability prior to 2016 was limited in terms of cloud-free images in the autumn season when deciduous leaves have senesced. Sentinel-2 satellites provide a larger range of spectral bands that are useful for deciduous and coniferous classification. The spatial resolution of 10 m of Sentinel-2 is also considered an appropriate spatial resolution for monitoring a landscape of this size and complexity (Hatfield Consulting, 2020). Hansen *et al.* (2013) produced a study for the University of Maryland using older Landsat images with a resolution of 30 m which reduced granularity and accuracy at a forest stand scale. Hansen *et al.* (2013) attempted to monitor global forest loss by identification of harvested areas. Comparing the Sentinel-2 images against Hansen data in the ABE catchment area, Hatfield identified a high degree of error in the older analysis.

The satellite data collected by Hatfield Consulting for 2016 for the ABE catchment area has been stratified into polygons representing relatively homogenous units of land classification. These units include non-forest land and different strata of forest land classified according to tree height and composition. The LiDAR data from 2016 has been used to determine the tree height of the forest cover at that point in time. The polygon delineation is shown in Figure 4.45.

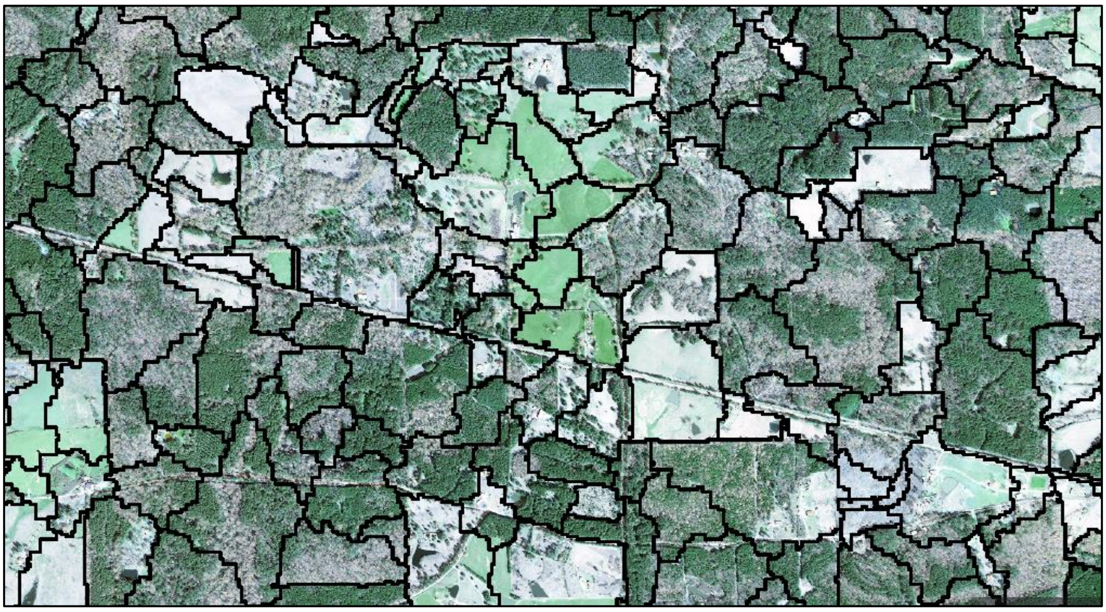


Figure 4.45: *landscape parcels derived from 'Tree Height Model' and Sentinel 2 (Hatfield Consulting, 2020).*

The tree height model has been used to define 4 categories of forest land as below:

- < 1 m (open)
- 1 to 5 m (low vegetation, dominated by shrubs)
- 5 to 10 m (coniferous [80%], deciduous [80%] or mixed)
- 10 to 20 m (coniferous [80%], deciduous [80%] or mixed)

LiDAR can be used alongside the satellite imagery to train an algorithm that can categorise each polygon of the image into a different height stratum. The algorithm was then used to compare images of the catchment area for each year of analysis and calculate any changes in the classification of each polygon. The results of the annual comparison are shown in Figure 4.46 which indicates the annual change in each broad forest type.

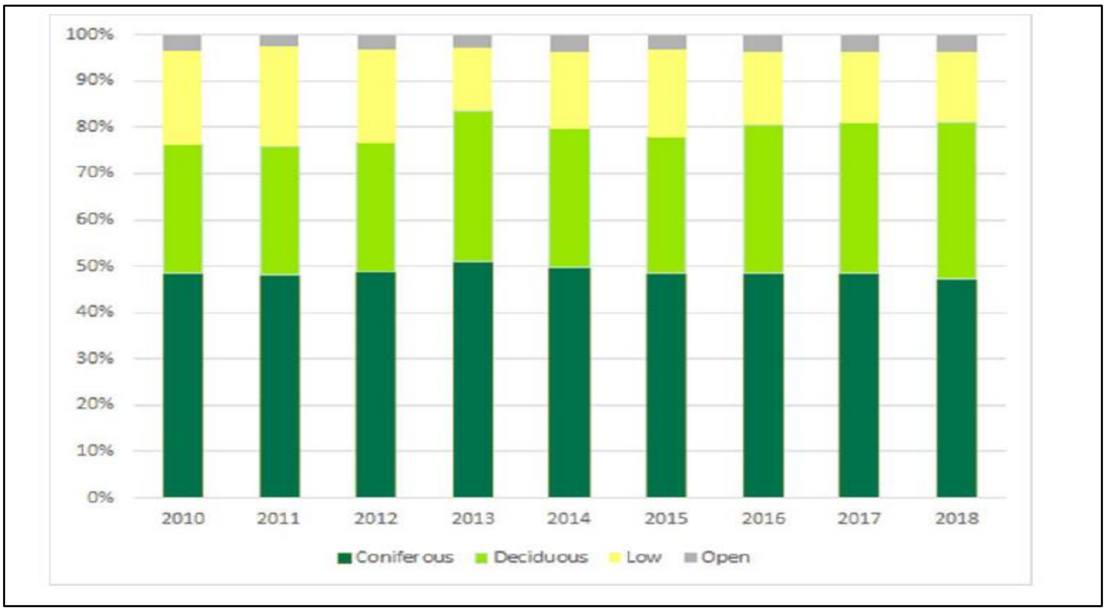


Figure 4.46: *ABE, change in forest cover (Hatfield Consulting, 2020). Note: this chart was provided by the consultant and therefore has a different format.*

The annual change in each polygon has also been graphically mapped (Figure 4.47) which shows a comparison of 2010 and 2019. The scale of the catchment area and the small degree of change over this period make it difficult to visually recognise any major change from the map images. The broad trend - that forest areas have remained stable - is evident.

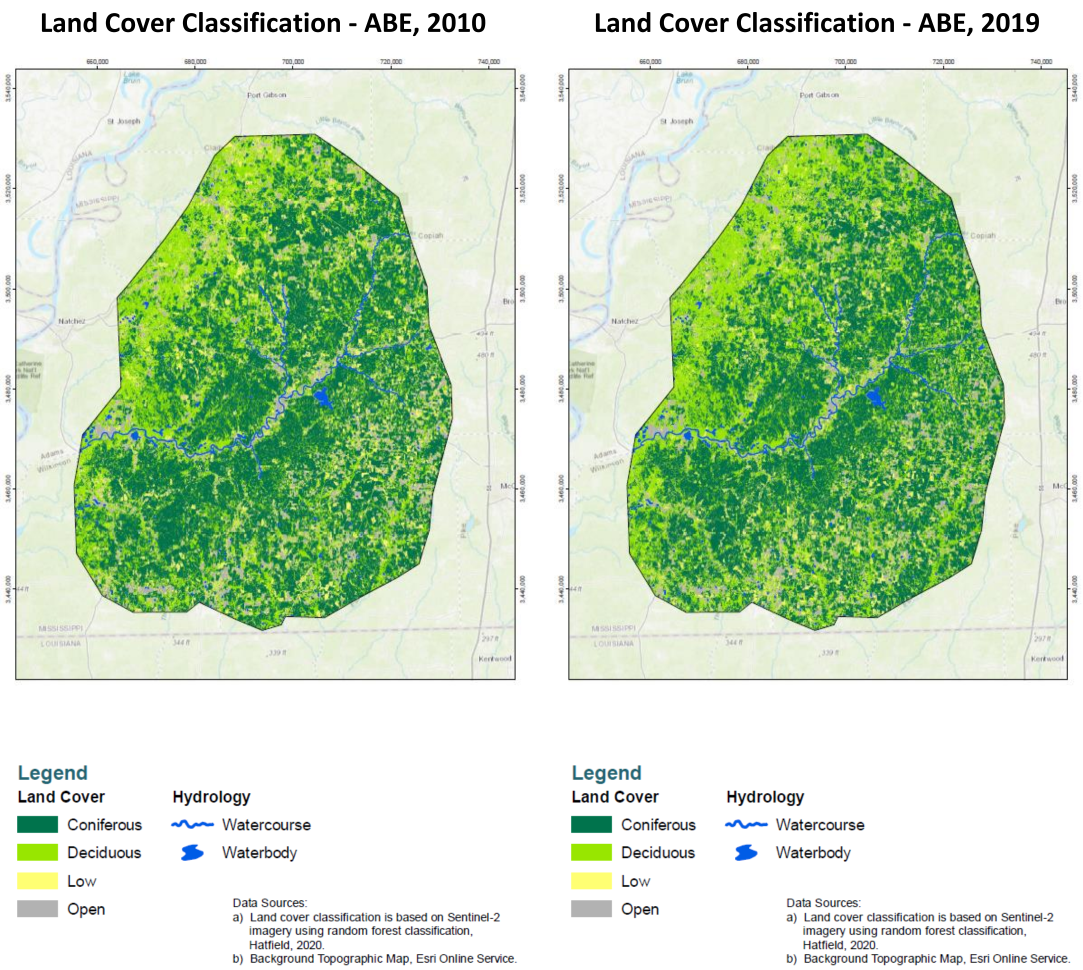


Figure 4.47: *remote sensing analysis (Hatfield Consulting, 2020).*

4.5.2 Discussion of remote sensing potential for forest area

Comparing the use of NFI data for forest area, forest type and composition in the CAA case study (section 4.4), with the remote sensing analysis; the NFI approach proved to be more a cost effective and accurate method (see section 4.4.2) of monitoring changes in forest cover. In the US South, inventory data is freely available, quick and easy to access. In comparison, using remote sensing to assess forest cover has a cost of around £30,000 for a catchment area the size of ABE, and takes several weeks of work.

In addition, there are multiple factors affecting the accuracy of the analysis as detailed below:

- **Boundary definition** – polygons are not exact, and therefore, mis-classify some forest and land types. Areas of open space are included within forest polygons and trees are present in open polygons. The extreme variability and complexity of forest landscapes (even relatively homogenous areas like the US South) make it challenging to categorise areas in consistent blocks that are large enough for efficient recognition and data training. These block or polygons are also likely to change over time; they can appear homogenous in one year, but interventions (either human or natural) change their composition and category from one year to the next. When multiplied over the larger area (more than 550000 ha at ABE) then it can lead to substantial discrepancies.

- **Broad strata** – 5 and 10 m differentials in tree height do not allow sufficient differentiation between forest types, other than a binary analysis of forest cover. These strata cannot be accurately used to calculate volume or quantity of biomass without a higher degree of granularity. Species differentiation is also an issue, with a failure to identify anything but the most extreme cases. No consistent definition exists to describe mixed forest, and therefore, it is not a transferable category (e.g. comparison with FIA and other datasets is complicated by different definitions).
- **TUP** – the algorithm cannot recognise temporarily unplanted land (TUP) that has been harvested and awaiting restocking, or where trees are growing but are below the height threshold required for recognition by the software. Consequently, the area of open land is overestimated and there is a lag of 5-10 years between harvesting and clear evidence that replacement forest is present or not.
- **Variability of image quality** – the resolution and granularity of older images (pre-2016) does not allow accurate comparison and analysis; cloud cover, leaf fall, smoke or other disturbance can all reduce accuracy. Future monitoring using sentinel-2 could be more accurate.

4.5.3 Remote sensing analysis of biodiversity impacts

The University of Oxford Department of Zoology (DoZ) was selected to carry out analysis of changes in biodiversity in the ABE catchment area. Two metrics were selected for monitoring over the time period (2010-2018), vulnerability and beta-diversity. The Local Ecological Footprinting Tool (LEFT) project (Long *et al.*, 2017) had been developed at Oxford and was used as a basis for evaluating the impacts at ABE.

4.5.3.1 Vulnerability

The methodology used for assessing the habitat for vulnerable species is described in Figure 4.48: datasets (green) are used and intermediate processing (pink) to provide output (red) map of the number of globally threatened and therefore vulnerable terrestrial vertebrate and plant species across a landscape (Department of Zoology (DoZ), Oxford, 2019).

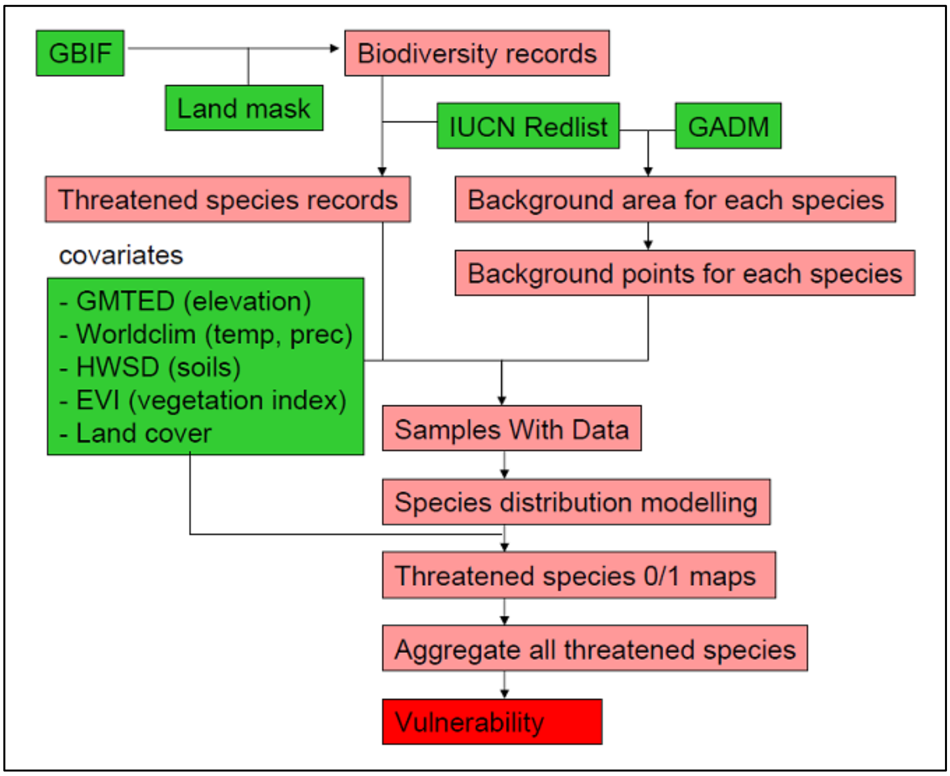


Figure 4.48: *Methodology for assessing vulnerability (DoZ, Oxford, 2019).*

The outputs were used to create a species distribution model for all International Union for Conservation of Nature (IUCN) threatened species in the area and a suitability model of the habitat where it should occur and where it is known to occur. The output maps for each species were combined into aggregated annual maps of the number of IUCN threatened species potentially present across the landscape; the parts of the landscape with the highest number of threatened species carry the highest ecological value. The results were modelled annually but are presented below for each end of the time period, 2010 and 2018 (Figure 4.49).

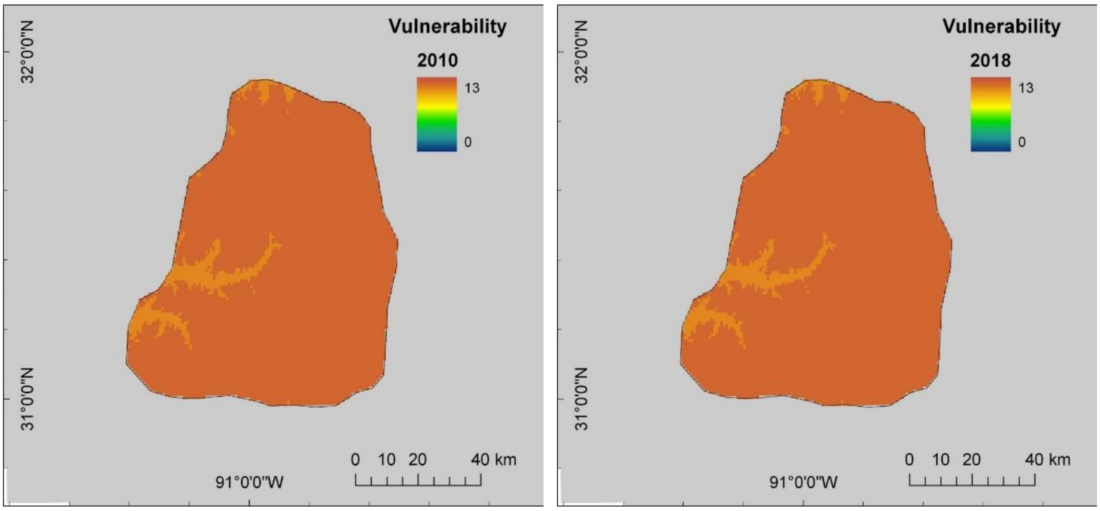


Figure 4.49: *Results of vulnerability monitoring at ABE (DoZ, Oxford, 2019).*

A total of 13 globally threatened species were modelled to be potentially present across the ABE landscape. There is limited spatial contrast in the distribution of these species: only in a limited area of lower elevation is one species modelled to be absent whereas all other potentially occur across the whole landscape (DoZ, Oxford, 2019). The results suggest that there has been no negative impact to vulnerability of threatened species as a result of the ABE pellet plant operations.

4.5.3.2 Beta-diversity

Richness of biodiversity can be seen as a result of the combination of the total species diversity in a given place (alpha diversity) and the turnover across space (beta diversity). In principle, it is possible to estimate the pattern of alpha diversity using species distribution modelling. However, if biodiversity data is sparse, an alternative strategy in such situations, therefore, is to shift the focus of species distribution models from individual species to emergent properties of biodiversity such as beta-diversity (DoZ, Oxford, 2019).

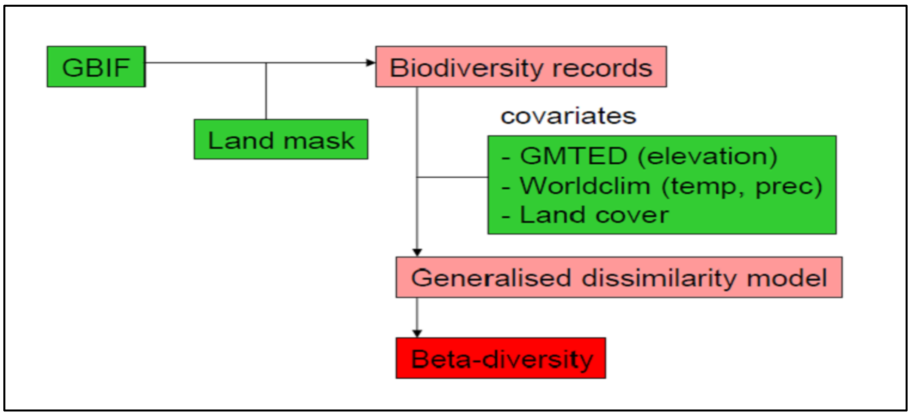


Figure 4.50: *Methodology for assessing vulnerability (DoZ, Oxford, 2019).*

To model beta-diversity, records of plants, amphibians, mammals, birds and reptiles were obtained from Global Biodiversity Information Facility (GBIF) alongside gridded covariates representing land cover, climate and topography. Beta-diversity was then calculated in each year using a generalised dissimilarity model. Generalised dissimilarity models (GDMs) were run for each taxonomic group (i.e. Plantae, Aves, Mammalia, Reptilia, and Amphibia). The biodiversity records are allocated to unique 'site identities', which were generated by concatenating the latitude and longitude strings for each record. The final beta-diversity map for each year was made by stacking the projections of these response functions (using gridded covariates) for all taxonomic groups. (DoZ, Oxford, 2019).
The results were modelled annually but are presented below for each end of the time period, 2010 and 2018 (Figure 4.51).

