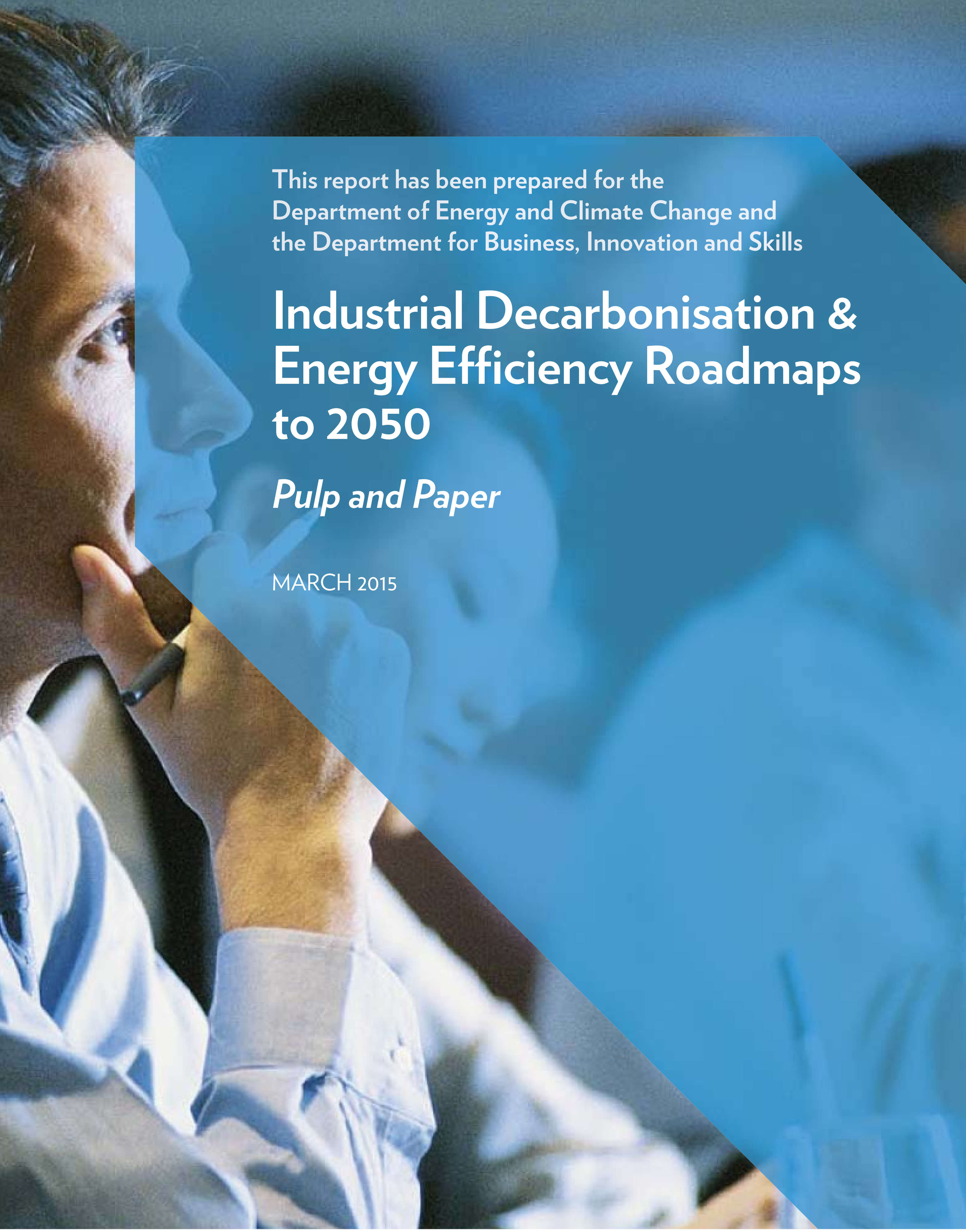

This report has been prepared for the Department of Energy and Climate Change and the Department for Business, Innovation and Skills

Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050

Pulp and Paper

MARCH 2015

WSP | PARSONS BRINCKERHOFF

DNV·GL

CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACRONYMS

ADt	Air Dried tonne
BAT	Best Available Technology
BIS	Department of Business, Innovation and Skills
CA	Compressed Air
capex	capital expenditures
CCA	Climate Change Agreement
CCS	Carbon Capture and Storage
CCS/U	Carbon Capture and Storage/Utilisation
CCU	Carbon Capture and Utilisation
CEO	Chief Executive Officer
CEPI	Confederation of European Paper Industries
CHP	Combined Heat and Power
CO_2	Carbon Dioxide
CPI	Confederation of Paper Industries (UK)
CPS	Carbon Price Support
DECC	Department of Energy and Climate Change
DIP	De-Inked Pulp
EDR	Electricity Demand Reduction
EII	Energy Intensive Industries
ESCO	Energy Service Company
EU ETS	European Union Emissions Trading System
G7	Group 7
GHG	Greenhouse Gas
HVAC	Heating, Ventilation and Air Conditioning
IEA	International Energy Agency
INDEMAND	Industrial Energy and Material Demand
ITT	Invitation to Tender
Max Tech	Maximum Technical
NAEI	National Atmospheric Emissions Inventory
OEM	Original Equipment Manufacturers
PITA	Paper Industry Technical Association
PM	Paper Machine
R&D	Research and Development
RD&D	Research, Development and Demonstration
REA	Rapid Evidence Assessment
ROI	Return on Investment
SAT	State-of-the-Art Technologies
SIC	Standard Industrial Classification
STEM	Science Technology Engineering Mathematics
SWOT	Strengths, Weaknesses, Opportunities and Threats
TRL	Technology Readiness Level
VSD	Variable Speed Drive

1. EXECUTIVE SUMMARY

1.1 What is the 'Decarbonisation and Energy Efficiency Roadmap' for the Pulp and Paper Sector?

This report is a 'decarbonisation and energy efficiency roadmap' for the pulp and paper sector, one of a series of eight reports that assess the potential for a low-carbon future across the most energy intensive industrial sectors in the UK. It investigates how the industry could decarbonise and increase energy efficiency whilst remaining competitive.

Changes in the international economy and the need to decarbonise mean that UK businesses face increasing challenges, as well as new opportunities. The UK Government is committed to moving to a low-carbon economy, including the most energy-intensive sectors. These sectors consume a considerable amount of energy, but also play an essential role in delivering the UK's transition to a low-carbon economy, as well as in contributing to economic growth and rebalancing the economy.

The roadmap project aims were to:

- Improve understanding of the emissions abatement potential of individual industrial sectors, the relative costs of alternative abatement options and the related business environment including investment decisions, barriers and issues of competitiveness.
- Establish a shared evidence base to inform future policy, and identify strategic conclusions and potential next steps to help deliver cost effective decarbonisation in the medium to long term (over the period from 2020 to 2050).

Each roadmap aims to present existing and new evidence, analysis and conclusions to inform subsequent measures with respect to issues such as industry leadership, industrial policy, decarbonisation and energy efficiency technologies, business investments, research, development and demonstration (RD&D) and skills.

This roadmap is the result of close collaboration between industry, academics and government (Department of Energy and Climate Change (DECC) and Department for Business, Innovation and Skills (BIS)), which has been facilitated and delivered by independent consultants Parsons Brinckerhoff and DNV GL; the authors of the reports.

1.2 Developing the Pulp and Paper Sector Roadmap

The development of the pulp and paper sector roadmap consisted of three main phases:

1. Collection of evidence relating to technical options and enablers and barriers to invest in decarbonisation and energy efficiency technologies. Evidence was collected via a literature review, analysis of publicly available data, interviews and workshops. Discussion of evidence and early development of the decarbonisation potential took place during an initial workshop.
2. Development of decarbonisation and energy efficiency 'pathways' to 2050 to identify and investigate an illustrative technology mix for a range of emissions reduction levels. Draft results were discussed at a second workshop.
3. Interpretation and analysis of the technical and social and business evidence to draw conclusions and identify potential next steps. These example actions, which are informed by the evidence and

analysis, aim to assist with overcoming barriers to delivery of technologies within the decarbonisation and energy efficiency pathways while maintaining competitiveness.

A sector team comprising representatives from the pulp and paper industry and its trade associations (the Confederation of Paper Industries (CPI) and the Paper Industry Technical Association (PITA)) and the government has acted as a steering group as well as contributed evidence and reviewing draft project outputs. In addition, the outputs have been independently peer reviewed. It should be noted that the findings from the interviews and workshops represent the opinions and perceptions of particular industrial stakeholders, and may not therefore be representative of the entire sector. Where possible we have tried to include alternative findings or viewpoints, but this has not always been possible; this needs to be taken into account when reading this report.

1.3 Sector Findings

In the papermaking process, either paper for recycling or wood fibres (or on occasion other types of fibres) serves as the raw material to the pulp production. The pulp is then processed, dewatered and dried into paper in the paper machine, after which the paper can be treated through various processes to produce a paper of the required quality. Pulp production can either be integrated with paper-making or carried out as a separate activity. The UK pulp and paper sector produced over four and a half million tonnes of diverse paper products in 2012: 37% comprised packaging paper from recycled fibre, 34% printing and writing (including newsprint), and the remaining 29% tissue and hygiene paper, specialist packaging paper and other specialist papers. The sector contributed to the UK economy with revenues of more than £10 billion in 2012. In that year, it was estimated to emit 2.4 million tonnes/year of CO_2, with a further 0.9 million tonnes/year emitted in grid electricity production for use within the sector (CPI, 2014).

The paper machine, and in particular the drying process, accounts for about two thirds of all energy use in a typical UK pulp and paper mill, using mainly steam produced by natural gas or biomass. The combustion of fuels to produce electricity and/or steam that is used in the process, together with indirect emissions from purchased electricity mainly make up the pulp and paper sector carbon footprint shown in Table 1. The UK pulp and paper sector has already reduced absolute emissions by 50% since 1990 (CPI, 2014).

SECTOR	TOTAL ANNUAL CARBON EMISSIONS 2012 (MILLION TONNES CO_2)
Iron and Steel[1]	22.8
Chemicals	18.4
Oil Refining	16.3
Food and Drink	9.5
Cement[2]	7.5
Pulp and Paper	**3.3**
Ceramic	1.3
Glass	2.2

Table 1: Energy-intensive industry total direct and indirect carbon emissions in 2012 (data sources include CCA data, EU ETS and NAEI)

The pulp and paper sector features a mix of globally active companies and local independent mills, with the majority of production dominated by international businesses. The sector is mature and capital intensive, with long investment cycles. The level of competition is high in general though to some extent this varies depending on the end-product. Overall, generally poor profit margins have resulted in a low level of recent capital investment in new machinery. The market is increasingly globalised and there is high price-sensitivity on the consumer side; UK mills compete with mills both in Europe and further afield. The UK consumes around 10m tonnes of paper based products per annum with less than 5m tonnes of UK production. The UK is the biggest net importer of paper in the world (RISI, 2014).

1.4 Enablers and Barriers for Decarbonisation in the Pulp and Paper Sector

In this report, we look at 'enablers', 'barriers' and 'technical options' for decarbonisation of the pulp and paper sector. There is some overlap between barriers and enablers, as they sometimes offer two perspectives on the same issue. Based on our research, the main enablers for decarbonisation for the pulp and paper sector include:

- Diversification of paper products
- Lower consumer prices
- Collaboration in the value chain
- Government policy
- Small incremental investments
- Senior management buy-in and formal business commitment

The main barriers to decarbonisation have been identified as:

- Competitive marketplace with lowering profit margins

[1] For the iron and steel sector, the reference year used is 2013. This was chosen due to the large production increase from the re-commissioning of SSI Teesside steelworks in 2012.
[2] For the cement sector, the 2012 actual production levels where adversely affected by the recession. Therefore we have assumed production of 10 million tonnes (rather than the actual production in 2012) and normalised emissions to this production level.