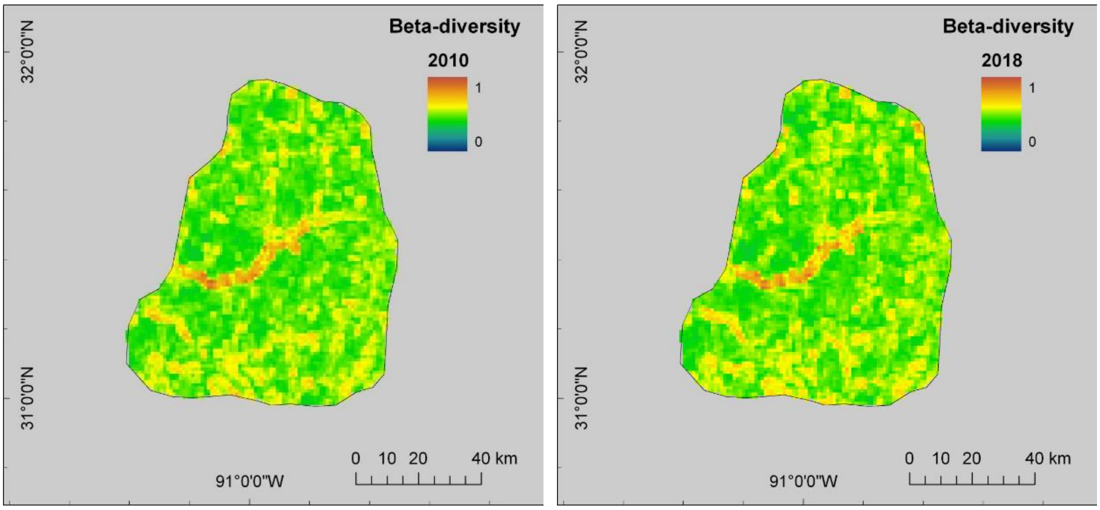


Figure 4.51: *Results of beta-diversity monitoring at ABE (DoZ, Oxford, 2019)*. On the graphic 1 represents a greater degree of change and 0 a lower degree of change.

There is a small contrast in beta diversity across the ABE landscape, most prevalent in areas of complex topography (e.g. stream channels and along gradients of vegetation productivity and density). However, there appears to be relatively little change in beta-diversity year to year and no evidence that there has been a negative impact on bio-diversity from the ABE pellet mill. To verify this conclusion temporal variance of each pixel from 2010 to 2018 was calculated and mapped to identify the areas in which beta-diversity changed most over this time period (Figure 4.52). The areas of the most stable beta diversity are in blue, those with the greatest variation are in red.

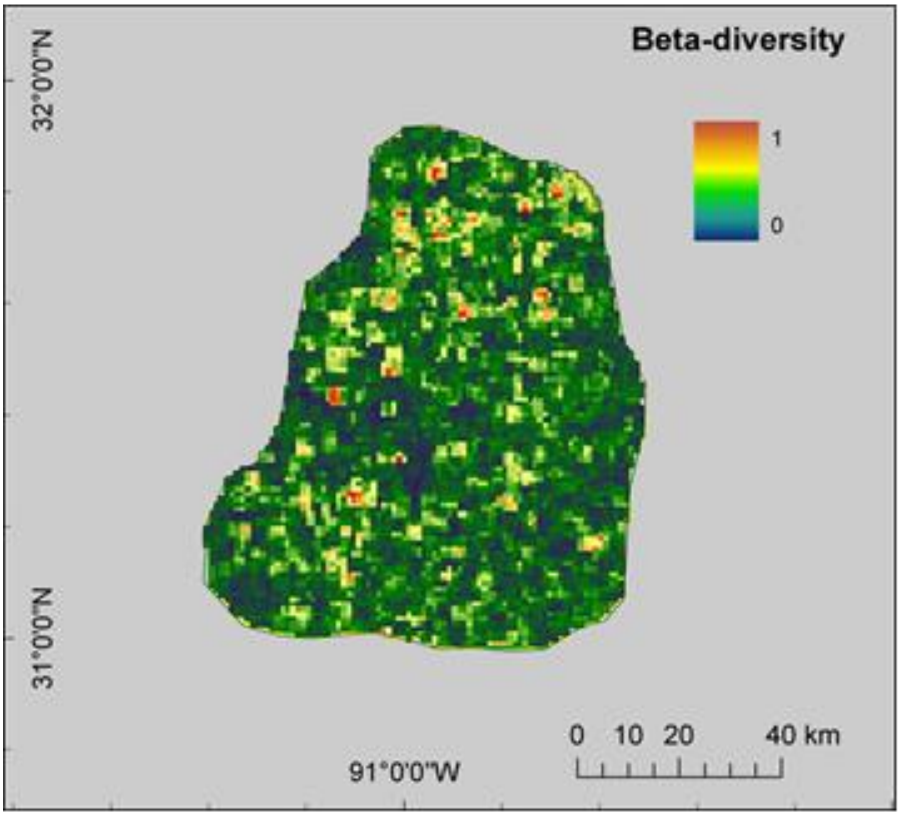


Figure 4.52: *Pattern of temporal variance in beta-diversity across the Amite landscape (DoZ, Oxford, 2019).*

Species vulnerability and beta diversity is just one approach to monitoring biodiversity. There are many alternative ways of defining, mapping, monitoring or measuring changes in bio-diversity. For example, it is possible to monitor fragmentation and urban development in forest areas; harvesting within protected areas or riparian zones; changes in specific indicator species or life cycle events. The approach described in this section has been recommended and produced by a very credible and experienced team of experts at the University of Oxford. The data output provides a degree of monitoring and analysis that can be used as an initial baseline and developed further with additional review and consultation. As an approach to monitoring bio-diversity remote sensing can be considered successful. However, the absence of any directly competing data (as in the case of forest area monitoring), and the complexity of the analysis, make it more difficult to challenge the results.

4.6 TOOL 4: POST HARVEST EVALUATION

Understanding and monitoring the impact of biomass demand and utilisation on the forest landscape is essential for demonstrating the long-term sustainability of biomass supply chains and ensuring regulator and stakeholder confidence that key criteria are being monitored, as discussed in Chapters 1 to 3. Established sustainability processes ensure a basic level of compliance, although important questions remain unanswered, as described in Chapter 3.

The catchment area and data analysis approaches, discusssed in 4.4 and 4.5, were aimed to better understand and communicate the higher level trends that are evident in biomass supply chains. Whilst insightful and valuable for a high level view, these approaches cannot directly assess the impact of the biomass used by energy generators, since they examine trends at a catchment area level of hundreds of thousands or millions of hectares, rather than looking at specific sites. In these catchment areas the pellet mill is often a very small component of the wood product market - typically 5-15% of demand as shown in the ABE and MBE CAA data. Consequently, any trends (either positive or negative) are difficult to attribute directly to biomass demand. Post-harvest evaluations, sampling a proportion of specific sites used to supply biomass to a pellet mill, can provide an additional layer of oversight and evidence to support a growing package of sustainability evidence and ensure confidence in the sustainability of biomass supply chains. Additional evidience can be particularly valuable if biomass use is to continue at scale post 2027 with BECCS.

4.6.1 Purpose of post-harvest evaluation

The purpose of post-harvest evaluation (PHE) is to verify that the information provided by the forest owner at the time of sale and harvesting is still valid. On clear-cut sites the PHE can verify that the forest has been replanted or regenerated as intended, sufficient to provide an equivalent area of future forest to the pre-harvest site. On a thinned site, PHE can verify that the thinning intensity and methodology was appropriate and in accordance with the pre-harvest plan (approved at the time of sale). In both instances PHE can be used to verify that any sensitive or protected sites remain intact and undamaged. The objectives of post-harvest evaluation are to:

- Ensure that deforestation or degradation has not occurred, that clear cut sites have been replanted/restocked and that there is no evidence to suggest that the productivity of the site has been impaired; it may only be possible to assess productivty at a superficial level without detailed measurement but it should be possible to verify appropriate species and silviculture has been used (planting density, seedling quality, ground preparation, weed control, pest control, drainage and protection).

- Ensure that thinning operations are appropriate to the stated aim at the time of harvest (e.g. for sawtimber production, aesthetic value or wildlife habitat creation).
- Determine whether there has been any change in forest type or character (e.g. from pure hardwood or mixed stand to pure planted pine or vice versa).

4.6.2 Assessment options

There are 4 options that can be used to achieve the objectives described above, with varying degrees of intensity, cost and accuracy as described below:

1. Physical inspection on the ground, an experienced forester walking each sample site.
2. Inspection from roadside through drone survey, mapping and video evidence.
3. Remote sensing through aerial photography.
4. Remote sensing through analysis of satellite imagery.

Table 4.11: *Review of PHE options.*

Methodology	Advantages	Challenges
Physical inspection	• Detailed and thorough • Most effective way to make appraisal of quality and character	• Time consuming therefore expensive • Legal right of access to land not guaranteed and access to every part of site may be challenging
Drone inspection	• Quicker and more detailed than physical inspection • Video/photographic record of survey, physical access not required • Lower cost than remote sensing	• Site quality and management issues may not be as easily identifiable • Can be time consuming to review and analyse data
Remote aerial photography	• No access to site required, entirely remote • Photographic evidence of site status	• Photography is expensive at large scale • Cost is wasted if restocking has not yet occurred • Evaluation of image can be challenging and time consuming
Remote satellite imagery	• Machine learning and algorithm can be used to cover a large number of sites • No site access required • Minimal human intervention once methodology established	• Degree of assessment is basic compared to other methods (i.e. trees or no trees), quality assessment cannot be made without human judgement • Algorithm development and training can be costly and time consuming • Accuracy of results is questionable

4.6.3 Range of questions that can be addressed through PHE

There are limitations with each approach to PHE; in general, a physical inspection will yield more data, but any form of inspection or analysis will be limited by the age and current condition of the site and future unknowns. For example, when walking through a restocked forest site after 5 years it is not possible to determine, with any degree of statistical accuracy, the future productivity potential of the site. The current growth and health status can be observed, but will only provide an indication of future status. Table 4.12 compares the physical approach to the remote sensing approach and identifies the potential to consider a wider range of questions when physically visiting the site. Both options have been assumed to be undertaken at around age 5; therefore, the ability to evaluate more nuanced trends in the site is limited. Remote sensing of a semi-mature forest (e.g. beyond 20 years of age) can provide a greater range of insights. The primary purpose of looking at PHE in this study is to evaluate deforestation and degradation; to confirm the reestablishment of forest post-harvest. Additional insights on forest quality, character and sensitive sites can be obtained through physical inspection where this is possible.

Table 4.12: *Questions that can be addressed through different approaches to site evaluation.*

Is it possible to address the questions below through each method of inspection?	Physical & Drone Inspection	Remote Image Inspection
Are there trees on the ground at a reasonable/appropriate stocking density?	Yes	Yes
Is the species mix as intended in the pre-harvest plan, does this differ from the previous crop?	Detailed species mix can be seen	Hardwood/Softwood can be determined
Does the site appear healthy and well managed or is there evidence of a management issue that requires intervention (e.g. natural mortality, pest damage, drainage issues, planting shock, nutrient deficiencies)?	Detailed evaluation can be undertaken	Extreme occurences could be observed.
What is the condition of any sensitive or protected areas on the site? Has management been appropriate to ensure they are maintained in their pre-harvest condition and according to regulations?	Detailed inspection and evidience can be observed	Limited assessment due to crop age and granularity of image
Is there evidence that the long term productivity of the site has been compromised or the character of the forest changed?	Basic assessment based on growth and health	Limited assessment of stocking and growth

4.6.4 Post-harvest case study at ABE

A range of recently harvested sites were visited during the field trip in March 2020. Physical inspection of a site by a trained forester can be the most comprehensive method of site evaluation (as described in Table 4.12 above). A selection of images is presented in Figure 4.53 below showing a range of young pine stands that have been replanted or regenerated after harvesting. These images were captured during the field visit to the ABE catchment area. There is a range of site variability and tree size according to age, species and other site conditions. Variability, and other attributes, can be assessed by physically walking across a site but may be less apparent, or trees less visible when observed by remote technology (either with a drone, aerial photography or satellite imagery). Due to the Covid-19 pandemic it was not possible to return to the US South during the period of study for this thesis to undertake further research into the potential for drone survey or physical inspection. However, remote imagery was available from satellite service providers to cover the US South in sufficient granularity to evaluate the potential for PHE by remote sensing.

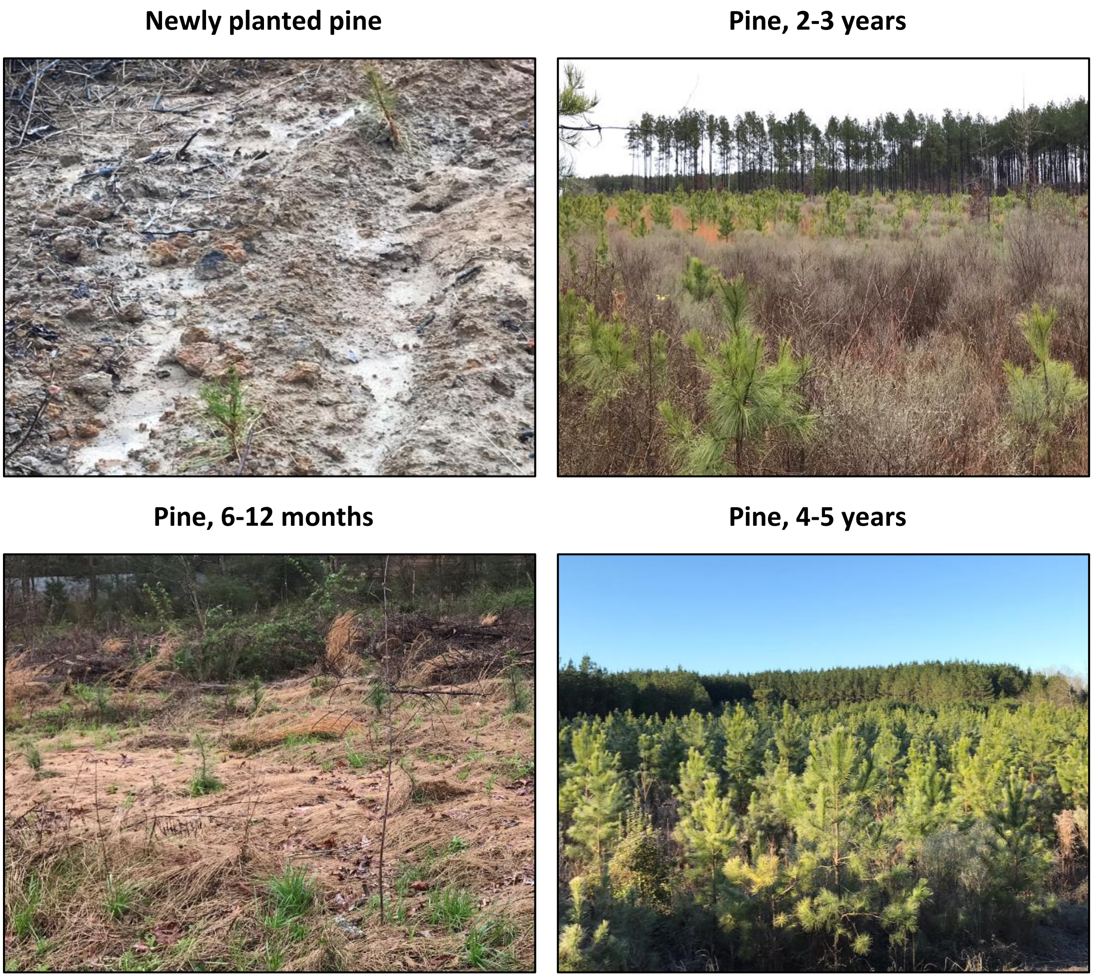


Figure 4.53: *Identifying replanted areas post-harvest.*

A case study has been completed looking at satellite images of forests captured from the ABE pellet mill catchment area. The service provider chosen for the case study was Maxar Technology's SecureWatch platform. A subscription to this service can be obtained for USD 2500 per GB of data used. DBI provided the locations of harvesting sites supplying the ABE pellet mill in 2017 and 2015. Only clear-cut sites are relevant to deforestation assessment, as tree cover remains post-thinning – although imagery could potentially be used to assess to quality and extent of thinning, but knowledge of the owner's objective would be required as this would affect the intensity of thinning and it would not be possible to determine the quality of the remaining trees from the imagery available. Initial analysis looked at 2017 harvesting sites due to better data accuracy (more complete information on land owners and suppliers). The sample sites were chosen to maximise the quantity of harvesting volume covered by the study, whilst limiting data usage of the software for cost effectiveness; the top ten sites by harvesting volume in 2017 and 2015 were chosen for analysis. The 2017 DBI supply data is more complete and represents a point at which the production operations at ABE were well established. In 2017 there were 195 clear-cut harvesting sites all of which had longitude and latitude coordinates, a summary of harvesting data for 2017 and 2015 respectively is shown in tables 4.13 and 4.14.

Table 4.13: *ABE 2017 roundwood supply data.*

Harvest Operation	Number of Sites	Total Acres	Total Tonnes
First Thin	117	15,108	305,319
Second Thin	47	6,403	92,493
Clear Cut	195	16,497	414,000
TOTAL	**359**	**38,008**	**811,812**

The 2015 harvesting data shows that there were 90 clear-cut sites in the ABE catchment area that provided roundwood during 2015. However, only 38 of these sites had latitude and longitude coordinates, as data collection at the time was limited as the mill was just establishing operations and building monitoring capacity.

Table 4.14: *ABE 2015 roundwood supply data.*

Harvest Operation	Number of Sites	Total Acres	Total Tonnes
First Thin	90	10,663	191,903
Second Thin	67	7,754	90,046
Clear Cut	90	9,735	115,647
TOTAL	**247**	**28,152**	**397,595**

SecureWatch was recommended by Hatfield Consultants as being the most appropriate tool for this specific research. The platform provides regular images of the US South (particularly since 2017); easy access and a simple user interface, allowing any user to search and review without specialist knowledge or training; relatively low-cost 'pay as you use' subscription options. Each of the top 10 sites from 2015 and 2017 has been reviewed pre-harvest and post-harvest to determine whether this technology can be used for rudimentary post-harvest evaluations; accepting that detailed analysis of a site is not possible without physical inspection.

4.6.4.1 Case study methodology

A list of all of the harvesting sites supplying the DBI ABE pellet mill were obtained for the target years. The top ten largest clear-cut harvesting sites by volume in 2017 were sampled, representing 5% of the total number of clear-cut sites and 22% of the clear-cut harvest volume. The top ten largest clear-cut harvesting sites by volume for 2015 were also sampled, representing 11% of the total number of clear-cut sites and 24% of the clear-cut harvest volume in that year.