- Regulatory uncertainty
- Conservative industry
- Uncertainty about return on capital
- Uncertainty regarding impact of new technology on machine operability
- Lack of awareness and information imperfections
- Lack of skilled labour
- Rising UK energy prices perceived as non-competitive
- Biomass availability
- Global competition for funding from group headquarters
- Lifetime of machinery of 30-60 years

1.5 Analysis of Decarbonisation Potential in the Pulp and Paper Sector

A 'pathway' represents a particular selection and deployment of options from 2012 to 2050 chosen to achieve reductions falling into a specific carbon reduction band relative to a reference trend in which no options are deployed. Two further pathways with specific definitions were also created, assessing (i) what would happen if no particular additional interventions were taken to accelerate decarbonisation (business as usual, BAU) or (ii) the maximum possible technical potential for decarbonisation in the sector (Max Tech)[3]. These pathways include deployment of options comprising (i) incremental improvements to existing technology, (ii) upgrades to utilise BAT, and (iii) the application of significant process changes using 'disruptive' technologies that have the potential to become commercially viable in the medium term.

The pathways created in the current trends scenario, the central of three scenarios used in this study, are shown below in Figure1.

[3] There are two alternative Max Tech pathways in this investigation, (i) Max Tech 1 simulates large scale electrification while Max Tech 2 assumes unlimited biomass

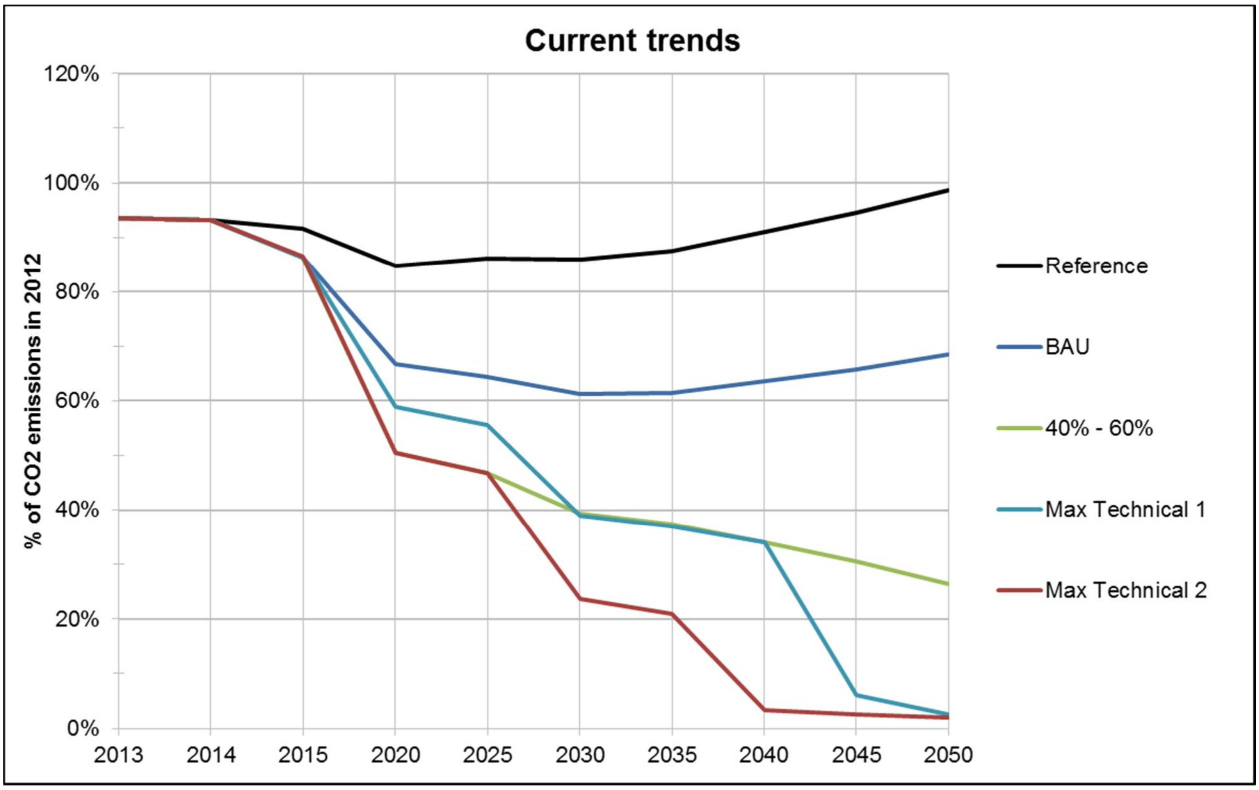

Figure1: Overview of the different decarbonisation and energy efficiency pathways

Analysis of the costs of the pathways used order of magnitude estimates to add up the capital cost of each pathway. As an indication, the net present capital cost for the pathways, discounted at 3.5%, falls within an estimated range of £700 million[4] to £1 billion[5]. There is a large degree of uncertainty attached to the cost analysis, especially for options which are still in the research and development stage. Also, costs of operation, energy use, research, development, demonstration, civil works, modifications to plant and costs to other stakeholders are significant for some options, but not included here. The costs presented are for the study period and are adjusted to exclude residual value after 2050, thus a proportion of the costs of high capex items deployed close to 2050 is excluded. Great care must be taken in how these costs are interpreted. While implementation of some of the options within the pathways may reduce energy costs due to increased efficiency, the scale of the investments associated with the pathways must be considered by stakeholders when planning the next steps in the sector.

1.6 Conclusions and Key Technology Groups

The following conclusions have been drawn from the evidence and analysis:

Strategy, Leadership and Organisation

It is critical that the pulp and paper sector, the government and other stakeholders recognise the importance of strategy and leadership in the context of decarbonisation, energy efficiency and general competitiveness for the sector.

[4] For the BAU pathway in the current trends scenario
[5] For the Max Tech pathway in the current trends scenario

Business Case Barriers

Important barriers to decarbonisation and increased energy efficiency include lack of funding for such projects as there is a lack of access to capital and also the return of investment often does not meet industry-defined thresholds.

Future Energy Costs, Energy Supply Security, Market Structure and Competition

It is clearly critical to ensure that future decarbonisation and energy efficiency actions maintain the position with respect to overall cost-competitiveness of the UK sector compared to competing businesses operating in other regions of Europe, Asia and the US. This strategic conclusion links to a number of external factors that influence the business environment in which the sector operates. These include energy security and energy cost comparison to other regions (both reality and perception), as these factors are important when investment decisions are made.

Industrial Energy Policy Context

Many in the sector have emphasised that a long-term energy and climate change policy is key to investor confidence. Furthermore, it was stated by industry stakeholders that there is a need for incentive schemes to become long-term commitments, as changes in policy can be damaging, particularly when the business case for investment is marginal and is highly dependent upon factors such as (fluctuating) energy related costs.

Life-Cycle Accounting

As diversification of pulp and paper products continues the tools and methodologies for carbon accounting, to ensure comparability and full understanding of the impacts across the product value chain, are important. An example of this is the functional surface concept in the Confederation of European Paper Industries (CEPI) Two Team project. Improved standardised carbon accounting methodology can enable appropriate value to be put on carbon benefits and therefore easing the investment in decarbonisation.

Value Chain Collaboration

Partnerships with machine suppliers are needed to refine existing and develop new technologies, as well as collaboration between different paper companies. If customers put a premium on low-carbon paper products then a differential pricing approach would be possible. The challenge for the pulp and paper sector is that it rarely has a relationship with the end customer as it typically sells its products to a distributor of some sort.

As a sector that has uses bio-materials, paper companies have the knowledge and experience to contribute towards the development of a Bio-refinery. In collaboration with other sectors, such a facility could covert biomass to high-quality products for the evolving bio-economy (e.g. bio-polymers and composites with new functionalities).

Research, Development and Demonstration

There is a general lack of Research, Development and Demonstration (RD&D) projects taking place in the UK pulp and paper sector, meaning that the sector could fall behind other regions with regards to strategy and leadership, knowledge, expertise, training and skills, technologies, and the supply chain. RD&D would form an important part of a competitive sector in the future, including the contribution to increased decarbonisation and improved energy efficiency. Universities still include some research on pulp and paper, but mills have limited RD&D and do not tend to participate in pan-European projects (like the Two Team project). There is also little development or activity by equipment manufacturers in the UK, meaning the UK tends not to be chosen for pilot plants.

People and Skills

To implement advanced technologies, appropriately trained labour is needed to understand and implement complex new technologies to deliver the most energy and carbon efficient options. This is, and will continue to be, key to decarbonising the sector. While ad-hoc training has continued in the UK, the last graduates from the paper science programmes at the University of Manchester graduated in 2005 and it will be important to the sector to retain and develop appropriate skills. In addition, the current sector age profile means that increased efforts are required to facilitate the next generation of operators and plant managers. Advanced technologies are attractive to the younger generation so it is also an opportunity to attract more young people to start working in the sector.

The key technology groups that, in this investigation, make the largest contributions to sector decarbonisation or energy efficiency are as follows:

Electricity Grid Decarbonisation

Decarbonisation of the national electricity grid could provide a significant contribution to the overall decarbonisation of the sector. Low-carbon electricity is a key part of any decarbonisation plan for the paper and pulp industry but can only be used by industry if it is technically and financially viable to do so, and if there is a sufficient secure supply. The government's reforms of the electricity market are already driving electricity grid decarbonisation, and this report uses assumptions of a future electricity decarbonisation trajectory that is consistent with government methodology and modelling.

Electrification of Heat

To reach the decarbonisation potential in one of two Max Tech pathways by switching to 100% electricity for heating, decarbonisation of the electricity grid is required, as illustrated above. Actions will be required to ensure that this takes place while maintaining cost-competitiveness.

Fuel and Feedstock Availability (including biomass)

Biomass clearly has significant potential as an alternative fuel for the pulp and paper industry, and provides an opportunity to decarbonise the sector (in the Max Tech 2 pathway, using biomass-based combined heat and power (CHP)). Feedstock availability and cost could, however, be a significant barrier, since power generation, other industrial sectors and domestic heating uses will be competing for the same, potentially limited, resource. Biomass is already heavily used as a raw material by a number of industrial sectors (including the pulp and paper sector) and is also a key feedstock for the quickly growing bio-economy. There are strong arguments that biomass should be used to maximise its value, with only low grade and otherwise waste materials being the feedstock for energy use. When used for electricity production, there is significant added value to use biomass for heat and power (via CHP technology) compared to power generation only and this is recognised in government electricity market support policy.

Energy Efficiency and Heat Recovery

Implementing current state-of-the-art technologies (SAT) has a significant decarbonisation and energy efficiency potential for the pulp and paper sector. Many of these technologies have low or low-medium investment costs and could be implemented cost effectively in existing plants.

Heat recovery with advanced technologies is required to reach the full decarbonisation potential of the sector. These technologies should be developed soon, requiring significant RD&D and sector collaboration including

OEMs, and attention must be paid to the timing of investments (as they typically have long lifespans). Opening waste industrial heat to support regimes is likely to be required to deliver the full potential of this opportunity.

Clustering

To reach the decarbonisation potential in the maximum technical 1 pathway (using carbon-neutral steam provided through heat networks), clustering represents a significant opportunity to decarbonise the sector. Industrial symbiosis, energy integration and clustering are well-known approaches and much work is available addressing best practice. However in practice these opportunities are limited for existing installations and there can be significant local planning difficulties. Industrial clustering could provide a profitable use for pulp and paper waste or by-products like CO_2 (for carbon capture and storage/utilisation (CCS/U)), recovered heat etc. By clustering local industries, costs are shared, heat is used more economically and total benefits increased.

Next Steps

This roadmap report is intended to provide an evidence-based foundation upon which future policy can be implemented and actions delivered. The report has been compiled with the aim that is has credibility with industrial, academic and other stakeholders and is recognised by government as a useful contribution when considering future policy.

2. INTRODUCTION, INCLUDING METHODOLOGY

2.1 Project Aims and Research Questions

2.1.1 Introduction

Changes in the international economy, coupled with the need to decarbonise, mean that UK businesses face increased competition as well as new opportunities. The government wants to enable UK businesses to compete and grow while moving to a low-carbon economy. The UK requires a low-carbon economy but the existing structure includes industries that consume significant amounts of energy. These energy-intensive industries have an essential role to play in delivering the UK's transition to a low-carbon economy, as well contributing to economic growth and rebalancing the economy.

Overall, industry is responsible for nearly a quarter of the UK's total emissions (DECC, 2011)[6]. By 2050, the government expects industry to have delivered a proportionate share of emissions cuts, achieving reductions of up to 70% from 2009 levels (DECC, 2011). Nonetheless, the government recognises the risk of 'carbon leakage' and 'investment leakage' arising from the need to decarbonise and is committed to ensuring that energy-intensive industries are able to remain competitive during the transition to a low-carbon economy.

The Department of Energy and Climate Change (DECC) and the Department of Business, Innovation and Skills (BIS) have set up a joint project focusing on the eight industrial sectors which use the greatest amount of energy[7]. The project aims to improve the understanding of technical options available to sectors to reduce carbon emissions and increase energy efficiency while remaining competitive. This includes include investigating the costs involved, the related business environment, and how investment decisions are made in sector firms. This will provide the industry and government with a better understanding of the technical and economic abatement potential, set in the relevant business context, with the aim to agree measures that both the government and these industries can take to reduce emissions while maintaining sector competitiveness. .

The project scope covers both direct emissions from sites within the sector and indirect emissions from the use of electricity at the sites but generated off site.

The industrial sectors evaluated in this project are listed in Table 2.

Cement	Glass
Ceramics	Iron and Steel
Chemicals	Oil Refining
Food and Drink	**Pulp and Paper**

Table 2: Industrial sectors evaluated in this project

[6] It has also been estimated that 70% of industrial energy use is for heat generation (DECC, 2014)
[7] The 'non-metallic minerals' sector has been divided into three sectors: glass, ceramics and cement.

2.1.2 Aims of the Project

The DECC 2011 Carbon Plan outlined the UK's plans to reduce greenhouse gas emissions and make the transition to a low-carbon economy while maintaining energy security and minimising negative economic impacts. This project aims to improve evidence on decarbonisation and energy efficiency for eight energy-intensive industry sectors, with the pulp and paper sector the subject of this report. For the purpose of this study the pulp and paper sector comprises the UK pulp and paper mills only excluding printing or converting. In addition this report has not looked at emissions associated with pulp and paper products used in the UK but produced outside of the UK.

The project consortium of Parsons Brinckerhoff and DNV GL was appointed by DECC and BIS in 2013 to work with stakeholders, including the UK manufacturers' organisations (i.e. trade associations), to establish a shared evidence base to support decarbonisation. The roadmap process consisted of three main phases:

i. Information and evidence gathering on existing technical options and potential breakthrough technologies, together with research to identify the social and business enablers and barriers to decarbonisation
ii. Development of sector decarbonisation pathways
iii. Conclusions and identification of potential next steps

A series of questions were posed by DECC and BIS as part of the project. These 'principal questions' guided the research undertaken and the conclusions of this report. The questions and the report section in which they are addressed are stated below:

1. What are the current emissions from each sector and how is energy used? - section 3.3
2. For each sector, what is the business environment, what are the business strategies of companies, and how does it impact on decisions to invest in decarbonisation? - section 3.4
3. How might the baseline level of energy and emissions in the sectors change over the period to 2050? - section 4.3
4. What is the potential to reduce emissions in these sectors beyond the baseline over the period to 2050? - section 4.4
5. What emissions pathways might each sector follow over the period to 2050 under different scenarios? - section 4.4
6. What next steps into the future might be required by industry, the government and others to overcome the barriers in order to achieve the pathways in each sector? - section 5

2.1.3 What is a Roadmap?

A 'roadmap', in the context of this research, is a mechanism to visualise future paths, the relationship between them and the required actions to achieve a certain goal. A technology roadmap is a plan that matches short-term and long-term goals with specific technology solutions to help meet those goals. Roadmaps for achieving policy objectives go beyond technology solutions into broader consideration of strategic planning, market demands, supplier capabilities, and regulatory and competitive information.

The roadmaps developed by this project investigate decarbonisation in various UK industries, including how much carbon abatement potential currently exists, what technologies will need to be implemented in order to extend that potential, and how businesses will be affected. The roadmap aims to present existing and new evidence, analysis and conclusions as a 'consensual blueprint' to inform subsequent action with respect to issues such as future energy and manufacturing industrial strategy and policy, decarbonisation and energy efficiency business investments, research and development, and skills. The roadmaps consist of three components: evidence, pathways analysis and conclusions, as illustrated in Table 3. Each component is necessary to address the principal questions, and is briefly defined below.

INDUSTRIAL DECARBONISATION AND ENERGY EFFICIENCY ROADMAP TO 2050			
SOURCES OF EVIDENCE	INTERMEDIATE OUTPUTS	PATHWAYS	STRATEGIC CONCLUSIONS AND EXAMPLE ACTIONS
Literature	Validated emission data	Analysis of evidence to construct decarbonisation and energy efficiency pathways	Analysis of evidence and pathways to develop strategic conclusions and possible next steps to: • Overcome barriers and strengthen enablers • Implement pathways
Publicly available emissions data	Decarbonisation options and associated data		
Interviews, meetings and workshops with stakeholders	Energy efficiency options and associated data		
Government policy and analytical teams, trade associations, academics as part of engagement with the sector team	Barriers and enablers to decarbonisation and energy efficiency options and investment		

Table 3: Inputs and outputs for the industrial decarbonisation and energy efficiency roadmap to 2050

The views of contributing organisations

These reports were commissioned by DECC and BIS, and jointly authored by Parsons Brinckerhoff and DNV GL. The project was progressed using a collaborative process and while important contributions were provided by the sector, it should not be assumed that participating organisations (i.e. government, trade associations and their members and academic institutions) endorse all of the report's data, analysis and conclusions.

The findings from the interviews and workshops represent the opinions and perceptions of particular industrial stakeholders, and therefore may not be representative of the entire sector. We have tried to include alternative findings or viewpoints, but this has not always been possible within the constraints of the project. This needs to be taken into account when reading this report.

2.2 Overall Methodology

The overall methodology is illustrated in Figure 2 and shows the different stages of the project. As can be seen, the stakeholders are engaged throughout the process that follows the main phases of the project: evidence gathering, modelling/pathway development and finally drawing out the conclusions and potential next steps. A detailed description of the methodology can be found in appendix A.

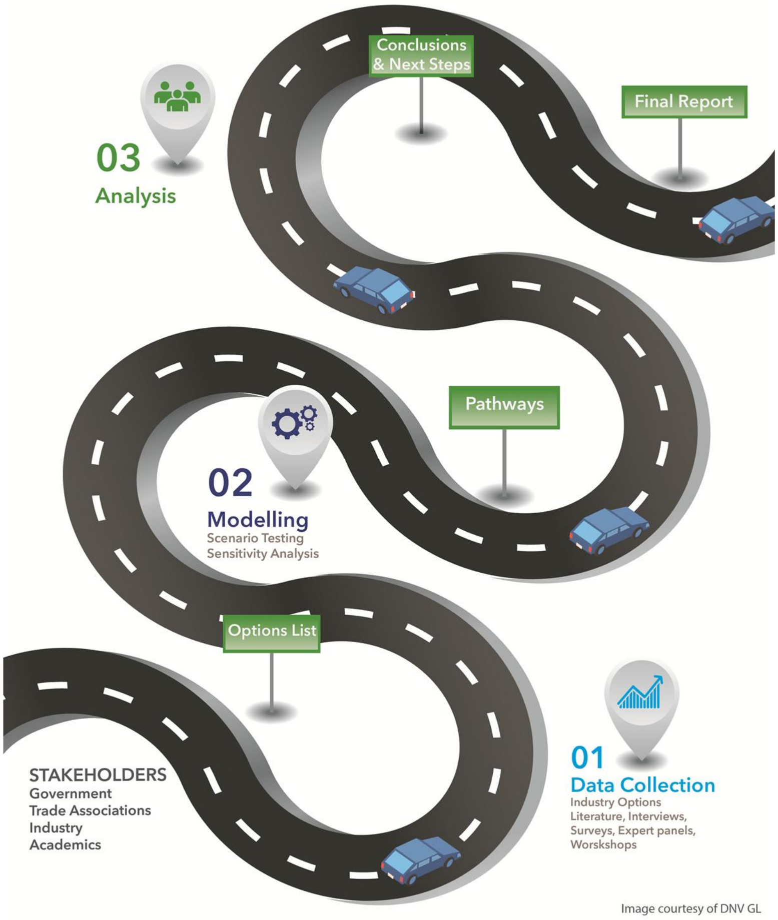

Figure 2: Roadmap methodology

Evidence was gathered for covering technical, and social and business aspects from literature reviews, interviews, and workshops with relevant stakeholders. These different sources of information allowed evidence triangulation to improve the overall research. The data was then used to develop a consolidated list of enablers and barriers for decarbonisation, and a register of technical options for the industry. This was subsequently used to develop a set of carbon reduction pathways to evaluate the decarbonisation potential of the UK pulp and paper sector and the main technical options required within each pathway.

Key to the overall roadmap methodology was engagement with all stakeholders, including with business and trade association representatives, academics and civil servants, to contribute to the evidence, discuss its quality and interpret the analysis. We have worked closely with CPI, PITA, DECC and BIS to identify and involve the most appropriate people from the pulp and paper sector, relevant academics and other stakeholders, such as representatives from the financial sector.

2.2.1 Findings

Evidence Gathering

The data focused on technical, and social and business information, aiming to acquire evidence on:

- Decarbonisation options (i.e. technologies)
- Barriers and enablers to decarbonisation and energy efficiency
- Background to the sector
- Current state of the sector and possible future changes within the sector
- Business environment and markets
- Potential next steps

Such evidence was required to either answer the principal questions directly and/or to inform the development of pathways for 2050. Four methods of research were used in order to gather as much evidence as possible (and to triangulate the information) within a short timescale. These methods were:

- **Literature review:** A short, focussed review of over 150 documents all published after 2000 was completed. The documents were either related to energy efficiency and decarbonisation of the sector or to energy-intensive industries in general. This was not a thorough literature review or rapid evidence assessment (REA) but a desktop research exercise deemed sufficient by the project team[8] in its breadth and depth to capture the evidence required for the purpose of this project. The literature review was not intended to be exhaustive and aimed to capture key documentation that applied to the UK. This included the sector structure, recent history and context including consumption, demand patterns and emissions, the business environment, organisational and decision-making structures and the impacts of UK policy and regulation. Further details are provided in appendix A.
- **Interviews:** In liaison with CPI, DECC and BIS, five face-to-face semi-structured interviews were initially conducted representing technical operations via environment and energy managers. Two additional interviews were subsequently agreed with senior management of two international paper companies with UK operations. The purpose of the interviews was to obtain further details on the different subsectors within the pulp and paper sector and gain a deeper understanding of the principal questions, including details of decision-making processes and how companies make investment decisions, how advanced technologies are financed, what a company's strategic priorities are and where climate change sits within this. The interviewees were interviewed using an 'interview protocol' template, developed in liaison with DECC and BIS. This template was used to ensure consistency across interviews, fill gaps in the literature review, identify key success stories and extract key barriers to investment in low-carbon technologies. The interview protocol can be found in appendix A. Interviewees were selected to maximise coverage across subsectors and emissions and also take into account company headquarters location, production processes and company size.
- **Workshops:** Two workshops were held, attendees for which were identified in consultation with CPI, PITA, DECC and BIS. The first workshop focused on reviewing potential technological decarbonisation and energy efficiency options (that had been provisionally generated from the literature review) and discussing adoption rate, applicability, improvement potential, ease of implementation, capex, return on investment (ROI), savings potential and timeline for the different options. This was done through two breakout sessions: one focused on collecting more data and the other one on timelines under different scenarios. The second activity involved group discussions on enablers and barriers to energy efficiency and decarbonisation investment, and how to overcome them. The second workshop focused on reviewing the draft pathways and identifying potential actions for delivering them. The workshop participants included the relevant trade associations, large

[8] DECC, BIS and the consultants of PB and DNV GL.

companies with the aim of achieving representation of key companies or subsectors and academics with expert knowledge of the sector, PB and DNV GL consultants, DECC and BIS project managers and senior civil servants. The average size of a workshop was 40 people.