The SecureWatch platform was opened and the harvesting site coordinates were entered (latitude first, space, then longitude). All available images were reviewed and then an image was selected at end of harvest year or shortly after, to confirm the location and evidence of the harvesting site. In many cases it was necessary to zoom out to a 300-metre view to determine whether any evidence of harvesting was present. Once the harvesting site has been located, the 2010 base-layer image (or best available) was selected to confirm that forest was present prior to harvest and an image snapshot was taken (usually at 100-metre or 200-metre resolution). These images now confirmed the presence of forest prior to the harvest year and evidence of harvesting in the specified year. Where no evidence of forest pre-harvest, or no evidence of harvest was available, it was assumed that the coordinates were incorrect. Where a harvesting event was evident, the most recent images of the site were then viewed, up to 20-metre resolution, if necessary, to determine whether there was evidence of restocking and tree growth – a snapshot of these images was also taken.

4.6.4.2 Case study results summary

- Image availability post 2018 was good and generally possible to see ground preparation and tree growth (where occurring) at 100m, 50m and 20m scale as required.
- 50% of 2017 sites had no evidence of tree growth despite clear imagery – probably due to limited time for restocking or growth post-harvest.
- 2015 DBI data accuracy was poor with 60% of clear-cut sites having no coordinates and 40% of sites viewed showing no evidence of clear-cutting operations around 2015.
- Supply data is more accurate from 2017 and image availability is much better from 2018, therefore SecureWatch can be a viable tool for assessment and future use.
- The analysis looked at 20 sites with a data usage of 365 MB, at a cost of USD 2500 per GB the average cost per site was USD 45.63.

4.6.4.3 Results of 2017 harvesting data analysis

Selected images demonstrating the findings are shown in Figures 4.54 and 4.55 below. A larger selection of images is included in Appendix II.

Figure 4.54: *Site 3 showing pre-harvest, post-harvest and young planting.*

Figure 4.55: *Site 4 showing pre-harvest, post-harvest and bare ground in 2020.*

The results show that 4 of the sites analysed had clear evidence of restocking or regrowth, one site had no clear imagery and the remaining 5 sites had recent clear imagery but no evidence of tree growth – probably due to the short time period between harvesting and assessment (Table 4.15).

Table 4.15: *ABE 2017 clear-cut PHE analysis results.*

Site Number	Vendor Name	County	Tract Area (acres)	Longitude	Latitude	Harvest Quantity (tonnes)	Imagery	Evidence of Regrowth/Restocking
1	J & N Timber	EAST FELICIANA (LA)	70	-90.884	30.875	10,927	Good	Clear evidence of regrowth
2	J & N Timber	WILKINSON (MS)	100	-91.165	31.079	10,857	Limited	No clear image
3	Weyerhaeuser	JEFFERSON (MS)	229	-90.886	31.650	9,896	Good	Clear evidence of restocking
4	Weyerhaeuser	JEFFERSON (MS)	99	-90.905	31.703	9,868	Good	No evidence (bare ground)
5	Weyerhaeuser	JEFFERSON (MS)	124	-90.924	31.813	9,514	Good	Clear evidence of restocking
6	Weyerhaeuser	JEFFERSON (MS)	129	-90.845	31.714	8,859	Good	No (green but no obvious trees)
7	Weyerhaeuser	JEFFERSON (MS)	195	-90.926	31.685	8,332	Good	No (green but no obvious trees)
8	Darden Timber, Inc	AMITE (MS)	55	-90.890	31.056	8,289	Limited	No (green but no obvious trees)
9	Weyerhaeuser	FRANKLIN (MS)	77	-91.103	31.505	7,336	Good	Clear evidence of restocking
10	LandMAX Timber	FRANKLIN (MS)	150	-90.924	31.451	7,262	Good	No evidence (bare ground)

Table 4.16: *ABE 2015 clear-cut PHE analysis results.*

Site Number	Vendor Name	County	Tract Area (acres)	Longitude	Latitude	Harvest Quantity (tonnes)	Imagery	Evidence of Regrowth/Restocking
1	Darden Timber, Inc	AMITE (MS)	45	-89.808	32.083	5,730	Good	No evidence of harvesting
2	Darden Timber, Inc	WILKINSON (MS)	34	-90.442	32.057	4,564	Limited	No evidence of harvesting
3	Weyerhaeuser	AMITE (MS)	148	-91.034	31.311	3,124	Good	Clear evidence of restocking
4	J & N Timber	AMITE (MS)	20	-89.860	32.040	3,052	Good	Clear evidence of restocking
5	J & N Timber	AMITE (MS)	40	-89.825	32.215	2,519	Good	Clear evidence of restocking
6	J & N Timber	AMITE (MS)	80	-89.996	32.042	2,115	Limited	Unable to identify 2015 site
7	Weyerhaeuser	WILKINSON (MS)	207	-91.294	31.131	2,102	Limited	Unable to identify 2015 site
8	J & N Timber	AMITE (MS)	100	-90.794	31.094	1,813	Limited	No evidence of restocking
9	LandMAX Timber	FRANKLIN (MS)	35	-90.709	31.473	1,665	Good	Unable to identify 2015 site
10	Weyerhaeuser	WILKINSON (MS)	153	-91.116	31.253	1,554	God	Unable to identify 2015 site

4.6.4.4 Results of 2015 harvesting data analysis

Only 42% of clear-cut sites supplying biomass in 2015 had harvesting coordinates and of the top ten, 6 showed no evidence of harvesting in 2015 (likely to be inaccurate coordinates). Where coordinates were accurate, the longer time gap post-harvest provided better evidence of restocking or regrowth (Table 4.16).

Selected images demonstrating the findings are shown in Figures 4.56 and 4.57 below. A larger selection of images is included in Appendix II.

Figure 4.56: *Site 5 showing pre-harvesting, post-harvest and young trees growing in 2020.*

Figure 4.57: *Site 8 showing pre-harvesting, post-harvest and no evidence of trees growing in 2020.*

4.6.5 Post-harvest evaluation discussion

The purpose of section 4.6 was to consider the viability of evaluating biomass supply sites following harvesting to consider the subsequent management of the site and any possible change in forest type or character in the next generation. During the field visit, and as shown in Figure 4.53, it was found to be possible to physically visit some sites and inspect the trees to form a judgement as to the quality and condition of the forest. Where it is not possible, due to access limitations or time and cost constraints, then remote sensing can be used to provide a basic assessment of the post-harvest condition. There is potential for additional research and testing of the options and possibilities for remote evaluation that fall outside of the scope of this study. Improvements in technology, image quality and availability are providing a greater scope for analysis. A combination of remote evaluation and site-based assessment is likely to provide a solid base of evidence to indicate the condition of biomass supply sites in the years subsequent to harvesting operations.

4.7 REVIEW, REVISE, MITIGATE

As discussed in section 3.11.5, for the tools described in Chapter 4 to be effective, each process must be continually reviewed, developed and updated to ensure that it can provide the best available, cost-effective, methodology for demonstrating biomass sustainability; continually evolving to meet changing sustainability demands and requirements; adapting to best available technology and data; adapting to different forest landscape and feedstock types. Where negative impacts or trends are identified (e.g. evidence of deforestation, carbon loss or market displacement) then the biomass user must take action to remedy these issues. All results and findings should be published for full transparency and accountability. Industry experts and other stakeholders should be consulted on findings and results so that they can contribute to the review and development process. An ongoing process of review, refinement and continual development is an integral part of effectively demonstrating biomass sustainability; learning from mistakes or data challenges; adapting the methodology and refining the approach for new supply regions with very different forest characteristics and data sources.

As a first step in this process, the work completed with Hatfield Consulting evaluating the use of EO technology TO monitor forest cover was developed further and enhanced to attempt a more accurate assessment for the catchment area surrounding Drax's Morehouse Bioenergy (MBE) pellet plant. The additional development included improving the training data to enable the algorithm to better identify changes in each polygon. The analysis only used Landsat imagery to avoid the inconsistency generated when using both Sentinel-2 and Landsat; providing a more consistent data set over the entire timeline but reducing the accuracy of data available post 2016. The results (Figure 4.58) show an improvement in the correlation with NFI data and give visual representation of the changes in forest cover and classification, but remain less reliable and cost effective than the NFI data available in the US South. In regions where high quality NFI data is not available then this approach can add more value.

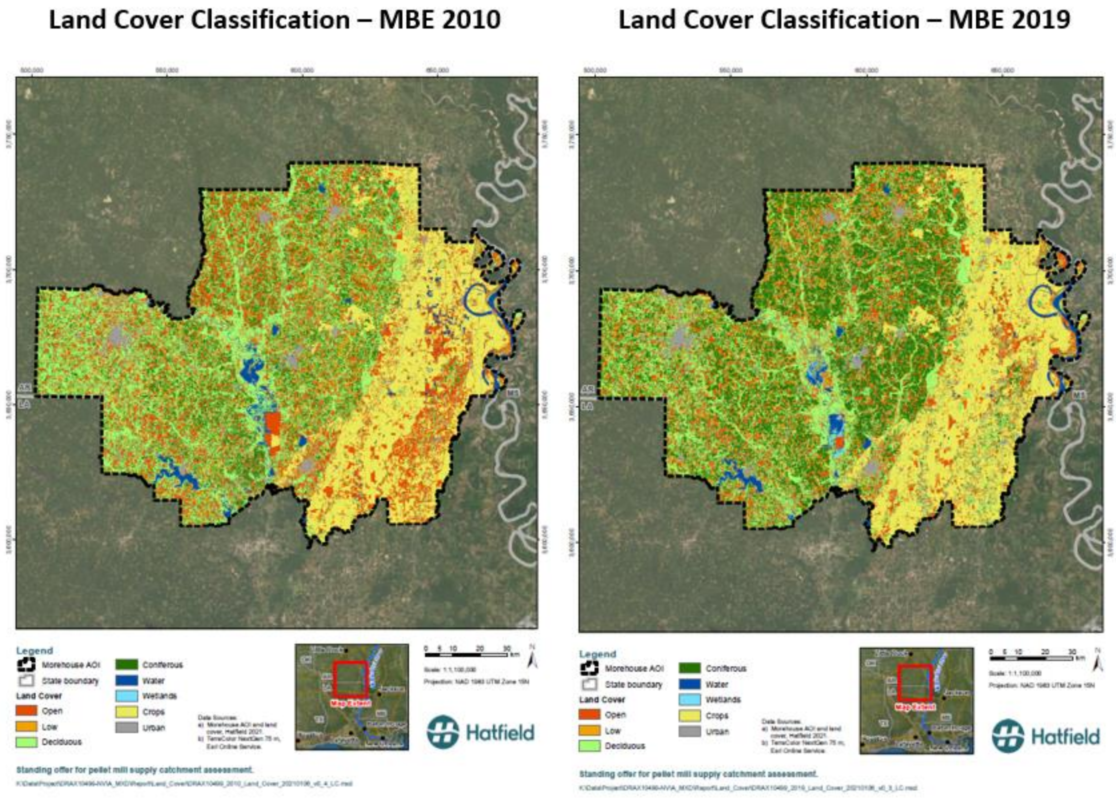


Figure 4.58: *Forest cover remote sensing analysis at MBE (Hatfield Consulting 2020).*

4.8 DISCUSSION OF CASE STUDY FINDINGS

A process for monitoring the sustainability of woody biomass has been developed and described in Chapters 3 and 4; including examples of data, evidence, methodologies and tools. These tools and processes can be used to set a benchmark of sustainability performance for the current use of woody biomass and the status of forest trends in each supply chain.

The collection of profiling data, describing feedstocks and forest types, is possible and valuable in helping to determine the sustainability of biomass supply chains. The CAA approach to identifying trends in forest management activity, growth, markets and carbon has proved successfully and useful in understanding more about the impact of biomass demand and trends in fibre supply catchment areas. The use of remote sensing technology to monitor forest cover has some limitations and, where robust NFI data is available, can be a less effective tool than using the CAA data. Remote sensing to benchmark and monitor biodiversity can be a useful tool but requires further development. Post-harvesting evaluations are also a useful tool for ensuring that forests remain as forest and can provide a varying degree of evidence depending on the approach used and the availability of data.

Chapter 5: Potential Scale of Future Biomass Utilisation

5.0 INTRODUCTION

There is an ongoing debate regarding the future role of biomass in mitigating the impacts of climate change (see section 1.2); in particular, the potential role of biomass in achieving negative emissions through carbon capture, utilisation and storage. There are two overarching questions relating to feedstock supply: how much biomass can be physically available? And, how much of this material can be sustainably utilised? These questions are complex and would require extensive in-depth analysis to address at a detailed level – this could form part of a separate piece of work but is not included in the scope of this study. This chapter considers the challenges associated with biomass availability forecasting, the limitations of currently available data and the requirement to make broad assumptions when completing a forecast.

5.1 CONTEXT AND APPROACH

The scale of future biomass demand was identified in chapter 1 and section 1.4 as being a key component of evaluating biomass sustainability. Understanding specific supply chains, forest types and feedstocks types, is necessary for monitoring and assessing the ongoing use of biomass. Understanding the scale of biomass availability is essential for future planning and the development of any support schemes to encourage an expansion in the use of biomass or development of BECCS projects. This chapter looks at the challenges associated with biomass availability forecasting. It also reviews some existing forecasts to consider the potential scale of future biomass use that could be achieved with both existing and new resources.

Examples of high-level global forestry data are included in section 5.4.1 (available from the FAO). A brief summary of existing research papers on biomass availability is included in section 5.5; which also summarises the results of two case studies that have been produced by forest industry experts - McKinsey Consulting (2020), Ricardo Consulting and UK Forest Research – FR (2020). In addition, the potential for new dedicated woody biomass plantations is considered alongside a discussion on the potential role that forests can play in climate change mitigation.

5.2 OVERVIEW OF BIOMASS AVAILABILITY FORECASTING

Existing biomass availability forecasts have been reviewed as part of this research. In many cases, the forecasting process follows the criteria shown in Figure 5.1 which details the variables that need to be determined and used to calculate a theoretical surplus.

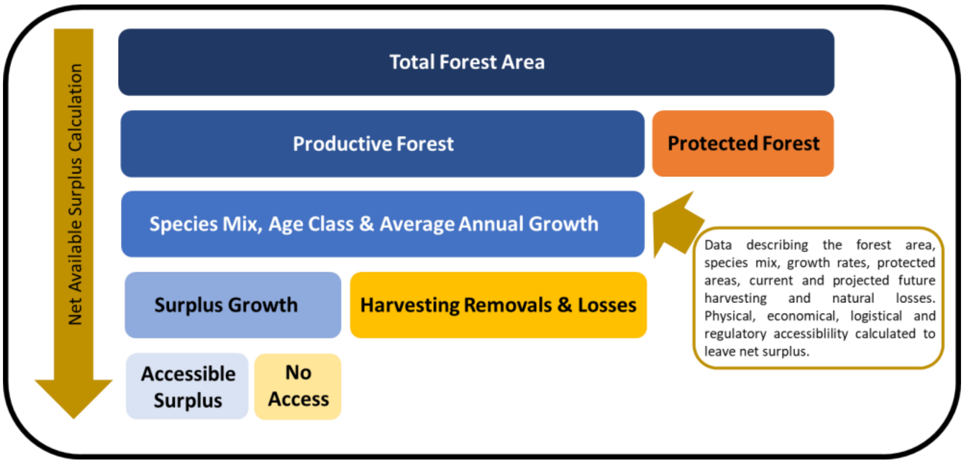


***Figure 5.1**: Surplus wood fibre assessment process (McKinsey 2020, Ricardo & FR, 2020).*

An outline of the process shown in Figure 5.1 is described below:

1. Identify the total area of productive forest – non-protected forest that can be sustainably managed and harvested.
2. Calculate the standing volume of timber by taking the total productive forest area, species mix, growth rates and age class to calculate current and expected future volume.
3. Compare the average annual rate of growth against the current and future harvesting removals for existing and future known market demand.
4. Deduct additional potential losses to natural mortality, pest, disease or disturbance (wind and fire).
5. Determine how much of any remaining surplus can be physically, economically, logistically and practically accessible – including constraints of governance and regulation, operational costs, topography, infrastructure, political climate and competing future markets; all of these variables must be considered to determine the potential surplus volume.

The challenge with using this forecasting process, particularly at a large scale, is the variability of each of these factors; the limited amount of accurate data, and the requirement to make broad assumptions where credible recent data are not available and for future unknown criteria. The degree of accuracy of any forecast will be linked to the availability of data and information to inform these assumptions. Typically, the larger the area being assessed the greater the degree of uncertainty and the broader the assumptions (Ricardo & Forest Research, 2020). Forecasting on a global scale can require extremely broad assumptions about some criteria as it can be time consuming and expensive to gather accurate and detailed intelligence and data about every country or every individual forest area. Circumstances and data are also regularly changing - forests continue growing or losing volume (to both harvesting and natural losses); market dynamics can change on a daily basis; regulatory and logistical constraints can also change. Consequently, forecasting on a smaller scale, at an individual country or regional level, can be more accurate and useful than large-scale assessment (as described in section 5.4).

At an individual forest level, an effective and appropriate management plan will include a detailed forest inventory (FAO, Forest Management Planning, 2017). The approach will break down the forest area into a number of compartments or sub-compartments, also referred to as 'stands' or 'forest management units' (FMUs). Each forest stand can be defined as a forest area consisting of the same species or species mix, age, yield class (growth rate), site type and management regime – it can be considered a homogenous unit for the purpose of management planning and forest operations (Nyland, 2007). The most effective way of understanding the volume of timber in each stand and the rate of growth, is to physically measure the trees (see section 5.3). In many of the more advanced forest industries around the world there is a government funded programme of forest inventory and measurement, sampling and forecasting. For example, the USDA FIA database in the US South (as described in 5.3). Each EU country also has its own National Forest Inventory (NFI), with varying degrees of data accuracy. In a recent report for the European Commission, the JRC (Camia *et al.* 2021) comments that the EU NFIs are not frequently updated, refer to different time and spatial scales and are not easily comparable or harmonised. Some are based on field measurements and more detailed survey, others are based on modelling and forecasting which relies on assumptions for growth, species mix and harvesting potential (see section 5.3). Therefore, the accuracy and credibility of any biomass availability forecast, depends on the scale of assessment and the quality of available base data, as described below.

5.3 OVERVIEW OF FOREST MEASUREMENT AND DATA ACCURACY

The NFI in each country or region can be quite different in its intensity and frequency of measurement and overall degree of accuracy (Camia *et al.* 2021). In this section, the FIA database produced by the USDA Forest Service will be discussed by way of example, the USFS FIA briefing notes have been used as a source for the details described below.

The FIA traces its origin back to the McSweeney - McNary Forest Research Act of 1928 and began the first inventory in 1930. Since that time, it has been in continuous operation with a stated mission to: make and keep current a comprehensive inventory and analysis of the present and prospective conditions of and requirements for the renewable resources of the forest and rangelands of the US (US Forest Service, 2021).

The fundamental science behind measuring tree height and diameter to calculate growth and volume has remained relatively consistent over recent decades, as explained below. A girth tape is used to measure the diameter at breast height (DBH), which is a point on the tree stem 1.37m above the base of the tree or the root collar (the exact height can vary by country and methodology, this figure relates to the US FIA method). The height of a standing tree is conventionally measured using a clinometer or hypsometer, which measures the angle from the top of the tree to a measured distance away from the base, which forms a triangle from which the tree height can be calculated.