By using a range of information sources, the evidence could be triangulated to improve the overall research. Themes that were identified during the literature review were subsequently used as a focus or a starting point during the interviews and workshops. The data from the literature was corroborated by comparing it with evidence from the interviews and workshops. Likewise, information gaps identified during the interviews and workshops were, where possible, populated using literature data. In addition, CPI collected data from its members that further helped to fill gaps and triangulate multiple data sources. It should be noted that the evidence-gathering exercise was subject to several limitations based upon the scale of activities that could be conducted within the time and resources available. Interview samples were gathered through purposive and snowball sampling techniques in collaboration with trade associations, DECC and BIS experts. But due to time, sampling and resource constraints the samples may be limited in terms of their numbers and/or diversity. Where possible we have attempted to triangulate the findings to counter any bias in the sample, but in some areas this has not been possible. Some caution should therefore be used in interpreting the findings. The literature review, while not intended to be exhaustive, aimed to capture key documentation that applied to the UK. The criteria for identifying and selecting literature is detailed in Appendix A.

The different sources of evidence together with the associated outputs are shown in Figure 3.

Figure 3: Evidence gathering process

The different sources of evidence were used to develop a consolidated list of barriers to and enablers for decarbonisation and energy efficiency, and a register of technical options for the pulp and paper sector. Evidence on adoption rate, applicability, improvement potential, ease of implementation, capex, ROI and saving potential of all options (where available) was collected, together with information on strengths, weaknesses, opportunities and threats (SWOT). A SWOT analysis is a different lens to examine the enablers and barriers and reinforce conclusions and linkages between evidence sources. It identifies how internal strengths mitigate external threats and can be used to create new opportunities, and how new opportunities can help overcome weaknesses. By clustering the various possibilities, we identified key stories from the SWOT analysis which enabled us to describe the business and market story in which companies operate. Further information on the SWOT analysis is provided in appendix B. The SWOT analysis was used to further understand and validate the initial findings from the literature review and provided the basis for workshop and interview discussions and further helped to qualify the interview and workshop outcomes. Enablers and barriers were prioritised as a result of the outcomes and analysis of the evidence-gathering process and workshop scores.

This information was used to inform the development of a set of pathways to illustrate the decarbonisation potential of the pulp and paper sector in the UK. The summary and outcomes of this analysis are discussed in Section 4.5.

The evidence-gathering process was supported by high levels of engagement with a wide range of stakeholders including industry members, trade association representatives, academics and staff from DECC and BIS.

The evidence-gathering exercise (see appendix A for details) was subject to inherent limitations based upon the scale of activities and sample sizes that could be conducted within the time and resources available. The pulp and paper companies interviewed represented over 80% of carbon emissions produced in the UK, and included UK decision-makers and technical specialists in the pulp and paper sector. These interviews were conducted to provide greater depth and insight to the issues faced by companies. Many of the companies in the UK are globally owned, therefore international senior management from two pulp and paper companies were also interviewed.

The identification of relevant information was approached from a 'global' and UK viewpoint. The global outlook examined dominating technologies and process types, global production, CO_2 emissions (in the EU-28), and the global outlook to 2050, including the implications for pulp and paper producers and consumers. The UK outlook examined the sector structure, recent history and context including consumption, demand patterns, emissions, the business environment, organisational and decision-making structures and the impacts of UK policy and regulation.

Options examined were relevant to fibre supply, the paper machine and the provision of utilities, as well as options that were applicable across the mill. Potentially transformative options from the CEPI Two Team Project (see appendix C) were also included.

Evidence Analysis

The first stage in the analysis was to assess the strength of the evidence for the identification of the enablers and barriers. This was based on the source and strength of the evidence, and whether the findings were validated by more than one information source. The evidence was also analysed and interpreted using a variety of analytical techniques. Elements of the Porter's five forces analysis, SWOT analysis and system analysis were used to conduct the analysis of the business environment, and the enablers and barriers (section 3.4); while concepts from storytelling and root cause analysis were used during the interviews with stakeholders. These different techniques are discussed in appendix B.

The options register of the technology options for decarbonisation was developed based on the literature review, interviews, the information gathering workshop, and additional information provided by CPI and its members. The strengths, weaknesses, enablers and barriers of each option were taken into account to refine the options register, which was then used to build up the different pathways in a pathway model.

A second stage in the analysis was the classification of technological options and an assessment of their readiness.

Limitations of these Findings

The scope of the study did not cover a full assessment of the overall innovation chain or of present landscape of policies and actors. Direct and indirect impacting policies, gaps in the current policy portfolio, and how future actions would fit into that portfolio (e.g. whether they would supplement or supplant existing policies) are not assessed in the report in any detail.

2.2.2 Pathways

The pathways analysis is an illustration of how the pulp and paper industry could potentially decarbonise from the base year 2012 to 2050. Together the set of pathways developed in the study help give a view of the range of technology mixes that the sector could deploy over coming decades. Each pathway consists of different technology options that are implemented over time at different levels. Each technology option included a number of key input parameters including carbon dioxide saving, cost, fuel use change, applicability, current adoption (in the base year), and deployment (both rate and extent). A 'pathway' represents a particular selection and deployment of options from 2014[9] to 2050 chosen to achieve reductions falling into a specific carbon reduction band.

In this project, up to five pathways were developed, three of which were created to explore possible ways to deliver carbon dioxide emissions to different decarbonisation bands by 2050, as shown below:

- 20-40% CO_2 reduction pathway relative to the base year
- 40-60% CO_2 reduction pathway relative to the base year
- 60-80% CO_2 reduction pathway relative to the base year

Two further pathways - with specific definitions - were also created, assessing (i) what would happen if no additional interventions were taken to accelerate decarbonisation (business as usual, BAU) or (ii) the maximum possible technical potential for decarbonisation in the sector (Max Tech)[10].

The BAU pathway consisted of the continued roll-out of technologies that are presently being deployed across the sector as each plant or site reaches the appropriate point to implement the technology. For the pulp and paper industry, two different Max Tech pathways were developed as it is presently not possible to determine which would be more likely.

Pathways were developed in an iterative manual process and not through a mathematical optimisation process. This was done to facilitate the exploration of uncertain relationships that would be difficult to express analytically. This process started with data collected in the evidence gathering phase regarding the different decarbonisation options, current production levels and the current use of energy or CO_2 emissions of the sector. This data was then enriched through discussion with the sector team and in the first workshop. Logic reasoning (largely driven by option interaction), sector knowledge and technical expertise were applied when selecting technical options for the different pathways. These pathways were discussed by the sector

[9] Model anticipates deployment from 2014 (assuming 2012 and 2013 are too early).
[10] Definitions are provided in the glossary.

team, modelled, and finally tested by the stakeholders participating in the second workshop. This feedback was then taken into account and final pathways were developed. All quantitative data and references are detailed in the options register and relevant worksheets of the model. The pathway model is available through DECC and BIS, and the methodology is summarised in appendix A.

Scenario Testing

The different pathways developed have been tested under different scenarios (i.e. there are three different scenarios for each pathway). A scenario is a specific set of conditions that could directly or indirectly affect the ability of the sector to decarbonise. Examples of these are: future decarbonisation of the grid, future growth of the sector, future energy costs, and future cost of carbon. Since we do not know what the future will look like, using scenarios is a way to test the robustness of the different pathways.

For each pathway, the following three scenarios were tested (a detailed description of these scenarios is provided in appendix A):

- **Current trends**: This would represent a future world very similar to our world today with low continuous growth of the industry in the UK.
- **Challenging world**: This would represent a future world with a more challenging economic climate and where decarbonisation is not a priority and the industry is declining in the UK.
- **Collaborative growth**: This would represent a future world with a positive economic climate and where there is collaboration across the globe to decarbonise and where the industry has a higher growth rate in the UK.

In order to produce pathways for the same decarbonisation bands under the different scenarios, the deployment rate of the options varied according to the principals set out in the scenarios. For example, in order to achieve a specific decarbonisation band in 2050 in the collaborative growth scenario, options were typically deployed at a faster rate and to a higher degree as compared to the current trends scenario (provided this was considered to be consistent with the conditions set out in the scenarios).

Key Assumptions and Limitations

The pathway model was developed and used to estimate the impact on emissions and costs of alternative technology mixes and macro-economic scenarios. Modelled estimates of decarbonisation over the period (2014 to 2050) are presented as percentage reductions in emissions meaning the percentage difference between emissions in 2050 and emissions in the base year (2012). CO_2 emissions reductions and costs are reported compared to a future in which there was no further take up of decarbonisation options (referred to as the reference trend).

The model inputs and option deployments are based on literature review, interviews and stakeholder input at workshops and sector meetings. Parsons Brinckerhoff and DNV GL sector leads used these sources to inform judgements for these key parameters. Key input values (e.g. carbon reduction factors for options) are adapted from literature or directly from stakeholder views. If data values were still missing then values were estimated based on consultant team judgements. Carbon reduction inputs and pathways were reviewed and challenged at workshops. The uncertainties in this process are large given this level of judgement, however, these are not quantified. A range of sensitivity analysis was carried out including the development of alternative versions of the Max Tech pathway and also testing of different availabilities of biomass.

Deployment of options at five-year intervals is generally restricted to 25% steps unless otherwise indicated. For example, an option cannot be incrementally deployed by 25% over ten years, but has to deploy over five years and flat-line over the other five years.

In this report, when we report carbon dioxide, this represents CO_2 equivalent. However, other greenhouse gases were not the focus of the study which centred on both decarbonisation and improving energy efficiency in processes, combustion and indirect emissions from electricity used on site but generated off site. Also, technical options assessed in this work result primarily in CO_2 emissions reduction and improved energy efficiency. In general, emissions of other greenhouse gases, relative to those of CO_2, are very low.

Assumptions in relation to the maximum technical pathway

Max Tech pathway: A combination of carbon abatement options and savings that is both highly ambitious but also reasonably foreseeable. It is designed to investigate what might be technically possible when other barriers are set to one side. Options selected in Max Tech take into account barriers to deployment but are not excluded based on these grounds. Where there is a choice between one option or another, the easier or cheaper option is chosen or two alternative Max Tech pathways are developed.