DBH measurement using girth tape **Tree height measurement using clinometer**

Figure 5.2: *Example of girth and height measurement in the US South.*

The combination of height and girth are then used to estimate total tree volume based on historical models for that particular species in that country or region. In the US South, data measurements have been collected and modelled for many decades and used to develop geometric equations to estimate the volume for each species and type of tree. The calculation process needs to estimate the rate of taper of the stem - the difference in diameter between the base, the middle, and the top of the tree. The taper can be consistent within a single species, but it can depend on growth rates and planting density - for example, closely stocked trees may grow taller and thinner but more openly planted trees can be shorter and fatter. Whether the site has been thinned, how many times, and at what age, can impact the degree of taper in the stem, in addition to other factors including genetics. Through many years of research, measuring and modelling, the Southern Research Station (SRS) FIA team has developed the formula below for under-bark volume calculation.

$$V = \alpha + \beta\left(dbh^{2}Ht\right) + \varepsilon$$

Where:
dbh = bole diameter at breast height
Ht = tree height
α and β are species-specific (or species-group-specific) coefficient

The formula is modified according to the parameters shown in Figure 5.3 below depending on species and stem characteristics of the sample trees.

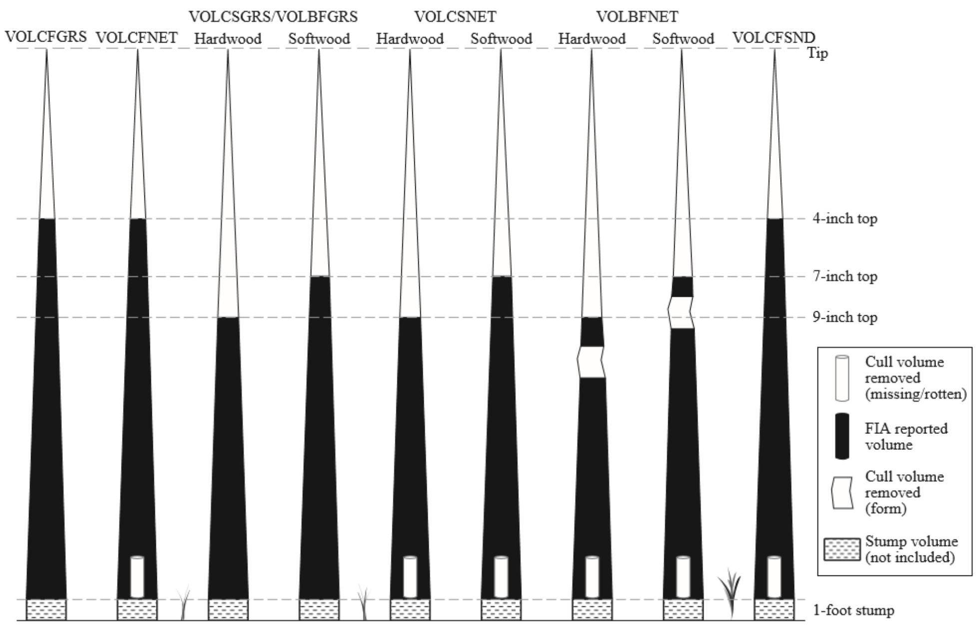


Figure 5.3: *Example of tree volume assessment variables (US Forest Service, 2021).*

Once the volume has been calculated, the basic density (solid wood per cubic metre) and moisture content can be used to calculate wet and dry weight, fibre content and yield.

The US Forest Service has built up an extensive historical record of data points through years of physical measurements – from both live tree sampling and from cutting down individual trees to determine the actual dimensions and variations to compare against the estimated volume of standing trees. Through many years of research and measurement, forest scientists have been able to build up data tables for each tree species that can be used to estimate growth and volume based on the DBH and estimated tree height.

The methodology described above looks at only one single tree; for production forecasting and forest inventory calculations, the result must be multiplied across the entire forest area being assessed. The forestland area of the US South covers more than 100 Mha in total which would be extremely challenging to measure in a cost effective and time efficient manner. The methodology applied in the FIA analysis is to use a network of sample plots randomly but sequentially distributed across the forestland in each state with undisclosed locations so as to avoid biased management. Field crews collect data on forest type, site attributes, tree species, tree size, and overall tree condition on accessible forest land.

In recent years, the FIA programme has involved a 5-year rolling measurement system where 20% of the plots are measured in each State, each year. At the end of a 5-year period, all plots will have been measured and the process begins again. The measurement process is overseen by a quality assurance system to maintain and ensure the quality and accuracy of the fieldwork.

Plots are distributed at a rate of 1 plot per 6,000 acres of land (or one per 2,400 ha). The degree of plot distribution is at an extremely course scale if attempting to understand the growth of an individual stand or forest area. For example, The UK Forestry Commission (FC) recommends using 8-12 plots (and top height measurements) for a relatively uniform stand of around 10 ha. The degree of accuracy recommended in the UK would be required to calculate the volume of standing wood for sale (FC). In comparison, the FIA data would be unreliable and inaccurate if trying to monitor growth and trends at an individual stand level or even at a single county level. The sampling intensity and the scale of measurement are the most critical factors in assessing the validity of data and trends that are identified through the FIA analysis, as described below and in Table 5.1.

The physical measurement procedure and volume modelling are well established processes with data and analysis collected over many decades to support the findings; which leads to a clearly quantifiable degree of error for each measured plot. The challenge comes when using plot data to estimate the values in the surrounding forest. The level of accuracy will depend on the ratio of plots to total forest area and the total number of plots measured. The ratio of plots per ha in the US South is pre-determined, limited by the physical and financial constraints of actually measuring trees on the ground. However, the total number of plots used to evaluate trends can vary according to how large an area is assessed.

If a single county is assessed then the total number of sample plots will be statistically low and the potential for error will be high (as shown in Table 5.1). If an entire state is assessed, then the number of plots is much larger (despite the same ratio of plots per ha) therefore the data and the trend are statistically much more accurate. An example of the variation in error is shown in Table 6.1 below, comparing county and state level accuracy with the Catchment Area Analysis boundaries which use multiple counties but are smaller than state level assessments.

Table 5.1: *Degree of error in USFS FIA data by varying scale of analysis (USFS, 2020).*

2018 Error (+/-95% CL))	Timberland Area	Inventory	Growth
MS County	49.9%	61.8%	65.9%
ABE CAA	5.5%	7.4%	10.2%
MS State	1.2%	2.5%	3.3%
NC/VA County	37.5%	46.5%	62.2%
Chesapeake CAA	3.1%	4.7%	5.3%
NC/VA State	1.3%	2.7%	3.4%
GA County	41.5%	51.9%	63.7%
GA CAA	3.1%	5.6%	5.5%
GA State	1.1%	2.4%	3.0%

The data showing total inventory (volume of wood growing in the forest) has been assessed for the ABE catchment area in Mississippi (Table 5.1 above). Considering each individual county, the data error calculation is +/- 61.8%, which is a high potential for error and not accurate enough for biomass availability forecasting when considering many millions of cubic metres of wood volume in each county. At state level, the data error is only +/- 2.5%. This degree of error is much more precise and demonstrates more credible and reliable data due to the much larger number of plots available across the entire state. The CAA analysis for inventory in the ABE area is +/- 7.4% which is closer to the state level accuracy due to the inclusion of multiple counties in the CAA analysis.

Since the catchment area boundary is defined by the pellet mill's historical and future sourcing pattern, it can vary in size according to each mill's procurement strategy and local market conditions. For example, the ABE pellet plant sources from a much smaller area close to the mill, and therefore the catchment area includes fewer counties than some other mills; leading to a higher degree of error as the total number of FIA plots used is smaller.

Measuring standing trees that are still growing is not an exact science: it is an estimation. Trees cannot be accurately weighed or measured until they are cut down. Consequently, there will always be a degree of error in the estimated data. In the US South, the long history of measurement, analysis and data modelling and the relatively homogenous nature of the main commercial species (southern yellow pine), mean that the error is uniform and predictable if a large enough sample area is considered. Therefore, using the FIA database for biomass availability forecasting in the US South can be considered to be relatively accurate if carried out at an appropriate scale, as shown in Table 5.1 and Figure 5.4.

Pöyry forest management consulting has produced a biomass availability forecast for the US South, using the FIA inventory database and bespoke market and availability forecasts. A breakdown of the supply and demand forecast for 2035 is shown in Figure 5.4, where the estimated surplus of available biomass for energy is 45.2 million oven dry tonnes (ODTs) per year from 2035. The Pöyry forecast demonstrates the level of detail that can be applied where credible growth and market information is available.

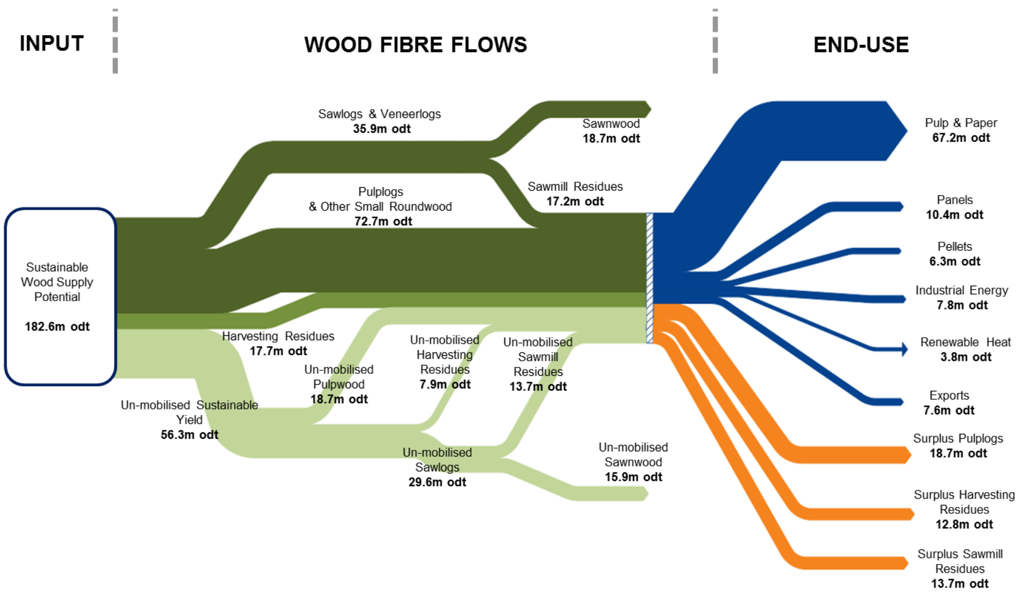


Figure 5.4: *Example of biomass supply and demand analysis for the US South in 2035 (Pöyry, 2018).*

The challenge in applying this methodology on a global scale is the lack of credible inventory and market data in some countries and the time required to analyse each individual area. Not all countries have the same intensity of measurement, analysis and public reporting. The base level of global forest data reporting is through the FAO in their Forest Resource Assessment (FRA) which is produced every 10 years and updated every 5 years. Interim data is available from the FAOSTAT database and is updated annually, examples of the FAO data are shown in section 5.4.1 and used for the case studies in 5.5.1 and 5.5.2 due to the absence of detailed and reliable NFI data for every country in the world.

At an individual forest or stand level, it is possible to carry out intensive measurement or to use Lidar to calculate volume and growth but it is not currently possible to do this at large-scale across several million hectares. Camia *et al.* (2021) concludes that, existing satellites have limited sensitivity to forest biomass and the biomass maps assessed for Europe capture the regional gradients but have moderate accuracy at local level. Therefore, time efficient global assessment must utilise the FAO data as a base for further analysis.

5.4 SUMMARY OF DATA AVAILABILITY AND CHALLENGES

As shown in previous sections, the credibility and accuracy of a biomass availability forecast depends on the scale of assessment and the degree of analysis and research that is applied to the process. Any forecast will require assumptions about future trends: forest growth, market demands, regulatory drivers and constraints, operational costs and prices, physical accessibility and logistical capacity (Pöyry, 2018). There is always uncertainty around these assumptions, irrespective of the degree of analysis and research used to support decisions. Forecasting future biomass availability from a single country or region, particularly one with a well-developed forest industry, can be more straightforward and accurate. The UK Forestry Commission has a long-term production forecast based on the age, species mix and growth rate of each individual forest area – based on a 10-year National Forest Inventory measurement and analysis programme. Information on current and future market demand is readily available through dialogue with the industry, logistical capacity can be mapped, regulatory support and challenges can be understood and incorporated into a forecast. The same situation can be described for the US South and most countries with a well-developed forest industry and a high degree of credible publicly available information. Therefore, a biomass availability forecast for a small number of developed countries is potentially much more accurate and reliable than a global assessment that includes a greater number of countries where data is less readily available and less reliable. It can be reasonable and cost effective to carry out detailed analysis for a small number of countries, but it is much more challenging and expensive to complete on a global scale. As a consequence, global biomass availability forecasts often rely on 'high level' data, reported at country level (through the FAO FRA), broad assumptions about growth rates, future demand and accessibility.

The following sections detail the potential for assessing biomass availability from both existing forest resources, using global datasets and broad assumptions, and from new biomass planting on degraded or unutilised land. Section 5.4.1 below gives a brief overview of some of the data and trends that are available through the FAO dataset as reported by each individual country. Existing biomass availability forecasts and then discussed and compared to provide an indication of the current range of forecasts and the theoretical scale of availability.

5.4.1 Global forest resource

Forest land represents 27% of the earth's surface area, Figure 5.6.

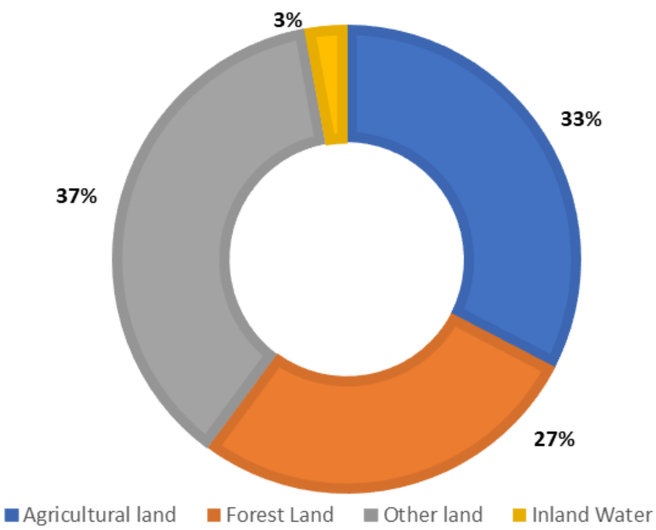


Figure 5.5: *Global area of forest (FAOSTAT, 2020).*

The total global area of forest land is 4.1 billion ha of which 31% is primary forest – untouched, unmanaged and requiring protection. Planted forest is 7%, the remainder is naturally regenerated forest that has had some form of management or human intervention in the past. A proportion of this area can be available for wood fibre and biomass production but the amount will vary by country and the forecaster must make an assumption on this point depending on local constraints (Figure 5.6).

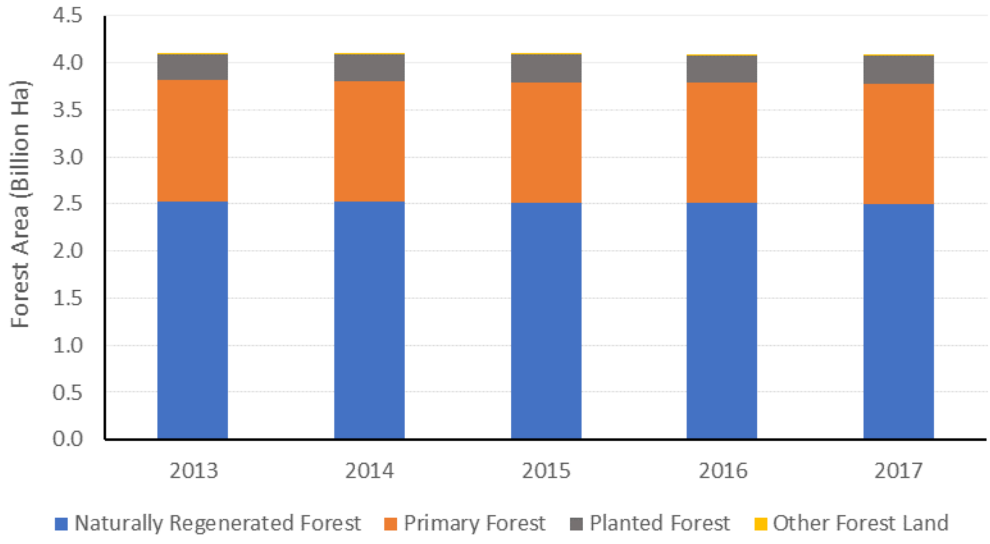


Figure 5.6: *Global area of forest by type (FAOSTAT, 2020).*

The production of wood products from the world's forests is split between industrial roundwood (used to produce solid wood products like saw-timber, pulp and paper, panel board and other material use) and wood-fuel (primarily used for domestic heat and energy on a non-industrial scale). Industrial roundwood production was at 2 billion m^3 in 2019 (51% of total production) and wood-fuel 1.9 billion m^3 (49%) - Figure 5.8.

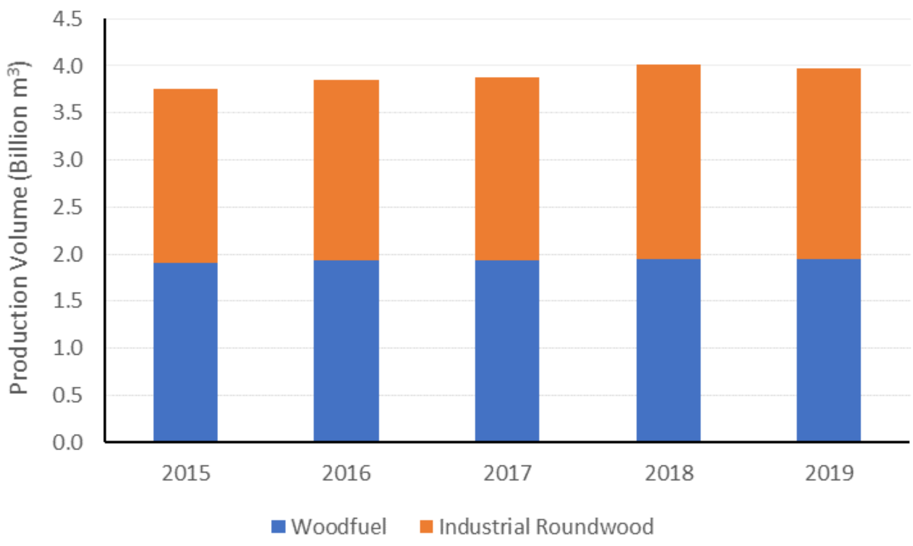


Figure 5.7: *Global production of roundwood (FAOSTAT, 2020).*

Russia has the largest forest land area, with over 800 Mha, followed by Brazil, Canada, USA and then China (Figure 5.8).

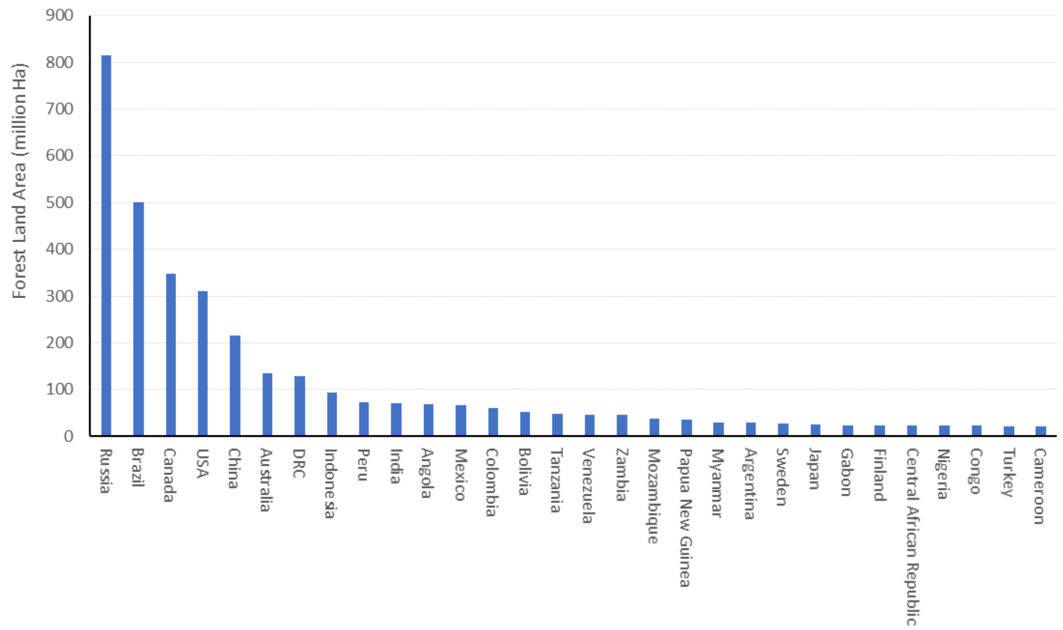


Figure 5.8: *Ranking of top 30 countries by total forest land (FAOSTAT, 2020).*

Separating primary and managed forest, Russia and Brazil remain the top two largest countries with managed forest areas, followed by the USA (Figure 5.9).

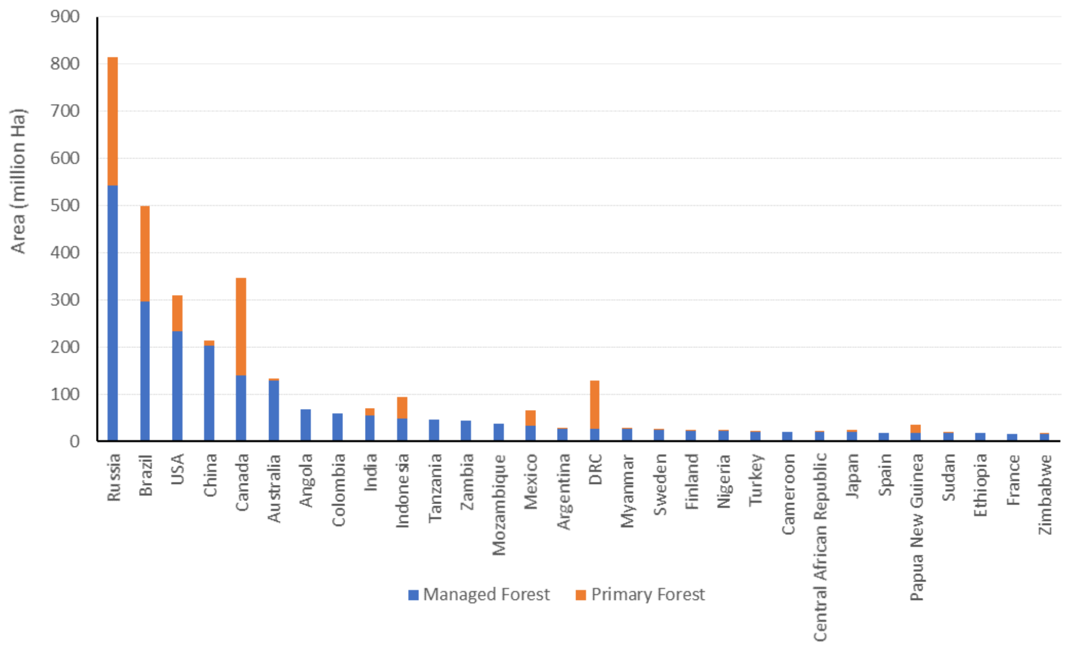


Figure 5.9: *Ranking of top 30 countries by non-primary forest land (FAOSTAT, 2020).*

The USA has the largest production of harvested roundwood with 437 Mm^3 in 2017 (85% industrial roundwood). Surprisingly, given the comparatively small forest area, India is second in the ranking with 354 Mm^3 (86% wood-fuel), Figure 5.10.

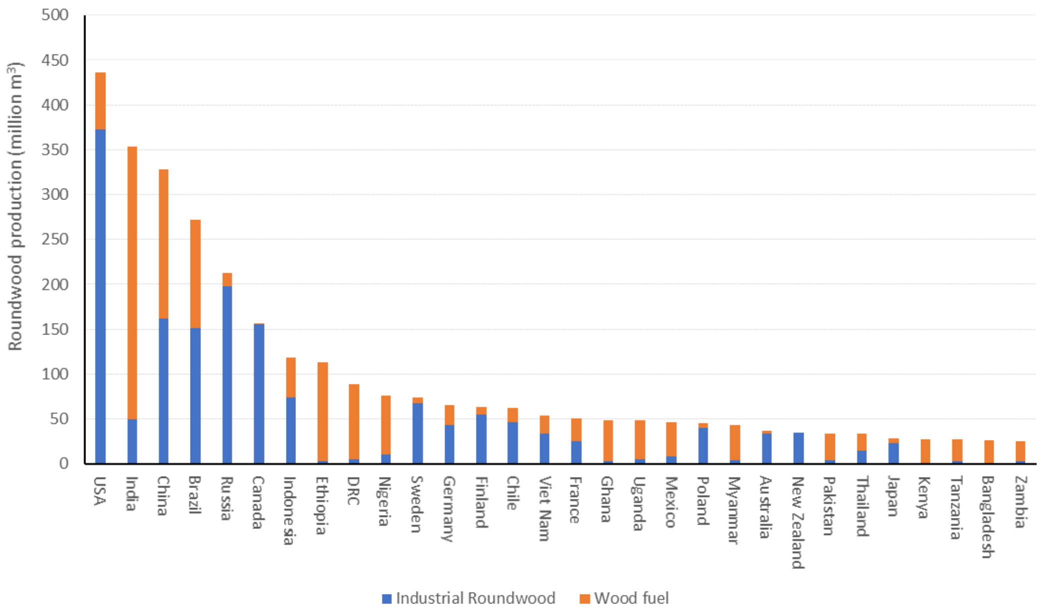


Figure 5.10: *Ranking of top 30 countries by production of roundwood (FAOSTAT, 2020).*

Brazil has the highest carbon stock, likely due to the tropical climate leading to higher vegetation density when compared to the boreal and temperate regions of Russia, Figure 5.11.

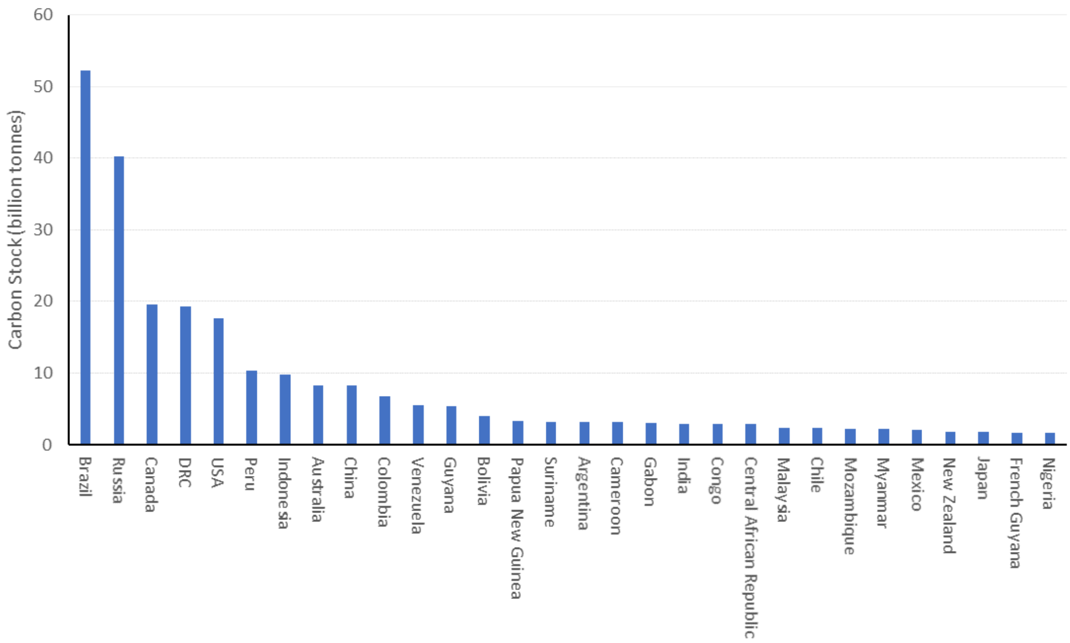


Figure 5.11: *Ranking of top 30 countries by total carbon stock (FAOSTAT, 2020).*

Table 5.2 summarises the FAO data for a selection of criteria and rankings of the top ten countries in each category globally. There are five countries present in each of the top ten lists (highlighted in colour and bold). Some countries have large forest areas and carbon stocks (e.g. Peru, DRC, Australia) but lower levels of industrial roundwood production – suggesting limited development of the forest industry and less accessible forests. Understanding why these theoretical large quantities of biomass are not available for sustainable utilisation is one of the challenges in global forecasting as discussed in section 5.4.

Table 5.2: *Top 10 countries in each category of forest area and volume (FAOSTAT, 2020).*

RANK	Forest Land	Non-primary Forest	Roundwood Production	Industrial Roundwood	Woodfuel	Carbon Stock
1	Russia	Russia	USA	USA	India	Brazil
2	Brazil	Brazil	India	Russia	China	Russia
3	Canada	USA	China	China	Brazil	Canada
4	USA	China	Brazil	Canada	Ethiopia	DRC
5	China	Canada	Russia	Brazil	DRC	USA
6	Australia	Australia	Canada	Indonesia	Nigeria	Peru
7	DRC	Angola	Indonesia	Sweden	USA	Indonesia
8	Indonesia	Colombia	Ethiopia	Finland	Ghana	Australia
9	Peru	India	DRC	India	Indonesia	China
10	India	Indonesia	Nigeria	Chile	Uganda	Colombia

5.5 FOREST BIOMASS AVAILABILITY FORECASTS

There have been a wide range of global forecasts of biomass availability, primarily based on a combination of agricultural residues, new energy crops, woody waste and forest residues. Slade *et al.* (2011) completed a detailed review and summary of existing studies for the UK Energy Research Centre. Figure 5.12 below, details Slade's findings on the pre-conditions or assumptions required for a varying scale of potential biomass availability. It demonstrates the variability and scale of potential availability and the challenge involved with creating a realistic forecast.

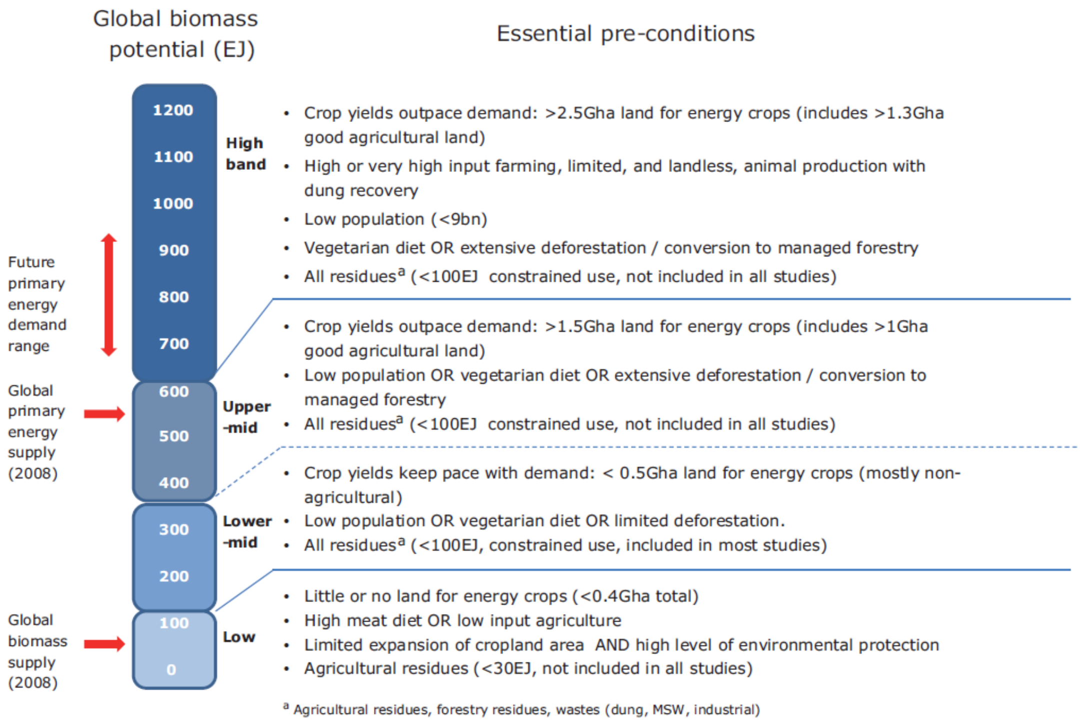


Figure 5.12: *Summary of variables in biomass availability forecasting (Slade et al., 2011).*

Since the Slade study, there have been a number of new forecasts with most tending towards the lower end of the scale shown in Figure 5.12. A selection of these studies is shown in Figure 5.13 with a maximum availability of 190 Exajoules (EJ), equivalent to 10 billion ODTs[1]. The forest biomass component of these studies is in the range of 10 to 40 EJ or from 500 MODTs to 1.7 billion ODTs[1] based on existing and anticipated future availability from existing forest resources – representing between 25% to 85% of the current global production of roundwood[2].

[1] Assuming 53.8 EJ per million ODTs (source: Ricardo)
[2] Assuming average basic density of 500 kg per cubic metre and total production of 4 billion m^3 per year.

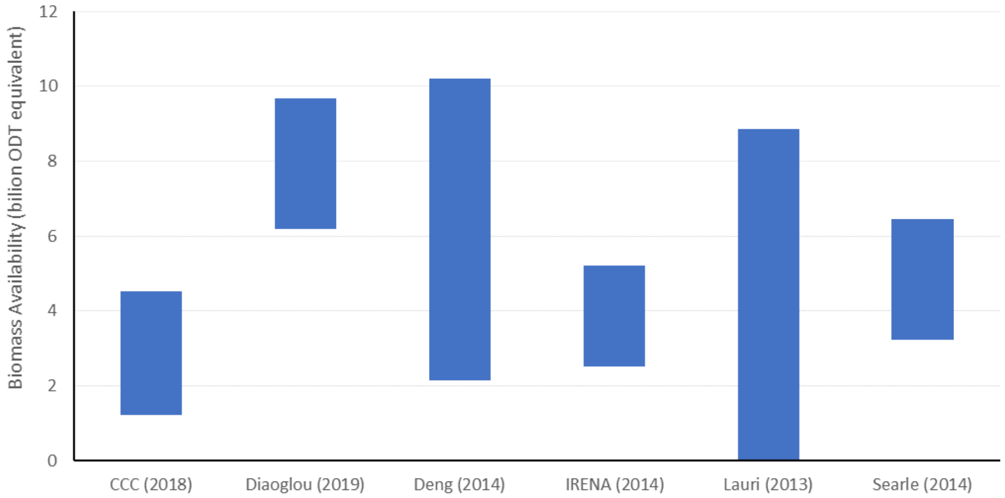


Figure 5.13: *Summary of recent global biomass availability forecasts.*

5.5.1 Global forest biomass availability forecast – McKinsey Consulting (2020)

To address the gap in existing research, two separate bespoke studies have been commissioned from consultants by Drax Power and included in the research for this thesis. The studies follow the same methodology - based on FAO data detailing forest area, age and growth – but the availability criteria applied during the screening process is based on the consultant's view of constraints and challenges and future sustainability criteria that may limit harvesting potential. The first study was completed by McKinsey Consulting in 2020, the results are shown in Figure 5.14 below.

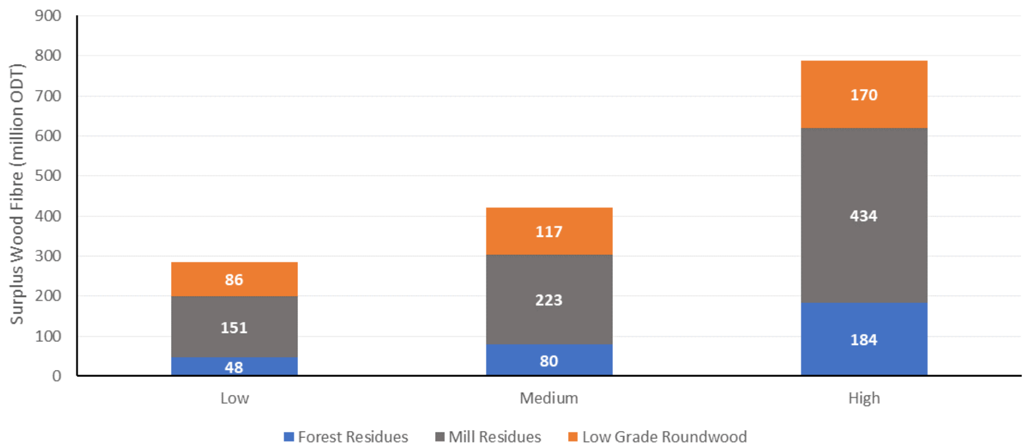


Figure 5.14: *Current global net surplus of wood biomass based on FAO data (McKinsey, 2020).*

McKinsey estimates a current global surplus of woody biomass of between 285 and 789 MODTs from the low to high scenarios. Three scenarios were used in the forecast: low, medium and high. The volume of total and available biomass was calculated with growth rate and availability adjusted for each individual country; the range of assumptions used is shown in Table 5.3 below.

Table 5.3: *Variable assumptions used in McKinsey modelling.*

Scenario:		Low	Medium	High
Growth rate range (m^3/ha/yr)	Max	12.8	14	18.21
	Min	0	0	0
	Average	1.82	2.45	3.08
Primary residue sustainability filter	Max	96%	96%	97%
	Min	0%	27%	47%
	Average	48%	64%	74%
Primary residue recovery rate	Max	15%	19%	27%
	Min	1%	3%	5%
	Average	7%	10%	13%
Secondary residue recovery rate	Max	60%	75%	90%
	Min	45%	55%	70%
	Average	54%	66%	81%

Considering the top 20 countries in the McKinsey medium forecast (Figure 5.15), the total surplus biomass is estimated at 364 MODTs from these countries. More than half of this biomass (54%) is expected to be produced as mill residuals from the production of solid wood products. The remainder is forecast to be directly available from the forest as forest residues (18%) and low grade roundwood (28%).