The following assumptions apply:

1. Technology readiness level (TRL): process or technology at least demonstrated at a pilot scale today, even if that is in a different sector.
2. Other disruptive technology options that could make a significant difference, but that are not mature enough for inclusion in the pathways, are covered in the commentary.
3. Cost is not a constraint: it has been assumed that there are strong and growing financial incentives to decarbonise which mean that the cost of doing so is not generally a barrier.
4. Option deployment rate: the sector team followed the roadmap method process to develop and test option deployments in all pathways, including Max Tech. Hence, in each sector, rates at which the options can be deployed were considered as ‘highly ambitious but also reasonably foreseeable’.
5. Biomass: maximum penetration of biogenic material as fuel or feedstock assuming unlimited availability. Carbon intensity and sensitivities are included in each sector.
6. Carbon Capture (CC): All sectors have made individual (sector) assessments of the maximum possible potential by 2050 based on what is ‘highly ambitious but also reasonably foreseeable’. This assessment included the most suitable CO_2 capture technology or technologies for application in the sector, the existing location of the sites relative to each other and anticipated future CC infrastructure, the space constraints on sites, the potential viability of relocation, the scale of the potential CO_2 captured and potential viability of both CO_2 utilisation and CO_2 storage of the captured CO_2.
7. Electricity Grid: three decarbonisation grid trends were applied through the scenario analysis.

Option Interaction Calculation

The pathway model incorporated two methods of evaluating potential interactions of options. The first method reflected the assumption that all options interacted maximally, and the second method reflected the assumption that the options did not interact. Neither of these cases was likely to be representative of reality; however the actual pathway trend would lie between the two. The two methods therefore provided a theoretical bound on the uncertainty of this type of interaction in results that was introduced by the choice of a top down modelling approach. Figures calculated based on the assumption of maximum interaction are presented exclusively in the report unless otherwise stated.

Cumulative Emissions

An important aspect of an emission pathway is the total emission resulting from it. The pathways presented in this report are not designed or compared on the basis of cumulative emissions over the course to 2050. Only end-targets are assessed e.g., it is possible for a pathway of lower 2050 emission to have larger cumulative emissions, and thus a greater impact on the global climate system. The exception to this is in the cost analysis section where total CO_2 abated under each pathway – as calculated by the model – is quoted.

Scope of Emissions Considered

Only emissions from production or manufacturing sites were included in scope (from combustion of fuels, process emissions and indirect emissions from imported electricity). Consumed and embedded emissions were outside the scope of this project.

Complexity of the Model

The model provided a simplified top down representation of the sector to which decarbonisation options were applied. It does not include any optimisation algorithm to automatically identify a least cost or optimal pathway.

Material Efficiency

Demand reduction through material efficiency was outside the scope of the quantitative analysis. It is included in the conclusions as material efficiency opportunities are considered to be significant in terms of the long-term reduction of industrial emissions: see for example Allwood et al. (2012) and the ongoing work of the UK INDEMAND Centre.

Base Year (2012)

The Climate Change Act established a legally binding target to reduce the UK's greenhouse gas emissions by at least 80% below base year (1990) levels by 2050. DECC's 2011 Carbon Plan set out how the UK will achieve decarbonisation within the framework of the carbon budgets and policy objectives: to make the transition to a low-carbon economy while maintaining energy security and minimising costs to consumers. The Carbon Plan proposed that decarbonising the UK economy "could require a reduction in overall industry emissions of up to 70% by 2050" (against 2009 emissions).

In this project for the analytical work, we have set 2012 as the base year. . This is the most recent dataset available to the project, and was considered to be a suitable date to assess how sectors (as they currently are) can reduce emissions to 2050. This separates the illustrative pathways exercise from national targets, which are based on 1990 emissions.

2.2.3 Conclusions and Next Steps

The conclusions and potential next steps are drawn from the outcomes of the pathways modelling, the scenario testing and the potential actions to overcome barriers and enhance enablers that were identified together with stakeholders. The strategic conclusions can include high-level and/or longer term issues, or more specific, discrete example actions which can lead to tangible benefits. The potential next steps are presented in the context of eight strategic conclusions (or themes) and six or seven technology groups. The strategic conclusions or themes are:

- Strategy, leadership and organisation
- Business case barriers
- Future energy costs, energy supply security, market structure and competition

- Industrial energy policy context
- Life-cycle accounting
- Value chain collaboration
- Research, development and demonstration
- People and skills

The main technology groups as presented in section 5 are:

- Electricity grid decarbonisation
- Electrification of heat
- Fuel and feedstock availability (including biomass)
- Energy efficiency and heat recovery
- Clustering
- Carbon capture
- Sector-specific technologies

3. FINDINGS

3.1 Key Points

For the UK the CO_2 emissions in 2012 from pulp and paper production totalled 3.3 million tonnes of CO_2 for a production of 4.6 million tonnes of paper products (Intelligent Energy Europe, 2012). Direct emissions originate largely from steam-producing boilers and gas turbines, and indirect emissions from electricity from the grid, with the paper machine –- and in particular the drying process –- accounting for about two thirds of all energy use in a typical UK pulp and paper mill. The fuel use in the sector is dominated by natural gas with 17% of the fuel used being biomass.

Before carbon-related legislation was introduced, the UK pulp and paper sector was already evolving towards a lower carbon energy strategy. Since 1990, it was reported by CPI that the sector has reduced their emissions by 50% while maintaining approximately the same level of production through improved energy efficiency and modernisation.

The pulp and paper sector in the UK is dominated by 17 companies representing 80% of the sector emissions in the UK with a mix of national and international companies (CPI, 2014), where the later represent the majority of the production. For this work the sector has been divided into the following subsectors:

- Specialist paper mills
- Tissue and hygiene paper mills
- Packaging paper mills using recycled fibre
- Specialist packaging paper mills
- Printing and writing mills including newsprint

There are a large number of smaller mills in the specialist packaging paper subsector compared to packaging paper mills using recycled fibre that are generally larger, producing 37% of all the paper products produced in the UK.

Competition in the sector is high, particularly in commoditised paper grades where margins are small. Competition is global, with UK mills competing with mills both in Europe and further afield.

Decarbonisation is not a priority in the current investment environment but two business drivers contribute to decarbonisation; the need to reduce energy costs and the cyclic investment in new equipment. The investment cycles are long, 30-60 years and 2050 is only one investment cycle away (EC, 2013). Despite decarbonisation not being a priority, most companies interviewed have decarbonisation targets for 2025.

The main enablers for decarbonisation for the pulp and paper sector are:

- Diversification of paper products
- Lower consumer prices
- Collaboration in the value chain
- Government policy
- Small incremental investments
- Senior management buy-in and formal business commitment

The main barriers to decarbonisation are:

- Competitive marketplace with lowering profit margins
- Regulatory uncertainty
- Conservative industry
- Uncertainty about return on capital
- Uncertainty regarding impact of new technology on machine operability
- Lack of awareness and information imperfections
- Lack of skilled labour
- Rising UK energy prices perceived as non-competitive
- Biomass availability
- Global competition for funding from group headquarters
- Lifetime of machinery of 30-60 years

Current low carbon prices and a required payback time of one year or less, can be seen as both enablers and barriers.

Future production for the UK pulp and paper sector is projected to grow somewhat and certain subsectors will either grow or decline: Tissue and Hygiene is likely to grow; Speciality will either grow slightly or stay the same; Printing and Writing, including Newsprint and Packaging, is expected stay the same or decline. Due to the high level of imports to the UK market, it could technically be possible for UK production to increase, even if overall UK consumption were to fall. Depending on the scenario, the overall sector is estimated to decline or grow by -0.5%, 1% and 2% for the challenging world, current trends and collaborative growth scenarios, respectively.

The energy-saving opportunities for the pulp and paper sector distilled from the literature review, interviews and workshops can be classified into five categories: across mill, fibre supply, paper machine, utilities, and Two Team Project options. The options were further grouped into existing SAT, major investment technologies, and Max Tech technologies, technologies that are related to the time and ease of implementation.

3.2 Pulp and Paper Processes

Since their conception on an industrial scale, pulp and paper technologies have improved in an evolutionary manner (Carbon Trust, 2011; Fleiter et al., 2012). An overview of the papermaking process is shown in Figure 4 (CEPI, 2014). As can be seen, either paper for recycling or wood serve as the fibre supply to the pulp production, though other fibre are used for some specialty products, such as cotton for banknotes or abaca for filtration papers. The pulp is then dewatered and dried into paper in the paper machine. Finally the paper is treated in the finishing line to have a paper of desired quality.[11] In addition to the pulp and paper production, there are also different utilities needed in the process, and technologies for delivering heat and power.

[11] For a full overview of the processes involved in making paper, please see BREF: BAT in the pulp and paper industry (EC, 2013).

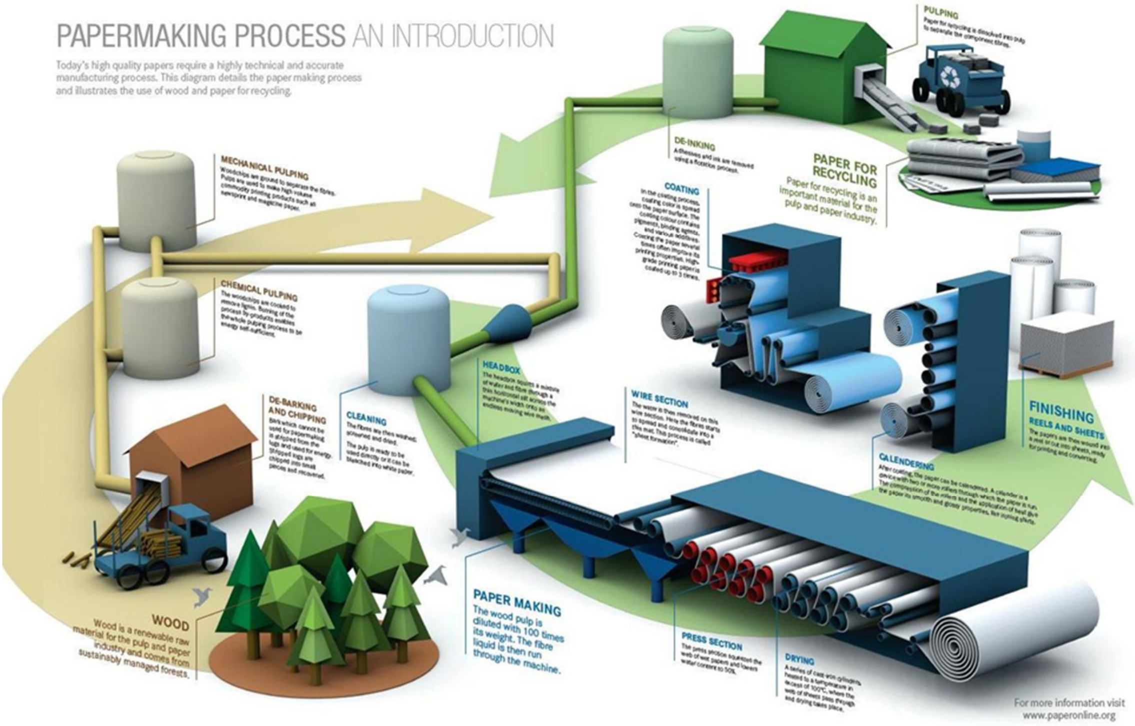

Figure 4: The papermaking process - an introduction (CEPI, 2014)

3.2.1 Fibre Supply (Pulp Production)

The pulp used to make paper is either produced from virgin fibre by chemical or mechanical means, or by re-pulping of paper for recycling. In the UK, the majority of pulp comes from paper for recycling, with a minority of the pulp used being virgin pulp. Only a few plants in the UK produce virgin pulp through mechanical refining, grinding of wood or through a chemical process. Due to the limited number of mills in the UK that produce virgin pulp, the pulping process is not included in this process description. For re-pulping, screened paper for recycling is used. To re-pulp paper, the paper for recycling is soaked in large containers where it disintegrates into fibres. For high-quality paper, the paper for recycling is also de-inked through screening, chemical addition and flotation. The pulp is then sent to stock-preparation processes where the pulp is transformed into slurry with properties suitable for entering the paper machine. It involves some or all of the following techniques: de-flaking, screening, cleaning, dispersing, dewatering, bleaching and refining (CEPI, 2014).