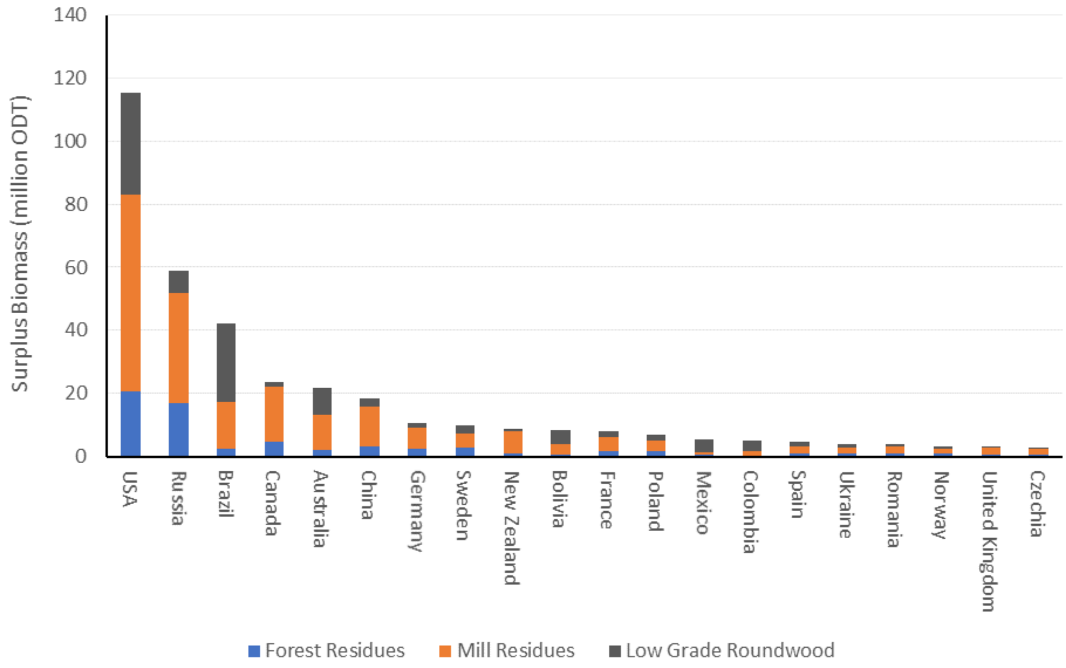


Figure 5.15: *McKinsey medium forecast of current biomass availability, top 20 countries.*

Many of the countries in the McKinsey top 20 forecast have well established forest industries and are also included in the FAO list of top 20 producers of industrial roundwood. There are 13 countries in the McKinsey list of top 20 surplus biomass suppliers from the medium forecast that are also in the list of FAO top 20 producers of industrial roundwood. Figure 5.16 compares the current FAO data with the McKinsey surplus forecast and shows that on average the estimated surplus in these countries is at 26% of the current production of industrial roundwood. Australia is the major outlier in this statistic, where the forecast surplus is estimated at 65% of current production of industrial roundwood. This degree of change is likely to require a substantial increase in growth or improvement in accessibility to existing forest, or may include bringing unmanaged natural forests into management which can cause sustainability concerns. At this high level of analysis, there is not enough specific detail about each country to make a judgment on how realistic or achievable the forecast might be. More detailed analysis would be required for each country and region.

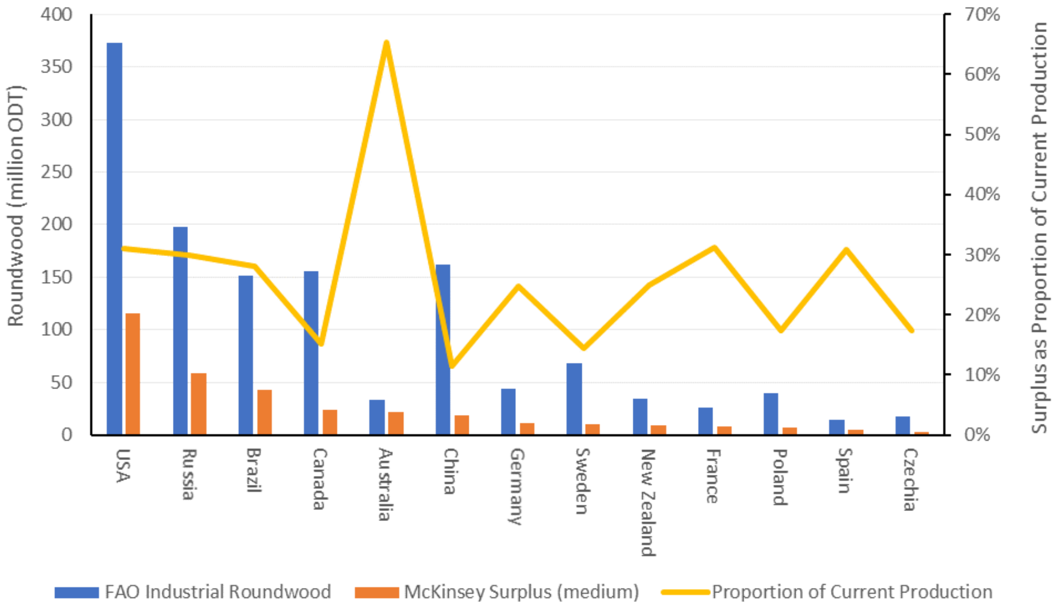


Figure 5.16: *Comparison of FAO ranking of industrial roundwood producers and McKinsey surplus biomass forecast (medium scenario).*

There are 7 countries on the FAO list of current top 20 industrial roundwood producers that are not included in the McKinsey forecast, a further 7 countries are projected to have a surplus of biomass in the McKinsey medium scale forecast that are not currently in the FAO top 20 list. These 14 countries are listed in Table 5.4 below alongside the associated data.

Table 5.4: *Variation between the FAO list of current industrial roundwood producers and McKinsey medium scale forecast.*

FAO Ranked Countries	Industrial Roundwood Production (ODT)	McKinsey Surplus Countries	Forecast Surplus (ODT)
Chile	45,987,000	Bolivia	8,342,833
Finland	55,330,267	Colombia	4,865,793
India	49,517,000	Mexico	5,500,694
Indonesia	74,041,000	Norway	3,085,724
Japan	22,645,000	Romania	3,820,983
Turkey	19,462,000	Ukraine	4,004,677
Viet Nam	33,835,420	United Kingdom	2,971,769

Table 5.4 highlights some of the variability and assumptions required when compiling a global forecast of biomass availability. On the left-hand side of the Table are some of the World's most developed forest industries and largest producers of industrial roundwood that are

considered by McKinsey to have only a limited surplus for future production; either due to declining future growth rates, an age class tending to younger immature crops, or an expanded industry already at sustainable capacity. On the right-hand side of the Table are countries with limited, relatively small-scale, existing forest industries and industrial roundwood production capacity, that are considered to have a surplus of biomass that could be sustainably utilised – according to the forecast. It is unclear how realistic these supply countries would be, Bolivia has a large area of primary forest (70%) which will not be accessible. Colombia and Ukraine have political instability that can complicate the development of new supply chains. There are potential logistical constraints in each of these countries; for example, it can uneconomical to transport solid wood in the UK more than 50 miles (depending on the value that the market can afford to pay – or the degree of subsidy in the biomass sector); if there is a surplus of growth as a result of an increasing age class in the forest, the surplus may only be economically accessible within a short radius of the forest and not available for large-scale aggregation for a new BECCS plant. Each of these potential issues must be analysed and evaluated at a local scale to identify genuine supply chain opportunities. Consequently, the value of a large-scale forecast is limited, without more detailed local knowledge.

5.5.2 Global forest biomass availability forecast – Ricardo and Forest Research

The second study was prepared by Ricardo and included research and analysis completed by the Forestry Commission's Forest Research team as part of a project for the Committee on Climate Change (CCC). The additional focus of the analysis was to consider the impact of additional demand on forest carbon levels; identifying where there may be a potential risk of depleting carbon stocks by increasing harvesting levels; this specific focus led to the application of stringent criteria to reduce the risk of increased GHG emissions, see Table 5.5.

Table 5.5: *Sustainability criteria created and applied by Forest Research in the Ricardo forecast.*

Criterion name	Adjustment(s) made in model calculations
PHY1	Reduce estimates of potential wood production by multiplying by a factor of 85%.
PHY2	Reduce potential stemwood production by 15% and branchwood and stumps and roots by 25%. Note that a 10% reduction factor for losses when converting and extracting stemwood from the forest (but not allowing for subsequent supply chain losses) is a standard reduction factor often assumed in wood production statistics, e.g. those reported by the Forestry Commission in Britain.
SFM1	Exclude primary forest areas completely from contributing to wood production. Reduce estimates of potential wood production from naturally regenerated forest areas (include 35% of

Criterion name	Adjustment(s) made in model calculations
	potential production from old naturally regenerated forest areas and 75% of potential production from young naturally regenerated forest areas). No adjustment to production from plantation forest areas.
SFM2	Reduce estimates for all boreal forests to 75% of maximum; for temperate coniferous non-plantation forests and all broadleaved temperate forests 75% of maximum; for temperate coniferous plantation forests 85% of maximum; for tropical coniferous non-plantation forests 75% of maximum; for tropical broadleaved non-plantation forests 85% of maximum; and for all tropical plantations 100% of maximum.
ECF1	Exclude all biomass in tree roots and stumps.
ECF2	Reduce estimates of potential wood production from branchwood by multiplying by a factor of 50% (this is in addition to the reduction under criterion PHY2).
ECF3	For forest areas with mean yield class less than 10, reduce estimates of potential wood production by multiplying by a factor of 45%. No adjustment to production from forest areas with mean yield class 10 or greater.
ECF4	Exclude all biomass estimated as suitable for converting into sawn timber products from potentials for bioenergy.
ECF5	Reserve a quantity of biomass production for use for material products (rather than bioenergy), consistent with currently reported and projected future levels of wood supply for material products.

The forecast also applied three shared socioeconomic pathways (described in Table 5.6) that were used to predict future rates of growth, availability and accessibility.

Table 5.6: *Description of future modelling scenarios used in Ricardo forecast.*

SSP 1	Strong drive to reach net zero emissions and Sustainable Development Goals (SDGs) stimulates development of green initiatives including a circular bioeconomy and an increased demand for wood products, leading to relatively rapid mobilisation of available wood resources. Conversely, there are efforts in some countries with existing relatively high levels of wood production to move production to levels consistent with the long-term annualised potential for wood production (and associated low risks of high GHG emissions).
SSP 1	Less concern about meeting net zero emissions and addressing SDGs compared with SSP1. Consequently, demand for wood products increases more slowly than in SSP1. Also, countries with existing relatively high levels of wood production make slower efforts to move production levels to be consistent with long-term annualised potential for wood production.
SSP 3	Similar to SSP2 but with limited concern about meeting net zero emissions or addressing SDGs means limited efforts to develop green initiatives including a circular bioeconomy. Consequently, demand for wood products increases at a slow rate.

The breakdown of each section of the forecast, and a comparison against 2015 global roundwood production levels, shows that the volume that is considered to be at low risk of increased GHG emissions is below the 2015 level of harvesting in each case (Figure 5.17).

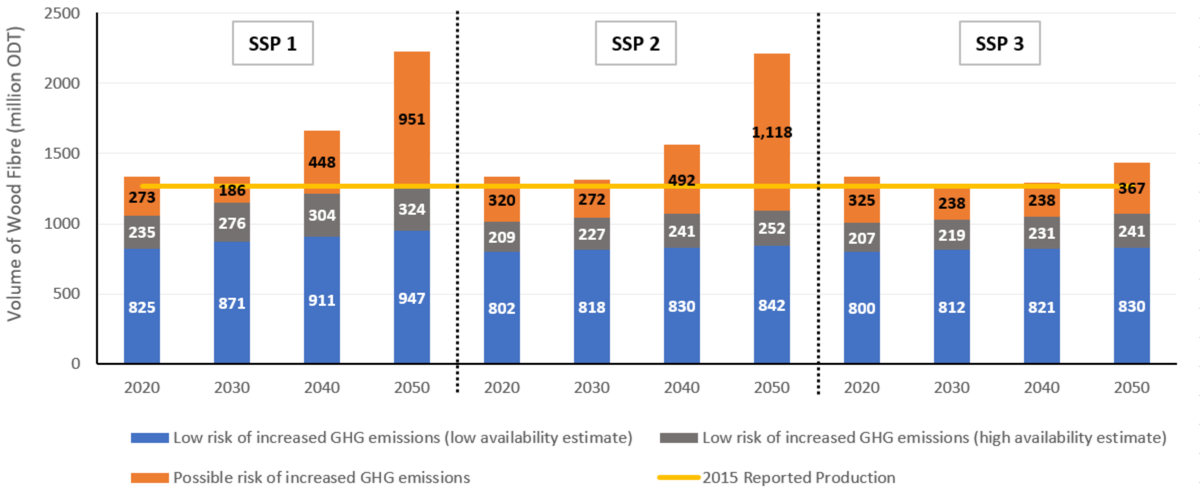


Figure 5.17: *Woody biomass availability forecast (Forest Research & Ricardo, 2020).*

Figure 5.18 below shows the theoretical physical surplus of biomass according to each scenario (in blue) and how it is reflected as a theoretical deficit compared to 2015 production levels when the risk of negative GHG impacts is applied to the forecast.

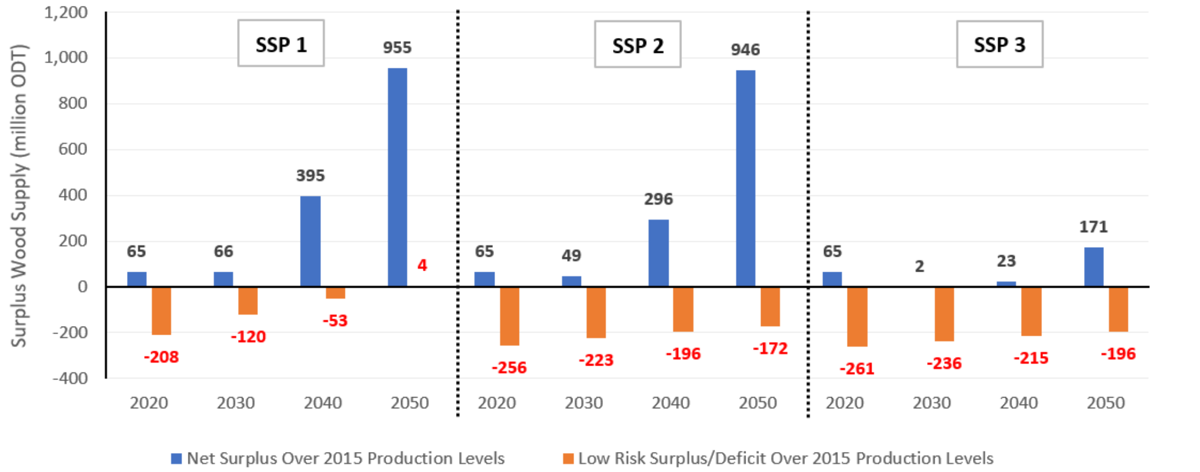


Figure 5.18: *Woody biomass net surplus forecast (Forest Research & Ricardo, 2020).*

Robert Matthews, of Forest Research, summarised these finding with the following statement (Mathews R, 2021, *email to A Dugan*): *"there is scope to increase the supply of biomass from existing forest resources, depending on a range of future variables (some of which are modelled in the SSP scenarios); however, utilisation of a proportion of the potential surplus is likely to pose a sustainability risk by increasing harvesting removals and decreasing forest carbon stocks below existing levels, or otherwise involving perturbations to the net carbon balance of some forest areas, the duration of which would depend on many factors"*.

The extent of the risk is unknown without further detailed analysis and clearer insight into the potential variables. Future sustainable biomass availability from existing forest resources could be increased above 2015 global production levels whilst avoiding such sustainability risks, if a coherent and coordinated approach could be adopted to forest management and wood supply at very large scale (global or large regions). This possibility also requires further analysis.

The conclusion reached in the FR analysis is based on the view that harvesting reduces the carbon stock in the forest. If increased harvesting removes more carbon from the forest and releases it into the atmosphere through bio-energy combustion, then it can lead to a negative GHG impact. Where the harvested forest is regenerated with an equivalent area of forest for the next generation, then the negative impact can be temporary (Matthews, 2015). The use of BECCS technology could reduce or mitigate emissions from increased harvesting by capturing and storing any atmospheric emissions. If the next generation of forest (replacing the harvest area) has improved management, that can lead to a greater rate of sequestration and a higher proportion of carbon stored in solid wood products; then the impact of harvesting and utilisation for biomass can lead to a reduction in atmospheric GHG levels.

5.6 BARE LAND AVAILABILITY & POTENTIAL ENERGY PLANTATIONS

Given the challenges described above in forecasting the availability of sustainable biomass from existing forest resources, and the potentially greater challenge of physically mobilising and utilising any surplus; many GHG reduction models have focused on new dedicated biomass energy crops as a primary feedstock source for the expanded use of biomass (IPCC, 2019). A review of existing studies on land availability (as described below) suggests that there is a general consensus that there are large areas of unutilised agricultural land that could be used for biomass crops. The literature review for this section did not identify any studies claiming that there is no surplus of unutilised land, but there is a wide variation in the area that is considered to be sustainably available. The variation can be due to forecasts for future food production requirements (e.g. population growth, agricultural efficiency, dietary changes etc.), concerns over the ecological impact of new plantations (e.g. impact on water resources, biodiversity, risk of pest, disease and fire); the cost and practicality of bringing this land into management. There is also a high risk of increased emissions from soil carbon if inappropriate sites are chosen for cultivation or management practice is not sustainable and appropriate to local conditions, this must be considered in identifying any new land for biomass planting.

In the second draft of the IPCC Special Report on Climate and Land (2019), it states that estimates of marginal lands currently considered available for bioenergy production range from 385 to 1100 Mha. The International Renewable Energy Agency - IRENA (2014) projected that 1.4 billion ha of additional land is suitable for biomass forest, but unused to date, and thus could be allocated for bioenergy supply in the future. Campbell *et al.* (2008) calculated that the estimated global area of abandoned agricultural land is between 385 and 472 Mha. Fritz *et al.* (2013), calculated the global area of marginal land available for bio-energy to be within an estimated range from 56 to 375 Mha depending upon the scenario and adjusted for human impact. These studies demonstrate extreme variability in assumptions and forecasting, but even at the lowest end of the scale (56 Mha) there is a considerable area of land that could be utilised. The scale of this potential contribution to additional biomass supply is discussed in section 5.6.2.

The historical development or classification of agricultural land use is shown in Figure 5.20. The utilisation of cropland and grazing land developed simultaneously alongside early civilisations and then began to diverge in the 20th century as the prevalence of grazing land increased and the total utilisation of land for agriculture increased.

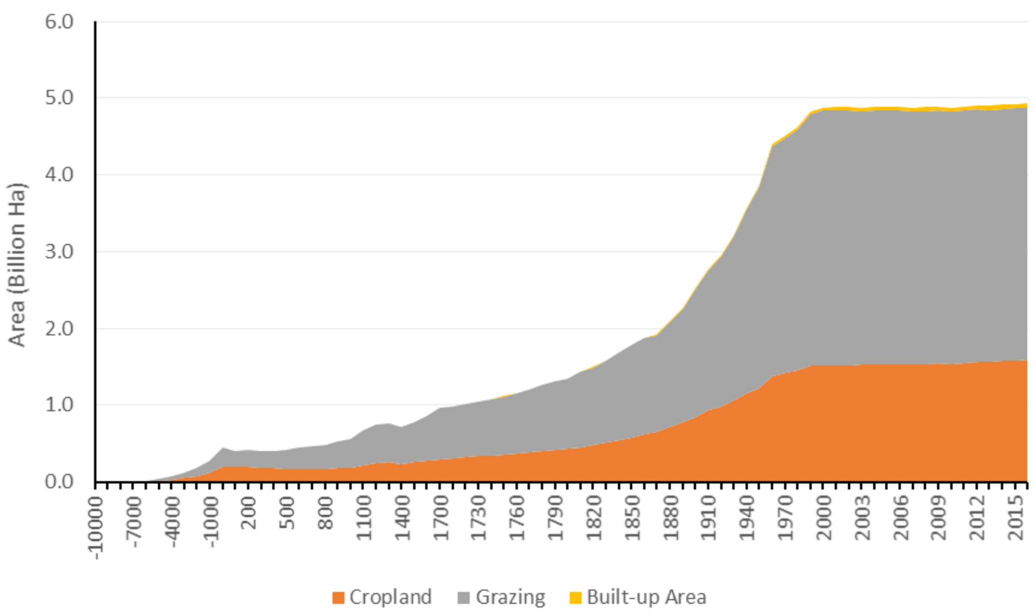


Figure 5.19: *Global land use, Historical Database of Global Environment (HYDE, 2020).*

The latest available FAO data (FAOSTAT, 2021) shows that 4.8 billion ha are classified as agricultural land with 33% cropland and the remainder grazing lands, Figure 5.20. It is the 3.2 billion ha of land under permanent meadows or pasture (grazing land) that could provide some surplus for new woody biomass crops in addition to expanded food production and urban development.