3.2.2 Paper Machine (Paper Production)

In the wire section – the first de-watering section of the paper machine – pulp slurry is sprayed on a flat wire screen that moves at high speed through the machine. The paper on the web is typically drained to 12-20% solids. The paper, supported on felts between rollers and through vacuum sections, is then de-watered to a dryness of around 50% solids in the press section. The next de-watering section is the drying section. Typically, the paper is passed through a series of heated cylinders, enclosed in a hood, where the paper is dried to the final dry content of 90-95% solids. Practically all heat introduced in the drying section leaves the hood as hot, wet exhaust air (typically 80-85°C and 140-160 g H_2O/kg dry air) (EC, 2013). As most energy is consumed in the drying section, more than one technology has been developed; but globally the multi-cylinder dryer is by far the most-used technology (85-90%) for paper and board. Other technologies are the Yankee dryer (4-5%, typically for tissue), infrared dryer (3-4%, coated paper), impingement dryer (2-3%, coated paper), and through dryer (1-2%, tissue) (Laurijssen and De Gram, 2010).

After the paper machine, the paper is passed through a calender. The calender consists of two or more rolls that apply pressure to the paper. The pressure results in a smoother and glossier paper and has an equalizing effect on the thickness of the paper. After the calender, the paper is rolled onto a 'jumbo' reel ready for rewinding to smaller reels and additional processing as required (CEPI, 2014).

3.2.3 Utilities

The vacuum system is an important utility in a pulp and paper mill, where the installed power of vacuum pumps can be equal to the motor power to drive the paper machine (Berkeley Lab, 2009). Using vacuum, wet paper can be de-watered to a greater degree before the energy-intensive step of drying paper. Low-vacuum is needed for forming and web de-watering, while high-vacuum is needed in the pressing section of the paper machine. Ventilation in the hall where the paper machine is installed is important, to maintain the right temperature and humidity for the paper.

For a pulp and paper mill there are only general demands (non that are specific) concerning compressed air. Hydraulics or lubrication play an important part in a paper mill, e.g. for handling the heavy paper. The biggest water flows are in the stock preparation and the first two de-watering sections of the paper machine. Water is recycled and re-used where possible.

3.2.4 Technologies for Delivering Heat and Power

The UK pulp and paper industry has a mix of technologies for delivering heat and power.

- Gas turbine CHP: gas is combusted and expanded in a turbine which provides electrical power. The gas exhaust produces steam in a heat recovery boiler that in turn provides steam to the process. A heat recovery boiler can also have a back-pressure turbine attached where the high-pressure steam goes through a turbine before being used in the process.
- Biomass CHP: Biomass is burned in a boiler to produce high pressure steam that then is passed through a steam or back-pressure turbine to generate electricity and produce the steam necessary for the process.
- Conventional CHP: a boiler produces high-pressure steam that is expanded through a steam or back pressure turbine.
- Boilers: a boiler produces the steam necessary for the process and is typically fuelled by either gas or biomass. Due to the economic constraint of installing a CHP, conventional steam boilers are still installed, especially in mills with lower steam demands.

The Pulp and Paper industry is well suited for CHP due to the ratio of its electricity and steam demand that fits the ideal operating envelope of a gas turbine.

3.3 Current Emissions and Energy Use – Principal Question 1

This section covers the findings in response to Principal Question 1: 'What are the current emissions from each sector and how is energy used?' It focuses on technologies that are currently used in the sector, the emissions associated with the activities, the heat and power demand of pulp and paper plants and the fuels that are used to deliver this energy and the lifespan of equipment and key timings for replacement or rebuild.

3.3.1 Evolution of Emissions Reduction

The pulp and paper sector has already achieved considerable CO_2 reductions. In Figure 5, the evolution of the emissions is presented. The left y-axis shows the absolute emissions and the right y-axis shows the specific emissions per tonne of paper product. As can be seen, the absolute emissions have been reduced by over 50%. Since production levels are almost at the same levels as 1990, the specific emissions have been reduced to the same degree – mainly through efficiency improvements and modernisation.

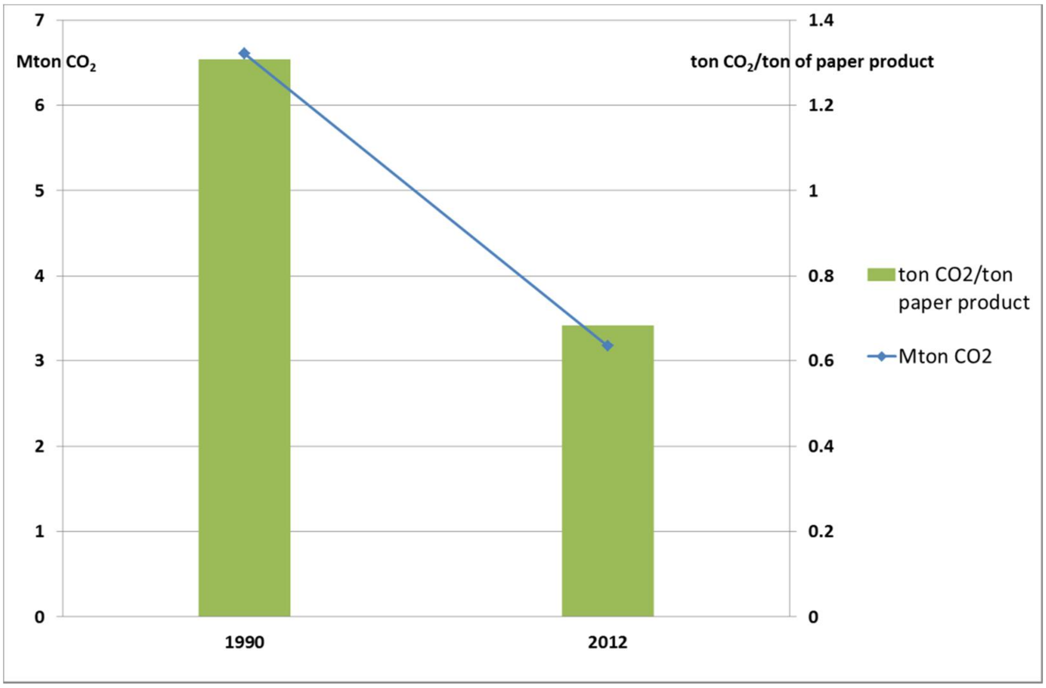

Figure 5: Evolution of CO_2 emissions for the pulp and paper sector since 1990 (CPI, 2014)

3.3.2 Emissions

Worldwide, the pulp and paper sector is responsible for 3% of the direct CO_2 emissions from industry (Carbon Trust, 2014). For the UK in 2008, the annual emission level of the pulp and paper sector was 4.1 million tonnes CO_2 for a production of 5.2 million tonnes of paper products (0.79 tonnes CO_2 per tonne paper products). In 2012, the emissions had reduced to 3.3 million tonnes CO_2 for a production of 4.6 million tonnes (0.72 tonnes CO_2 per tonne paper products). This corresponds to 9% CO_2 emissions reduction from 2008 to 2012 (Intelligent Energy Europe, 2012; CPI, 2014).

The sources of emissions are both direct and indirect. Direct emissions originate mainly from boilers producing steam that is used in the process, and gas turbines; whereas indirect emissions originate from electricity purchased from the grid. In 2012, direct emissions were 2.4 million tonnes of CO_2 and indirect were 0.9 million tonnes of CO_2. The ratio between indirect and direct emissions was 0.27 in 2008 and 0.38 in 2012 (Intelligent Energy Europe, 2012; CPI, 2014). This shows that the industry has made a significant effort to decrease direct emissions, and that carbon emissions from the electricity grid play an increasingly important role in the emissions from the pulp and paper industry.

3.3.3 Heat and Power Demand

The UK pulp and paper industry is a considerable consumer of heat, representing 7% of the total industrial heat consumption in the UK in 2012, as illustrated in Figure 6.

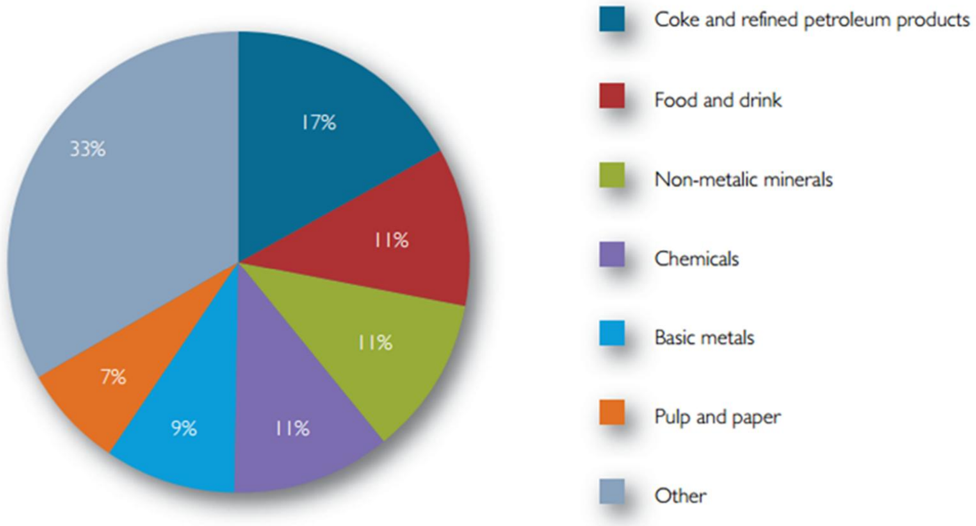

Figure 6: Industrial heat consumption UK (DECC, 2013)

The requirement for heat and power needed across a typical pulp and paper mill is shown in Figure 7. As can be seen, the paper machine uses about two-thirds of all the energy, dominated by the dryer section. The latent heat in the dryer section is currently quite difficult to reuse as it is wet exhaust air and of too low quality. The biggest proportion of the electrical power (13%) is needed to drive the paper machine, the vacuum system and the stock preparation (Carbon Trust, 2011). Heat is primarily used in the paper machine (low-pressure steam at ca. 150°C and some additional 430°C steam heat in the dryer section (Laurijssen et al., 2010)), and some low-temperature heat is used for heating, ventilation and air conditioning (HVAC). There is some direct-heat use in the press section and water system, but the majority of the heat supplied is through indirect heat (Carbon Trust, 2011). Cooling, which is mainly achieved by using cooling water, is not a large energy consumer in the pulp and paper Industry.