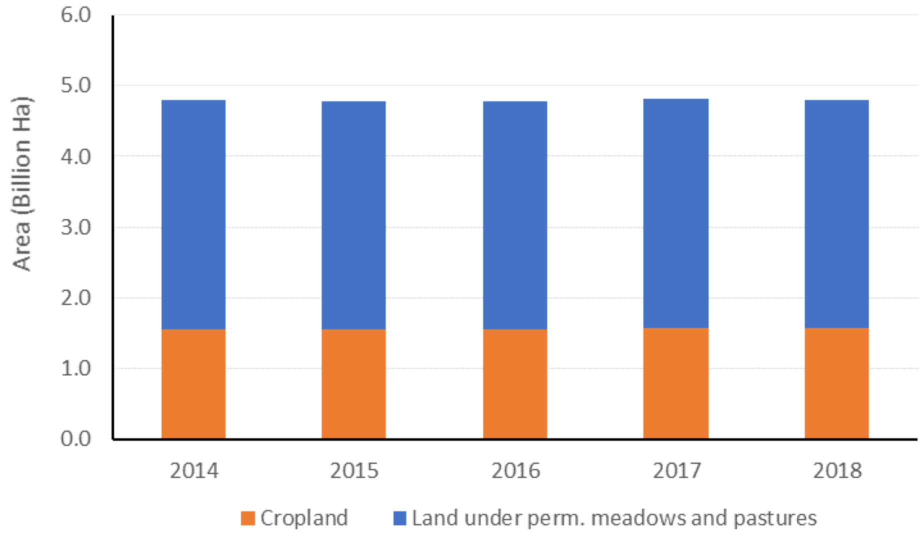


Figure 5.20: *Distribution of cropland and grazing land, (FAOSTAT, 2020).*

5.6.1 The role of forests in climate change mitigation

The IPCC Special Report on Climate and Land Use (2019) discussed multiple tools for reducing GHG emissions and recognises the importance of negative emissions in counteracting future unavoidable atmospheric emissions of carbon dioxide. The same conclusion was reached by the CCC (2018) when it concluded that negative emissions will be essential for the UK to achieve its GHG targets and that BECCS could be an effective tool for capturing emissions produced from industrial processes, particularly energy generation, especially if the biomass combusted is linked to an improvement in sequestration at the forest. Increased forest level sequestration can be achieved through improved forest management or it can be from new planting (afforestation).

There is substantial scope on a global scale for improving forest management to increase sequestration (WWF, 2012), which could involve protecting some forest areas to avoid illegal logging or deforestation, or it can involve more active management to improve growth and carbon storage in solid wood products as shown in the case studies in the US South in Chapter 4. Figure 5.21 below shows the WWF estimate of global areas where forest sequestration can be increased either through protection, reforestation or improved forest management practice; 2.2 billion ha globally.

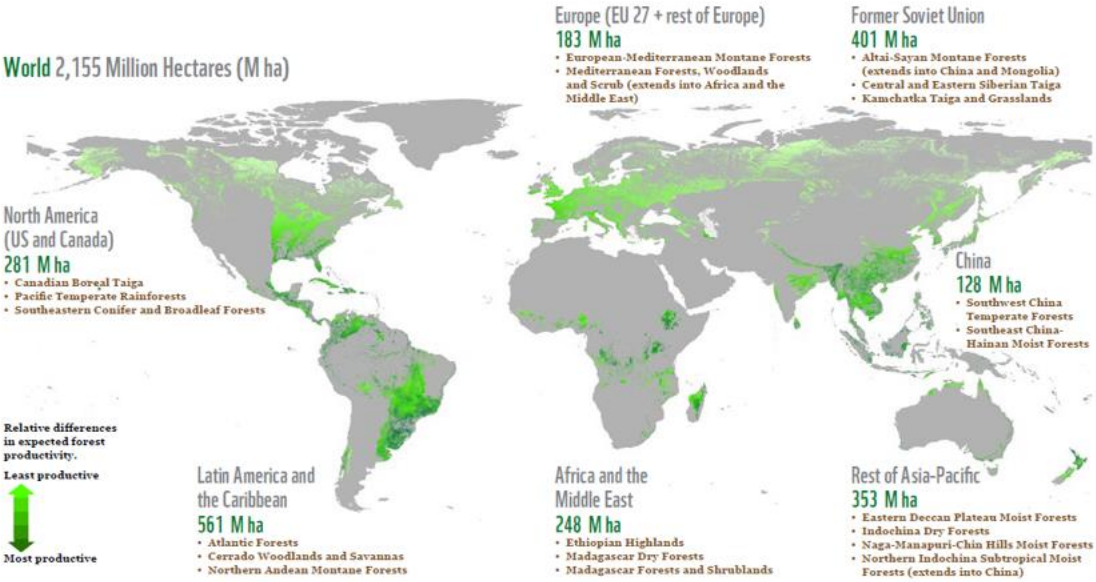


Figure 5.21: *Potential to improve sequestration of carbon from the world's forest lands (WWF,2012).*

Other research also supports the view that forests and active forest management are effective climate change mitigation tools. Oliver *et al.* (2014) comments that more CO_2 can be sequestered synergistically in the products or wood energy and landscape together than in the unharvested landscape. Harvesting sustainably, at an optimum stand age, will sequester more carbon in the combined products, wood energy, and forest than harvesting sustainably at other ages.

Werner Kurz of the University of British Colombia has studied the carbon impact of active management in Canada's forests compared to protected National Park areas where no harvesting has taken place. Kurz presented the following recommendations based on this research at an IEA Bio-energy Conference in May 2020 (Kurz, 2020):

- Optimise the GHG balance by growing more trees, faster and increasing the use of wood products to displace other higher carbon materials
- Increase thinning to reduce emissions from natural mortality and disease and reduce the risk of wildfire by removing 'deadwood fuel'
- Avoid land-use change and deforestation, conserve forests in areas of high conservation value and at low risk of natural disturbance
- Use harvested trees first for long-lived harvested wood products (HWPs), maximize carbon retention in HWPs and reduce wood waste at every stage

In all of these pieces of research there is a role for dedicated energy plantations on unutilised agricultural land; where those plantations are sustainably managed; at an appropriate scale and used for optimal carbon displacement or storage. Section 5.6.2 shows some examples of the potential contribution of new plantations and indicative cost of per tonne of carbon sequestered.

5.6.2 Dedicated forestry plantations

Rudimentary and high-level modelling has been completed in this section to demonstrate the potential for carbon sequestration from new forestry plantations in selected locations globally. Growth rates and operational costs have been obtained from commercial forestry organisations operating within each country and whilst typical for a high-level comparison can be extremely variable depending on site specific circumstances and not universally applicable. As with a biomass availability forecast, specific data is required for each individual forest site to achieve an accurate cost and productivity estimate. Table 5.7 shows a summary of assumptions and outputs comparing dedicated forestry plantations to optimise carbon sequestration. In practice, as discussed in 5.6.1 (Kurz, 2020), longer rotation stands (e.g. pine and spruce plantations in the UK and US South) would serve an optimal carbon benefit by providing material for solid wood products in the first instance and biomass for energy from the remaining residues. For the purpose of comparison in Table 5.7, it has been assumed that all of the harvested material would be used in BECCS.

Table 5.7: *Comparison of carbon sequestration and indicative cost in selected plantation areas.*

Country	Volume/Ha at Harvest (m^3)	Rotation Length (Years)	MAI (m^3 / ha / yr)	Delivered Cost/m^3 (USD)	Species	Basic density at harvest (tonne/m^3)	Total CO2 per m^3 (Tonnes)	Total CO2 per 100 years/Ha (Tonnes)	Cost/tonne CO2 (USD)
UK	490	35	14	51.05	Sitka spruce	0.425	1	1050	38.29
US South	400	25	16	35.53	Loblolly pine	0.575	1	1616	35.88
Brazil	252	6	42	23.33	E. grandis	0.450	1	3360	18.66
China	144	6	24	37.70	E. urophylla	0.450	0.8	1920	30.16
Africa	211	8	26	29.36	E. grandis	0.450	0.8	2107	23.49

Figure 5.22 shows a comparison of the indicative total CO_2 sequestered per hectare.

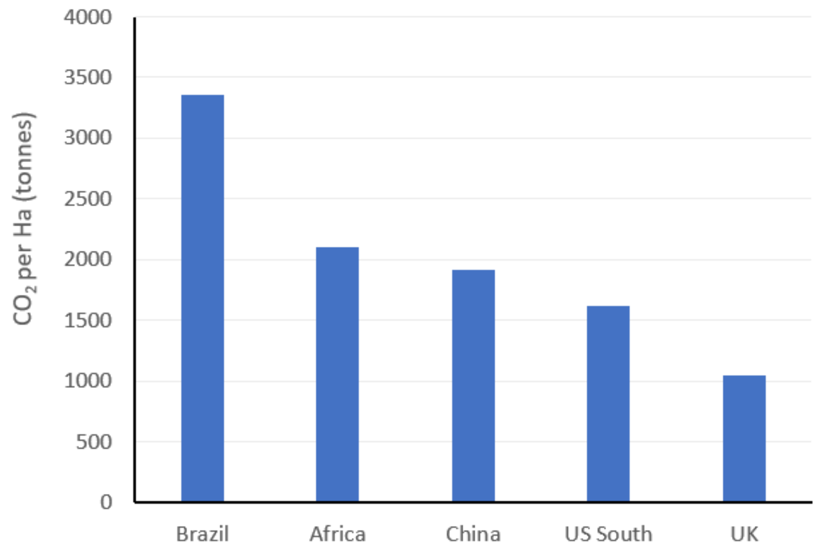


Figure 5.22: *Total CO_2 per hectare over 100 years.*

The Brazilian example above shows that total CO_2 sequestered can be up to 60% higher than the next best example (Africa) and 2.2 times greater than the lowest sequestration area (UK). Figure 5.23 also demonstrates that Brazil has a much lower cost of production than in the other regions.

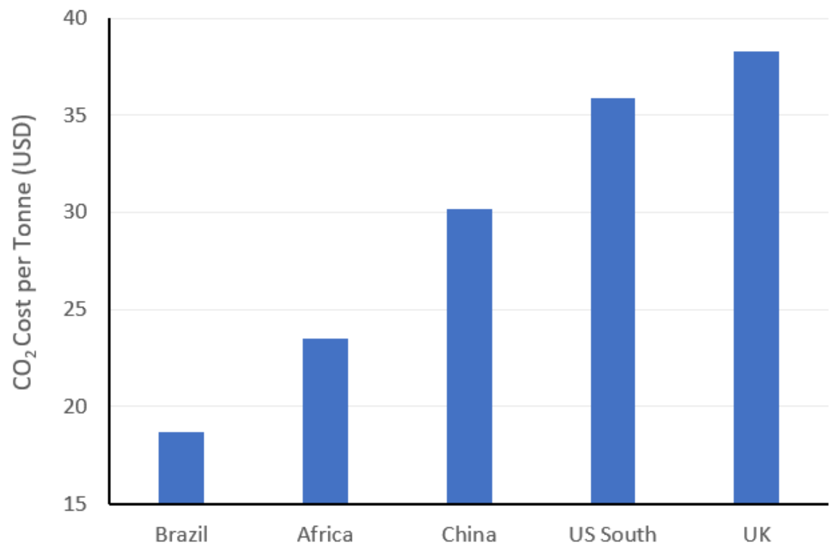


Figure 5.23: *Indicative cost per tonne of CO_2 sequestered.*

Logistical costs can vary depending on the location and commercial terms for a specific route. A comparison of various potential ports locations is shown in Figure 5.24 for locations that could be used to supply the UK (China is excluded due to distance and strength of local demand).

Figure 5.24: *Example of shipping distances to UK (Sea-distances.org).*

The analysis above suggests that Brazil could be an attractive location for new energy plantations in terms of potential to maximise carbon sequestration, forestry operational costs per unit of CO_2 and indicative transport distances. FAO data from 2018 (FAOSTAT, 2021) indicates that Brazil has 173 Mha of permanent pasture or meadow and 63 Mha of cropland. If 10 Mha of the pasture land were utilised for eucalyptus plantations (a conversion of 5.8%) it could produce 420 Mm^3 /yr which could be enough for 30 BECCS power plants of the size of the current Drax biomass power station in the UK[3]. If the lowest end of the scale of land availability discussed in section 6.5 (56 Mha) were utilised globally, then more than 160 BECCS plants the size of Drax could be fuelled. These are not precise calculations but demonstrate that there is scope to increase the use of sustainable biomass and improve the contribution to climate change mitigation through BECCS, afforestation, reforestation and improved forest management.

5.6.3 Conclusions

The issues and challenges discussed in the previous sections and the examples of existing attempts at global biomass availability forecasting, all provide an indication of the difficulty in accurately forecasting biomass availability at a global scale. There are too many unknown variables, and insufficient quality data, to genuinely determine a precise quantity of sustainably available biomass surplus at any future point in time. Narrowing the scope of the question to a specific forest area, region or country, can increase the likelihood of a more

[3] Assumes 4 generating units at 650 Mw capacity using c. 14 million m^3 equivalent per year in total.

accurate assessment (e.g. as shown in Figure 5.4 Pöyry analysis of the US South). It can be possible to determine high level indicative forecasts of surplus biomass growth for large areas, but it is not possible to determine the sustainability and accessibility of this fibre without more detailed and specific local knowledge. The case study example shown in Chapter 4, demonstrates the local variability and potential impacts that can influence sustainability and fibre availability. To genuinely assess the potential for sustainable future biomass supplies from existing forest resources a high degree of local knowledge is required.

There is potential to develop new large-scale biomass resources, in dedicated plantations on suitable land – unused or degraded land that is not required for agriculture and has no environmental or sustainability constraints. High level data and existing research papers suggest that the potential availability of land for these plantations can be very large, over 50 million hectares at the lowest end of the spectrum. These plantations have the potential to add multiple levels of value, contributing additional sequestration and bringing economic value to regions and communities where other land use options have declined.

The evidence considered in this chapter would suggest that there is potential to increase the use of industrial biomass from both existing resources and new plantations. Any new biomass plantations should be developed in consultation with relevant local and international stakeholder groups and in particular consider the needs and rights of local populations, where there is interaction with indigenous people or community groups reliant on forests and land for their livelihoods.

Chapter 6: Conclusions and Recommendations

6.0 INTRODUCTION

Chapter 6 details the findings and conclusions reached through the research and analysis carried out against each aim, as detailed in section 1.5.

6.1 REVIEW OF RESEARCH AIMS

6.1.1 Aim 1

Identify a range of biomass feedstock and forest types, specific to the US South, that can be considered to provide biomass that has a positive or neutral climate impact. The feedstocks will be described through ***acceptable biomass pathways*** and specific criteria relating to the origin and impacts of the wood fibre being utilised.

The aim has been achieved and the acceptable biomass pathways described in section 2.5 can be used to improve the understanding of the sustainability of biomass supply chains and specific feedstocks. The pathways can be used as an interrogative tool to consider whether sufficient evidence exists to clearly demonstrate that the criteria have been met. However, the pathways do not describe the extent or degree of evidence required, and in some cases, it can be a subjective judgement as to whether the criteria have been met and the extent to which any evidence is able to demonstrate compliance. Use of the pathways should be as a guide and specific instructions describing the interpretation of the criteria in each specific forest area would be required to apply them in practice. In addition, the field of biomass sustainability and the scientific research around the impact on forest carbon, biodiversity and other important metrics is continually evolving and developing; using this tool in the future would require continued development and modification to ensure that it remains current, relevant and appropriate.

6.1.2 Aim 2

Review current regulatory reporting and sustainability evidence gathering processes to identify gaps between current evidence provision and the criteria necessary to demonstrate the use of good biomass.

A number of gaps in the current process of reporting and demonstrating biomass sustainability were identified at the time of the review. Some of these are already being addressed (e.g. with a revision of the SBP standard and auditing process). Gap analysis, review and revision is an ongoing process and this should continue to be a regular part of the work of the biomass sustainability sector. Transparency and public reporting of data, audit findings and sustainability challenges must improve to build confidence in the process of monitoring and measuring biomass sustainability.

6.1.3 Aim 3

Develop a test methodology to demonstrate biomass sustainability; providing evidence that can address the gaps in the existing reporting process.

A series of new approaches to gathering and presenting data, setting benchmarks and monitoring key metrics have been developed and tested as part of this research. These were all successful in providing more clarity on trends and impacts in biomass supply chains. Every data source and methodology will have flaws and weaknesses, e.g. availability or accuracy of underlying data, limited access to on the ground information, limitations of resources to carry out research. It is not possible to definitively answer the question about whether a particular biomass supply chain is sustainable or not, as there are too many variables and potential interpretations of data and decisions (e.g. management decisions that improve forest carbon, may have the consequence of reducing biodiversity or *vice versa*). Forest management decision-making is often a trade-off between multiple objectives, some of which are complementary whilst others are competing. The purpose of these new approaches is to better understand the trends in each key metric, benchmark and monitor, so that any trade-off decisions can be based on a clearer idea of the impact. The methodologies developed and tested in this thesis can be a useful starting point in this process.

6.1.4 Aim 4

Evaluate, through a case study, the effectiveness of the test methodology in demonstrating the sustainability of the recent use of biomass for pellet production in the US South.

The case study successfully tested the methodologies and found useful data and evidence. Improvements can be made to the process of each different approach. Better quality data can be gathered from forest owners at the time of harvest to describe the feedstocks, forest types and intended future management objectives. It would also be helpful to understand the proportion of each harvest supplying each individual market and the relative value (where commercial sensitivities can be avoided) of each product, to better determine the role of biomass and the likely impact of the biomass market on forest management decisions. Future improvement to remote sensing technologies can further enhance the value of this approach and improve monitoring of forest cover, forest type and the post-harvest status of the forest. Each of these methodologies will need to be improved and adapted to different forest regions where the challenges may be quite different.

6.1.5 Aim 5

Consider the potential for expansion in the scale of future biomass use, explore the challenges associated with biomass availability forecasting and consider the potential for new dedicated biomass plantations to contribute to climate change mitigation.

The challenges around biomass availability forecasting have been described and discussed, examples of forecasts and their limitations have been presented. The scale at which future biomass utilisation can expand within sustainable limits remain an open question. The evidence of existing studies suggests that there is substantial potential to increase the use of biomass, but the point at which this can become unsustainable is not yet clear. Sustainability is not only a question of scale; current levels of utilisation could be unsustainable if the wrong feedstock is sourced from the wrong forest type. Large-scale expansion could be more sustainable than current supply levels, if sourced and monitored effectively and appropriately. The biomass sustainability sector must ensure that it is transparent and objective in questioning the impact of biomass demand and utilisation and that the evidence presented to demonstrate this is credible, specific and appropriate.

6.2 STUDY LIMITATIONS

This research is limited by the range of factors described below:

- **Geographic scope:** focusing only on the US South when biomass is sourced from a range of diverse forest regions (e.g. western Canada, Brazil, Baltics, northwest Russia). Data availability and sustainability challenges are likely to be quite different across a range of supply regions, this will affect findings and conclusions.

- **Biomass type:** focusing only on wood pellets is also a limitation. The use of alternative biomass feedstock types (e.g. wood chips, biochar, agricultural residues etc.) will affect the sustainability challenges, impacts and data options.

- **Data availability:** the forest industry in the US South is large-scale and relatively advanced, with a large quantity of publicly available datasets. However, even in the

US, data can be limited in availability and accuracy. There is also often a delay in updating inventory and market data, trends are not always apparent until one or two years later, sometimes longer, depending on the efficacy of the State monitoring and measurement programmes.