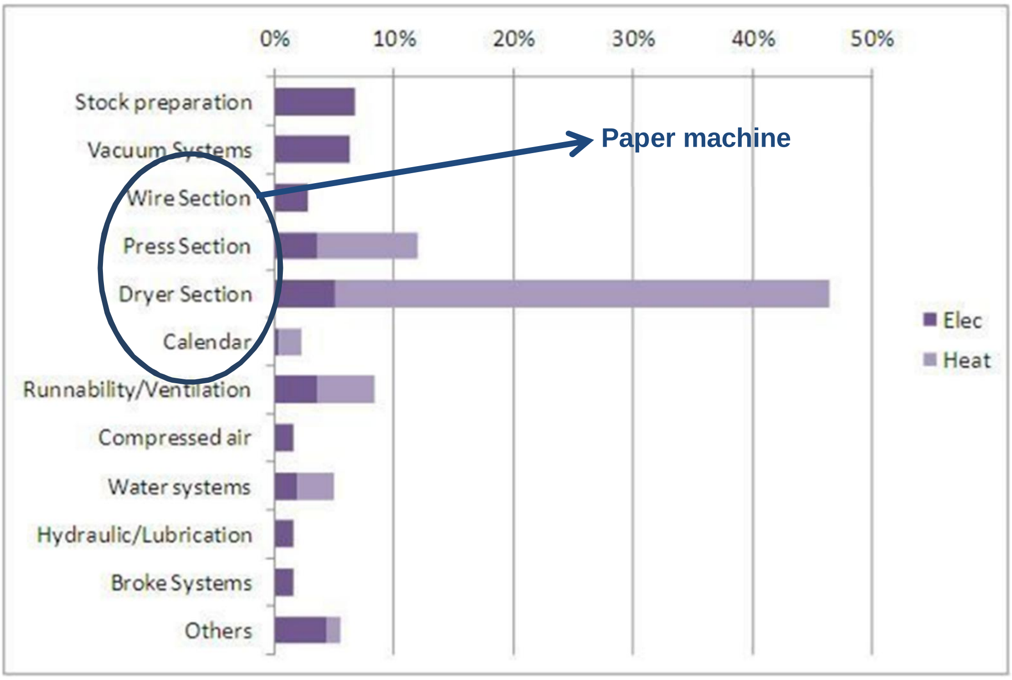

Figure 7: Carbon emissions from a typical paper mill (Carbon Trust, 2011)

Heat, power and cooling demand may change in the future due to trends in market behaviour, technological developments and regulation. Historically, there has already been a shift from heat to electricity use in the pulp and paper industry and this is likely to continue (ABP, 2008). One of the options presented in the Two Team Project (see appendix A for more information) is a 100% electricity pulp and paper production, which would result in increasing decarbonisation as the electricity grid reduces its carbon intensity.

3.3.4 Fuels Used

The 2012 fuel mix for the UK pulp and paper sector is shown in Figure 8.

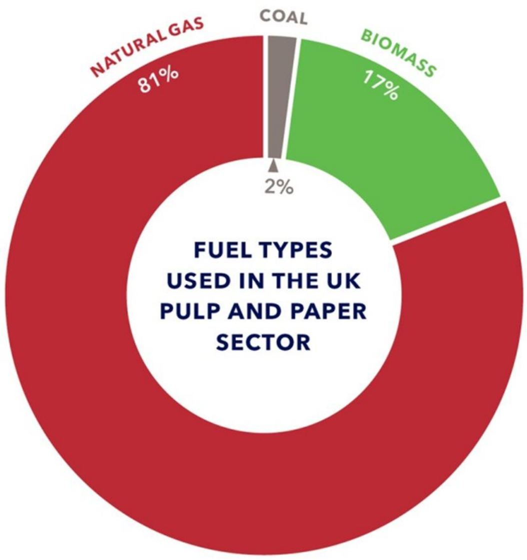

Figure 8: 2012 distribution of fuel type use in the UK pulp and paper industry (CPI, 2014)

In the UK, the total fossil fuel used in 2008 in the pulp and paper industry was 16,718 GWh (Carbon Trust, 2011), being mostly natural gas. Biomass is mostly used by four installed biomass CHP plants. Sludge from wastewater treatment plants is also used as fuel in some mills. Since 2012, the sectors use of coal has decreased to well below 1%, due to the replacement of a coal CHP by a biomass CHP. Due to its 'ideal' mix of heat and electricity demand, compared to other sectors, the industry has been a forerunner in using CHP producing 2.3 GWh in 2012 (CPI, 2014). Additional CHP power in the future may be limited, mainly due to the fact that the pulp and paper Industry is no longer growing and many mills already have CHP installed. Investment in CHP is only feasible if there is a sufficient gap between fuel price and electricity price (DECC, 2013).

3.3.5 Lifespan of Equipment and Key Timings

The lifespan of both process technology and utility equipment is typically 25 to 40 years. According to the CEPI 2050 Roadmap, the 40 years ahead comprise only two investment cycles for a capital-intensive industry, in other words "*2050 is two paper machines away*" and "*mills and machines that have just been built will still be operating by 2050 or coming to the end of their life*" (CEPI, 2011).

There are few newly built mills in the UK, although a number of mills have been making serious investments over the past years. The majority of the mills have equipment from different time periods and major items of equipment have typically been rebuilt over the lifespan of the equipment. It is not unlikely to find a paper machine built in the 1960's that has had two major rebuilds since and would be considered almost equivalent to a modern machine. As a consequence, there are no publicly available key dates for when major equipment will be replaced. For steam boilers, a lifespan of 25 to 40 years is common with refurbishment and rebuilt needed for them to last 40 years. Historically, boilers have been refurbished or rebuilt, making it difficult to compare it exactly to a boiler of a specific age. CHPs and turbines have a typical life span of 10 to 20 years (with a major refurbishment during this period). Vacuum pumps can also easily reach a lifetime of 25 years, whereas smaller utilities (compressed air, HVAC, lighting) have typical lifetimes of 10 to 15 years before replacement or major upgrade. Electrostatic precipitators in exhaust systems can last for several decades (EC, 2013).

To summarise, considering a typical investment cycle of 25 to 40 years for process and utility equipment, there are one or at most two investment cycles before 2050.

3.4 Business Environment - Principal Question 2

This section provides an assessment of the range of questions under Principal Question 2: 'For each sector, what is the business environment, what are the business strategies of companies, and how do these have an impact on decisions to invest in decarbonisation?'

3.4.1 Market Structure

The UK pulp and paper sector is declining in size. Revenues for the entire UK pulp and paper sector, including printing and converting, in 2012-2013, were £10.26 billion (4% down from 2011-2012) resulting in shrinking profit margins in the range of 3-10% (IBIS, 2013). The sector had a share of 4.8% in the CEPI paper and board production in 2012 (CEPI, 2012) and contributed 0.18% to the UK economy (IBIS, 2013). In the future, EU27 GDP growth is expected to slowly drop from 2% in 2015 to just over 1% by 2050 (CEPI, 2012). This limited growth is reflected in the long-term projected demand, which remains practically stable on 200 million tonnes for Europe. The UK's population, on the other hand, is expected to grow, according to EU27 population projections (Eurostat, 2013). This predicted population growth in the UK presents an opportunity for the sector but adds to the complexity of predicting demand for pulp and paper sector products to 2050. Currently, exports account for 26% of total production, but that figure is expected to decrease in the future (IBIS, 2013).

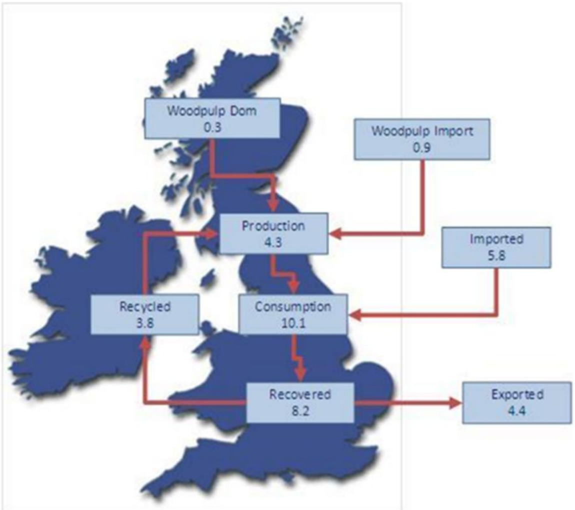

Figure 9: Mass flows for paper production and consumption (Carbon Trust, 2011)

The main sources of fibres for the papermaking process are wood chips, purchased virgin pulp, or paper for recycling. Figure 9 represents the mass flows for the UK pulp and paper industry in 2009 (in millions of tonnes). Production met 43% of domestic consumption, and 81% of domestic consumption was recovered. The fact that UK production only supplies 43% of the domestic consumption is a cause for concern as the carbon emissions for the additional paper used are not accounted for in the UK. Of the recovered paper for recycling, 46% was used in UK mills. Wood pulp is 24% of the material flow into production, and domestic wood pulp represents only 6% of the material flow into production (Carbon Trust, 2011).

The sector features a mix of globally active companies and local independent mills. There are 50 mills operating in the UK. The biggest ten mills account for 70% of the total production (CPI, 2014). The mills can be divided into five categories:

- **Specialist paper mills** producing products with different and closely specified properties in relatively small tonnages.
- **Tissue and hygiene paper mills** making tissue grades, cellulose wadding and wet wipes.
- **Packaging paper mills using recycled fibre,** large mills**,** supplying a range of products, mostly traditional corrugated boxes and cores.
- **Specialist packaging paper mills** supplying a wide variety of products, including luxury product packaging.
- **Printing and writing mills including newsprint,** producing paper for general printing, newspapers and magazines, high-grade packaging, and graphics.

Energy consumption patterns in the UK mills vary: some mills only produce ten hours per day, five days a week, whereas the majority of the pulp and paper is produced 24/7, 360 days per year (EC, 2009).

Cost structures are most heavily influenced by the ownership nature of the mill. Independent mills, by definition, are cost centres in themselves. Global groups, to which most of the major UK mills belong, arrange cost centres on business units grouped by product category, for example grouping all newsprint and magazine papers into one division. In some cases, individual paper machines are designated cost centres, providing an added level of granularity in assessing the efficiency and financial performance of each machine. Profit-improvement programmes implemented by global groups continue to alter how business groups and individual mills are accounted for within the group.

The pulp and paper market is divided among the mills as following: specialist paper, tissue and hygiene paper, packaging paper from recycled fibre, specialist packaging paper, and printing and writing including newsprint. The number of mills for each subsector is illustrated on the left-hand side of Figure 10.

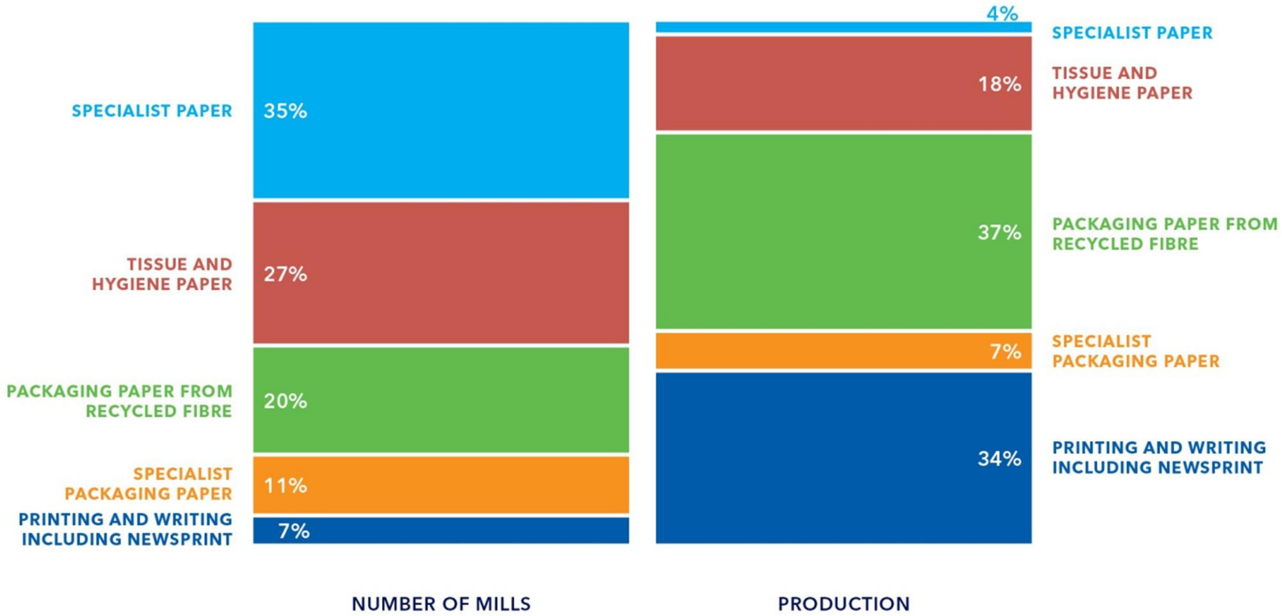

Figure 10: The UK pulp and paper sector composition in terms of number of mills and production in 2012 (CPI, 2014)

There is a big difference when comparing the number of mills to the level of production from each subsector (right-hand side of Figure 10). In general, there are many specialty paper mills that are smaller, producing low quantities of paper. There are a number of tissue and hygiene mills producing a medium quantity of paper. Then there are a small number of mills producing large quantities of packaging paper from recycled fibre and printing and writing including newsprint.