- **Time-scale of forest change:** the long-term nature of forest growth cycles, involving several decades, make it challenging to draw clear conclusions from short-term datasets and snapshot views. There is also a complex range of biological, economic and social factors that contribute to physical outcomes in the forest, rarely one specific cause or effect. Therefore, it can be difficult to make conclusive decisions about the sustainability of biomass supply chains, other than in extreme cases where a negative impact is very clear.

- **Interpretation of data and results:** a degree of subjectivity and interpretation is required to formulate a view of the overall sustainability of a specific supply chain, the absence of a negative indicating a neutral or positive outcome. Consequently, a range of different data sources or evidence tools should be used to create a portfolio of indicative evidence.

6.3 FUTURE RESEARCH

There are several potential areas for future research, building on the initial work and findings of this thesis and expanding the scope to include other regions and additional sustainability challenges. Some examples of potential future research include:

- Expansion of the use of evidence gathering tools to other parts of the US and other biomass supply regions.
- Ongoing monitoring to build up a longer-term picture of trends and changes. Improved data, both in quantity and accuracy, can better help to understand the relationship of biomass demand to forest management trends and suitability impacts.
- Work to improve the quality and analysis of remote sensing data, developing better data collection processes and improving data analysis with ground truthing and cross-comparison of data sources.
- Further research to quantify the specific impact of biomass demand at a local level, to determine the range of areas where a genuine impact can be identified and to quantify the positive and negative outcomes that can result from each impact. This

can include positive economic or social impacts, positive carbon impacts from improved management or increased saw-timber production. It can also include potentially negative impacts where biodiversity and habitats are threatened, solid wood product markets are disadvantaged or forest cover and forest carbon are reduced.

The most important factor that could improve the monitoring of sustainability impacts and trends is improved granularity and management of site-specific data at the point of harvesting and throughout the lifecycle of the forest. The questions asked and data recorded prior to and post harvesting are critical to understanding any change in the forest resource and the scale and nature of any impacts. Clearly defining the status of the forest resource, at each stage in the lifecycle as a continuous monitoring process, can be an effective method of monitoring change and determining the impact of specific management decisions. If the biomass sector collected better quality data from each supply site at the point of harvest (or purchase of fibre), this would enable better corelation of site-specific trends and impacts with the wider catchment areas trends and links to the use of biomass. Some examples of the type of information that could be useful are:

- More specific site inventory data: species mix, age class, growth rates, product assortment, market availability and access.
- Ecological survey data, land categorisation, incidence of sensitive sites, prevalence of vulnerable species or areas of high conservation/biodiversity value.
- Previous management regime, historic and future management priorities and objectives. Range of potential counterfactual management options.

6.4 RECOMMENDATIONS

The use of wood pellets for industrial energy generation has been challenged as unsustainable and leading to negative impacts in both forest and atmospheric carbon levels. Common challenges include: deforestation; damage to sensitive sites and biodiversity; long-term loss of forest carbon; displacement of solid wood product markets; changes in forest management practice leading to lower rates of carbon sequestration and storage.

Current regulation and certification standards, used to demonstrate biomass sustainability, do not go far enough, in both criteria and evidence gathering requirements, to fully monitor performance against these specific challenges for each biomass supply chain. Additional data and information, and detailed monitoring of key metrics within each biomass supply chain, are required to better demonstrate the sustainability of feedstocks and the neutral or positive impact of biomass utilisation.

In the US South, inventory and market data is available to monitor trends and determine the impact of wood pellet markets on the forest resource. Remote sensing data can also be used to evaluate changes in biodiversity, forest type and character. Satellite imagery can be used to visually check the status of harvesting operations and regeneration of forest sites. These tools and technologies are nascent but can still offer useful indicators of sustainability performance and key metric trends.

To be able to determine the impact of any forest operations or management decisions, accurate and detailed data are required. Current sustainability regulations in the UK do not require the provision of detailed data and evidence. Therefore, there is little incentive to invest in better technology and measurement systems. Voluntary provision of additional evidence is a positive step forward but a more collaborative approach to sustainability monitoring, across the forestry sector, and the use of remote sensing tools and data sets, can help to build a better evidence base going forward. This may need to be driven by changes in legislation for future biomass use.

APPENDIX I - GLOSSARY

Forest Residues: Branches, tops, bark and stumps are commonly referred to as forest or harvesting residues. However, this category sometimes includes any woody material that doesn't have a market and would therefore be left on site, also called "un-merchantable wood". In some circumstance this could include long lengths of stemwood that are not suitable for sawtimber or do not have an alternative market.

Low Grade Roundwood: stemwood of any size or length that is not suitable for, or cannot access, higher value markets. Higher value markets include: sawtimber, plywood, chip n saw. Low value roundwood is used by the pulp and panel industries or for biomass.

Pulpwood: Small diameter stemwood that does not have a higher value market. Pulpwood can be used in the pulp and paper industry, the panel board sector and for biomass. Pulpwood is a generic term commonly used in the US South; it refers to the same material as low value roundwood.

Sawmill Residues (secondary residues): Any wood residue in the form of chip, bark, sawdust, etc. that is produced by a sawmill.

Sawtimber/sawlog: Large dimension and higher quality stemwood that can be used to produce sawnwood for use in construction, furniture or other wood products.

Small Roundwood: This is commonly used in the UK to refer to low value roundwood that could be used in the pulp and paper industry, in the chip and panel industries or for biomass. Species is also a factor in determining which markets can be accessed, some species cannot be used in the pulp or panel sector.

Stemwood: The utilisable woody material from just above the stump, up to the minimum top-diameter (as defined by the local markets for wood products), excluding branches and tops.

Thinnings: Wood from a forestry harvesting operation where the main objective is to reduce the density of trees in a stand, improve the quality and growth of the remaining trees and produce a higher value final product. Thinning can achieve other objectives such as altering the species composition of a stand, improving the health of the remaining trees or disturbing an established ground flora to enhance opportunities for natural regeneration. Thinning can take place multiple times over a rotation, typically a maximum of 3 thinning cycles are used to produce high quality sawtimber in the final crop.

Roundwood produced from thinning can fall into many categories, it can be “pre-commercial”, therefore too small to access any markets, it could be low value roundwood (for use in the pulp, panel or biomass sectors) or it could include a proportion of higher value sawtimber grade material (particularly from 2nd and 3rd thinning operations later in the rotation).

Whole tree: This term is not clearly defined and is not included in Ofgem guidance. When used in reference to “whole tree harvesting” it refers to everything from above ground level. In practice it has a similar meaning to stemwood.

Clear-cutting (or clear felling): has been the most widely used silvicultural system globally since the advent of organised forest management. It involves uniformly clearing all of the trees within a given area (tract or coupe) primarily to produce commercial timber and to start the process of re-establishing the next generation of forest cover on that site. The size of each harvesting tract could be less than 1 hectare or up to several hundred hectares. This largely depends on the ownership, age and species mix of the forest; the environmental and aesthetic impacts; the objectives of management and the local regulations and guidelines. Clear cutting is most prevalent in even aged, predominantly single species, stands (including plantations).

Selective Felling: The selection system aims to maintain a continuous forest cover by continually encouraging regeneration of a young understorey by retaining mature seeds trees throughout the crop. Harvesting can be done by selecting individual trees for removal or small groups or strips. It’s important that the forest structure, micro-climate and ecosystem is maintained through this harvesting operation.

This type of forest management system can be most appropriate in stands of mixed species with an uneven age class structure, particularly where there are some species that are very high value and that require a long rotation (e.g. some hardwood species). However, this system is sometimes used negatively to select and remove individual high value trees to generate significant revenue, but then ongoing management does not ensure that the next generation of this species is regenerated (e.g. in selective harvesting of tropical species in natural forests). There is also a common practice in US hardwood forests called “high grading” where only the large valuable trees are removed at the time of harvesting. This can often leave very poor quality, partially stocked forest with small trees of less desirable species that have limited value and provided inadequate seed sources for future stands. Without careful management this can lead to the long-term degradation of the forest resource.

Tract/Coupe: an area of forest or land that can be large or small but typically managed as one management unit, e.g. an area that undergoes that same management treatment at the same time (e.g. planting, thinning, clear cutting). The trees within a tract are commonly the same age but can be of different species and quality.

APPENDIX II – POST HARVEST EVALUATION

2017 Sample, Site 1:

Clear rows of trees are evident in 2020 at 50m scale.

Site Number	Vendor Name	County	Tract Area (acres)	Longitude	Latitude	Harvest Quantity (tonnes)	Imagery	Evidence of Regrowth/Restocking
1	J & N Timber	EAST FELICIANA (LA)	70	-90.884	30.875	10,927	Good	Clear evidence of regrowth

Mar 2010 (100m)

Dec 2017 (100m)

Aug 2020 (50m)

5

2017 Sample, Site 2:

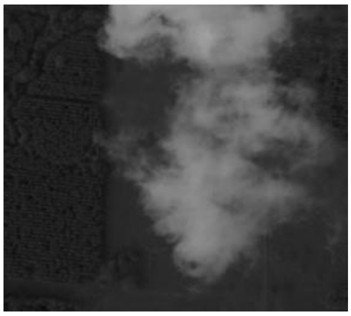
No clear image post harvest, cloud cover obscuring view and limited image availability.

Site Number	Vendor Name	County	Tract Area (acres)	Longitude	Latitude	Harvest Quantity (tonnes)	Imagery	Evidence of Regrowth/Restocking
2	J & N Timber	WILKINSON (MS)	100	-91.165	31.079	10,857	Limited	No clear image

Jan 2016 (100m)

Dec 2017 (100m)

Sept 2020 (100m)



6

2017 Sample, Site 3:

Cultivated rows with green vegetation are evident in 2020 at 20m scale.

Site Number	Vendor Name	County	Tract Area (acres)	Longitude	Latitude	Harvest Quantity (tonnes)	Imagery	Evidence of Regrowth/Restocking
3	Weyerhaeuser	JEFFERSON (MS)	229	-90.886	31.650	9,896	Good	Clear evidence of restocking

Mar 2010 (200m)

Jan 2018 (100m)

Nov 2020 (20m)

7

2017 Sample, Site 4:

No evidence of trees, bare ground in 2020 at 50m scale.

Site Number	Vendor Name	County	Tract Area (acres)	Longitude	Latitude	Harvest Quantity (tonnes)	Imagery	Evidence of Regrowth/Restocking
4	Weyerhaeuser	JEFFERSON (MS)	99	-90.905	31.703	9,868	Good	No evidence (bare ground)

Mar 2010 (200m)

Nov 2020 (200m)

Nov 2020 (50m)

8

2017 Sample, Site 5:

Cultivated rows with green vegetation are evident in 2020 at 20m scale.

Site Number	Vendor Name	County	Tract Area (acres)	Longitude	Latitude	Harvest Quantity (tonnes)	Imagery	Evidence of Regrowth/Restocking
5	Weyerhaeuser	JEFFERSON (MS)	124	-90.924	31.813	9,514	Good	Clear evidence of restocking

Mar 2010 (200m)

Jan 2018 (200m)

Nov 2020 (20m)

9

2017 Sample, Site 6:

No evidence of trees, bare ground in 2020.

Site Number	Vendor Name	County	Tract Area (acres)	Longitude	Latitude	Harvest Quantity (tonnes)	Imagery	Evidence of Regrowth/Restocking
6	Weyerhaeuser	JEFFERSON (MS)	129	-90.845	31.714	8,859	Good	No (green but no obvious trees)

Mar 2010 (200m)

Dec 2018 (100m)

Jul 2020 (100m)

10

2017 Sample, Site 7:

No evidence of trees, bare ground in 2020.

Site Number	Vendor Name	County	Tract Area (acres)	Longitude	Latitude	Harvest Quantity (tonnes)	Imagery	Evidence of Regrowth/Restocking
7	Weyerhaeuser	JEFFERSON (MS)	195	-90.926	31.685	8,332	Good	No (green but no obvious trees)

Mar 2010 (200m)

Jan 2018 (200m)

Nov 2020 (100m)

2017 Sample, Site 8:

No evidence of trees, bare ground in 2019 (latest available imagery).

Site Number	Vendor Name	County	Tract Area (acres)	Longitude	Latitude	Harvest Quantity (tonnes)	Imagery	Evidence of Regrowth/Restocking
8	Darden Timber, Inc	AMITE (MS)	55	-90.890	31.056	8,289	Limited	No (green but no obvious trees)

Mar 2010 (200m)

Jan 2018 (200m)

May 2019 (20m)

2017 Sample, Site 9:

No evidence of trees, bare ground in 2020.

Site Number	Vendor Name	County	Tract Area (acres)	Longitude	Latitude	Harvest Quantity (tonnes)	Imagery	Evidence of Regrowth/Restocking
9	Weyerhaeuser	FRANKLIN (MS)	77	-91.103	31.505	7,336	Good	Clear evidence of restocking

Jan 2016 (200m)

Nov 2020 (200m)

Nov 2020 (20m)

13

2017 Sample, Site 10:

No evidence of trees, bare ground in 2020.

Site Number	Vendor Name	County	Tract Area (acres)	Longitude	Latitude	Harvest Quantity (tonnes)	Imagery	Evidence of Regrowth/Restocking
10	LandMAX Timber	FRANKLIN (MS)	150	-90.924	31.451	7,262	Good	No evidence (bare ground)

Jan 2016 (200m)

Nov 2020 (200m)

Nov 2020 (50m)

14

2015 Sample, Site 1:

No evidence of harvesting around these coordinates.

Site Number	Vendor Name	County	Tract Area (acres)	Longitude	Latitude	Harvest Quantity (tonnes)	Imagery	Evidence of Regrowth/Restocking
1	Darden Timber, Inc	AMITE (MS)	45	-89.808	32.083	5,730	Good	No evidience of harvesting

May 2010 (200m)

Sept 2018 (200m)

Aug 2020 (200m)

2015 Sample, Site 2:

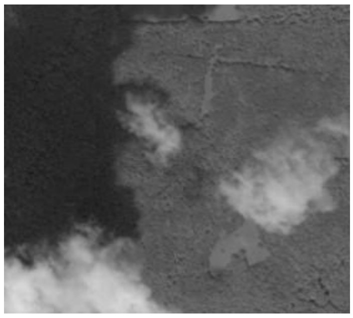
No evidence of harvesting around these coordinates.

Site Number	Vendor Name	County	Tract Area (acres)	Longitude	Latitude	Harvest Quantity (tonnes)	Imagery	Evidence of Regrowth/Restocking
2	Darden Timber, Inc	WILKINSON (MS)	34	-90.442	32.057	4,564	Limited	No evidience of harvesting

Jul 2010 (200m)

Oct 2018 (200m)

Jul 2019 (200m)



2015 Sample, Site 3:

Clear rows of established trees in 2020.

Site Number	Vendor Name	County	Tract Area (acres)	Longitude	Latitude	Harvest Quantity (tonnes)	Imagery	Evidence of Regrowth/Restocking
3	Weyerhaeuser	AMITE (MS)	148	-91.034	31.311	3,124	Good	Clear evidience of restocking

Dec 2010 (200m)

Jul 2017 (200m)

Nov 2020 (100m)

18

2015 Sample, Site 4:

Clear rows of established trees in 2020.

Site Number	Vendor Name	County	Tract Area (acres)	Longitude	Latitude	Harvest Quantity (tonnes)	Imagery	Evidence of Regrowth/Restocking
4	J & N Timber	AMITE (MS)	20	-89.860	32.040	3,052	Good	Clear evidience of restocking

May 2010 (200m)

Sept 2018 (200m)

Oct 2020 (100m)

19

2015 Sample, Site 5:

Clear rows of established trees in 2020.

Site Number	Vendor Name	County	Tract Area (acres)	Longitude	Latitude	Harvest Quantity (tonnes)	Imagery	Evidence of Regrowth/Restocking
5	J & N Timber	AMITE (MS)	40	-89.825	32.215	2,519	Good	Clear evidience of restocking

May 2010 (200m)

Sept 2018 (200m)

Aug 2020 (50m)

20

2015 Sample, Site 6:

No evidence of 2015 harvesting, likely inaccurate coordinates.

Site Number	Vendor Name	County	Tract Area (acres)	Longitude	Latitude	Harvest Quantity (tonnes)	Imagery	Evidence of Regrowth/Restocking
6	J & N Timber	AMITE (MS)	80	-89.996	32.042	2,115	Limited	Unable to identify 2015 site

Mar 2011 (200m)

Oct 2018 (200m)

Aug 2020 (200m)

21

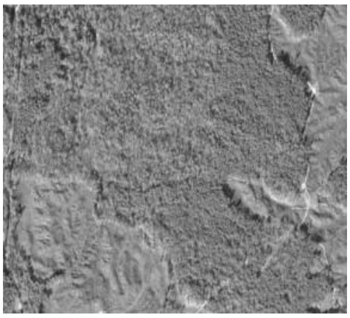
2015 Sample, Site 7:

No evidence of 2015 harvesting, likely inaccurate coordinates.

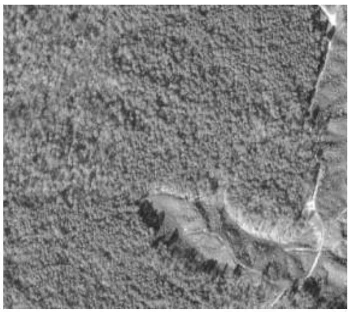
Site Number	Vendor Name	County	Tract Area (acres)	Longitude	Latitude	Harvest Quantity (tonnes)	Imagery	Evidence of Regrowth/Restocking
7	Weyerhaeuser	WILKINSON (MS)	207	-91.294	31.131	2,102	Limited	Unable to identify 2015 site

Dec 2010 (200m)

Jan 2018 (200m)



Jan 2018 (100m)



22

2015 Sample, Site 8:

No evidence of restocking, possibly inaccurate coordinates.

Site Number	Vendor Name	County	Tract Area (acres)	Longitude	Latitude	Harvest Quantity (tonnes)	Imagery	Evidence of Regrowth/Restocking
8	J & N Timber	AMITE (MS)	100	-90.794	31.094	1,813	Limited	No evidience of restocking

Mar 2010 (200m)

May 2019 (200m)

May 2019 (50m)

23

2015 Sample, Site 9:

Unclear if imagery represents 2015 harvesting site, apparent growth in 2018 is advanced.

Site Number	Vendor Name	County	Tract Area (acres)	Longitude	Latitude	Harvest Quantity (tonnes)	Imagery	Evidence of Regrowth/Restocking
9	LandMAX Timber	FRANKLIN (MS)	35	-90.709	31.473	1,665	Good	Unable to identify 2015 site

Mar 2010 (200m)

Oct 2018 (200m)

Oct 2018 (100m)

24

2015 Sample, Site 10:

Unable to identify 2015 harvesting site.

Site Number	Vendor Name	County	Tract Area (acres)	Longitude	Latitude	Harvest Quantity (tonnes)	Imagery	Evidence of Regrowth/Restocking
10	Weyerhaeuser	WILKINSON (MS)	153	-91.116	31.253	1,554	God	Unable to identify 2015 site

Dec 2010 (200m)

Jul 2017 (200m)

Nov 2020 (200m)

25

APPENDIX III

List of search terms used in literature review:

- Woody biomass sustainability US South
- Forest biomass impacts, US
- Forest carbon
- Carbon debt and carbon payback
- Landscape level carbon accounting
- Biomass sustainability requirements UK
- Biomass sustainability reporting
- Biomass negative impact and challenges US
- Forest damage biomass US
- Sustainability reporting process UK biomass
- Forest carbon modelling
- Biomass and emissions reductions
- Biomass counterfactuals US South
- Biomass sustainability monitoring
- Forest loss biomass USA
- Biodiversity impact of biomass USA
- Monitoring biomass impacts in the forest
- Positive impact of biomass on forests US South

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