The sector is mature and capital intensive. The level of competition is high in general with slight variations depending on the end product. Overall, the shrinking profit margins have resulted in a lower level of capital investment in new technologies – currently under 2% of revenue (IBIS, 2013).The market is increasingly globalised and there is high price-sensitivity on the consumer side. The most commoditised products include newsprint and packaging. The impact of digital communications and changing consumer behaviour has had a negative impact on the demand for many of the sector products. This is confirmed by the recent announcement by UPM Kymmene of its closures of newsprint machine at the Shotton mill (UPM Kymmene, 2014) and Aylesford Newsprint entering into administration (BBC, 2015). These announcements also cause concern with regards to paper recycling as the local authority collection market for recycled paper in the UK is now considerably reduced. Total paper and board consumption in the UK across all subsectors (as in other EU countries or the USA) has been decreasing since 2000 (12.9 million tonnes) to a level of 10 million tonnes in 2012 (IBIS, 2013). Tissue and Hygiene products are the exception to the declining trend, having seen an overall growth in demand, which may continue.

The global market price for pulp and paper and raw material has impacted the sector dynamics in the past. In 2012, the total amount of recovered paper in the UK was 8.2 million tonnes, more than half of which was exported (driven by market price that can be achieved for recovered paper and a lack of domestic reprocessing capacity). In the same year, 1.1 million tonnes of wood pulp were used, of which 0.9 million tonnes were imported (CPI, 2014).

Competition in the sector is high, particularly in commoditised paper grades where margins are small. Competition is global, with UK mills competing with mills both in Europe and further afield. Currency variations impact imports and exports, as companies seek to increase market share in regions that offer the highest profitability.

3.4.2 Business Strategies

While energy efficiency for energy savings is often perceived as important to the sustainability of the company, decarbonisation is not perceived as a priority in the current investment climate, according to interviewed managers. Two significant business drivers push companies towards decarbonisation: the cyclic investment cycle of a paper mill, and reducing energy costs.

Investment cycles (typically 30-60 years) characterise the sector's investment process (Carbon Trust, 2011). Modern machines run more efficiently at higher speeds and produce higher quality paper – but at significant capital cost at the investment stage. Older machines gradually become obsolete, prompting a cyclic nature to step changes in the sector. Paper machine investments drive associated site investment, such as power equipment – which in turn deliver efficiency improvements and, in most cases, a decarbonisation benefit. Essentially, a mill must continue to invest to remain competitive; those lacking investment risk falling behind peers in the sector, become uncompetitive, and eventually close.

One interviewee, responsible for environmental issues, stated: *"Payback and ROI is key, we are driven by profitability decisions, not necessarily by a drive to reduce carbon. Energy is a significant cost to our mills, this is our commercial drive."*

Literature from Carbon Trust (2011) and DECC (2013) indicated that conservatism is prevalent in the industry, creating a business environment in which companies are only willing to invest in technologies that have already been proven to be successful. In one study (Carbon Trust, 2011) companies indicated that they would rather not be the first to implement a new technology, but look at proven technologies in other industries, or to copy competitors.

"Participants in the sector have stated that ideally they would like to be second or third to implement a technology, i.e. there is a degree of risk aversion in the sector. Given the nature of the sector with high capital intensity, high volumes and low margins, this is understandable. Technological failures would have a significant impact on business performance." (Carbon Trust, 2011)

One company stated that a first priority should be for governments, industry and society to develop a business environment with a common vision for transitioning towards a low-carbon economy. The process of developing the vision should involve sharing information and views on the importance of using a portfolio of low-carbon technologies, the costs and benefits of various technology options, and the need for infrastructure and technology changes. This shared vision will be important in helping to secure public support for low-carbon technology spending and subsidies. Governments and the private sector will need to complement this with expanded community engagement.

"We need support for demonstration projects and technology transfer projects to bring cutting edge technology into mainstream papermaking and collaborative R&D projects to bring close to market technologies into mainstream papermaking." And *"The UK sadly lacks the technical skills needed for a '21st Century Paper Industry' and most mills are now faced with succession planning issues. The demise of all paper training establishments in the UK leaves a significant vacuum to fill."* (CPI, 2014)

Decarbonisation Strategies

Before carbon-related legislation was introduced, the pulp and paper sector was already evolving towards a more carbon-neutral energy strategy, mainly through the utilisation of wood-based waste as fuel source.

The maturity of carbon-related strategies varies across the sector and most companies have corporate-level objectives and targets in place, and associated sustainability reporting. None of the current company strategies looks further than 2025 in terms of carbon reduction targets, in line with most other industrial sectors.

Of the companies interviewed for this report, three set group-level targets for reducing CO_2 emissions by 15-20% by 2020, whilst one company stated a target of 5% reduction by 2015. In all cases these are set against a 2010 baseline. One company had no target or communicated any intention to establish a target. Drawing comparisons between decarbonisation strategies is difficult, given the differences in the organisations' products, locations, age of machinery and methodology used to calculate both the baseline and reductions achieved.

What is important is how these de-carbonisation strategies influence decisions both at a group and mill level. In one senior management interview, it was stated that decarbonisation targets for the group *do* influence significant mill investment; whilst not being the sole driver for such investments, they provide a helpful 'push', alongside other business drivers that come with any significant investment.

The drivers behind these strategies are twofold – all companies are seeking reduced operating costs, which drive energy and therefore carbon emissions. The second driver, albeit weaker, is the adaptation of corporate wide sustainability strategies. These have a much wider remit than carbon, and are about much more than decarbonisation, yet the vast majority steer organisations into setting and working towards decarbonisation targets.

In all interviews conducted with individuals responsible for smaller-scale site-level investments, each showed an awareness of group-level targets and how activities at site level impact this; but the driver remains ‘energy’ (and therefore cost), and not carbon. Carbon reductions are an associated benefit and not the direct driver.

3.4.3 Decision-Making Processes

In the pulp and paper industry, a large proportion of mills operating in the UK have headquarters overseas. A challenge is how to secure investment in a pan-EU and pan-global context. It was stated that this applies to smaller-scale investments as well as new developments needed to keep plants competitive.

The mills in the UK are themselves responsible for proposing any small- to medium-sized investments to a corporate group. Large-scale significant investment decisions, such as rebuilding a paper machine or installing a new power plant, are made at the highest level, either at business- or group-level senior management. For the small- to medium-sized investments, the interviewed managers stressed that within their organisation the mills should make their own case and justify any potential investments to the group. The group then selects the projects each year that are being pursued based on other operating priorities and the overall budget available which is linked to the overall profitability of the sector. It was expressed in one of the interviews with an environmental manager that the growth projection for the UK business is lower than for businesses elsewhere, which dis-incentivises the group to invest in the UK.

One interviewee, responsible for environmental performance, said *“Mills tend to make their own case for projects, sometimes the business unit has pots of cash available for investments that the mills will compete for. We look at all potential projects globally every year, select a top ten to progress further with and consider.”*

“Security of price is the main driver. Future scenario planning assumes UK growth in sales of 3-5%, considerably higher outside of Europe. This is key, and influences a lot of decisions for where project investment will go.”

Companies also expressed that smaller investments do not need to be approved at a group level if they are mutually beneficial in areas such as maintenance, or replacement of old parts. The threshold for the investment decision to be made at group or mill level, varies greatly per organisation, and ranged between £20,000, to £100,000 and £250,000. Some mills receive an annual investment budget of around £50,000 to be used at their discretion.

3.4.4 Financing Investments

As a result of the difficult economic climate and the decline of the sector, financial capital for large capital expenditures in decarbonisation is difficult to obtain. This was reflected in the literature review (CPI, 2014) and strongly reinforced in the interviews and workshops. UK mills were said to be in a weak position to receive funding from headquarters compared to their peers abroad. This is related to the weak economic forecast of UK demand for paper and pulp products, but also the views around the UK’s regulatory uncertainty and its energy prices.

"Recent actions have reduced industrial confidence in government policy and this will take time to rectify. Companies must have confidence that policies and support will be in place for the lifetime of an investment. In this context I would identify three examples of how not to do this: (i) the damage done to CHP operation by policy changes last year, (ii) the damage caused by the unilateral Carbon Price Floor policy, and (iii) (of direct relevance to persuading energy managers to engage with this project) the cancellation of the Carbon Trust Sector efficiency programme after potential projects had been collaboratively identified and were ready to be implemented." (CPI, 2014)

Investment cycles are part of the ongoing successful operation of a paper mill to remain competitive. Although some mill groups are struggling financially, and closures in the UK demonstrate the tough economic climate in which some mills find themselves, it would be a reasonable expectation that investment in the sector will continue and opportunity exists to influence the level of this investment.

An environmental manager stated: *"Renewable incentives in the UK were strong at the time compared to Sweden. We needed to invest in the mill anyway so it made sense to put the CHP in at the same time."*

Investor confidence was stated by the sector as a prerequisite to give industry the background and confidence against which investments can be made. It was stated specifically by workshop attendees that the industry seeks overall reassurance on how the government can ensure that pulp and paper manufacturers (and other energy-intensive industries) are not driven out of the UK by policy decisions around energy and carbon.

When taking smaller-value investment decisions, i.e. up to approximately £250,000, both interviewees and from the literature agreed that one of the most important decision factors is the payback time, varying from one to four years. A one- or two-year ROI period is deemed acceptable to the industry.

The combination of the large upfront costs with relatively uncertain and long payback times, the observation that large investment costs need to be approved by headquarters, and the weak competitive position of UK mills, caused several interviewees to express that the most successful approach to achieve decarbonisation is likely to be through small, incremental changes. The level of success, in terms of securing investment from a budget held at group level, is influenced not only by the investment conditions in the UK, but by the product (i.e. the profitability, market outlook, and strategic importance to the organisation of the grade being produced) and the overall financial health of the group.

Literature (CPI, 2014) also identified 'hidden' costs as a major factor; which included, for example, overhead costs related to investments, the cost of collecting and analysing information and production disruptions. This was, however, neither confirmed nor denied during interviews.

3.4.5 Enablers and Barriers

One of the outcomes of the analysis of the sector is a list of the most prevalent enablers and barriers for decarbonisation. The enablers and barriers have been identified through a number of different research methods, namely literature review, interviews and workshops. Triangulating data has been of utmost importance. Seen below are details of the enablers and barriers that have not only been triangulated with regards to research methods, but were also selected at the workshops as the most important enablers and barriers.

Table 4 and Table 5 below indicate the enablers and barriers across literature, interviews, and workshops. Although the number of times an enabler or barrier was referenced or highlighted could provide some guidance as to the strength of sentiment towards a particular enabler or barrier, the discussions during workshops and interviews provided a greater understanding as to the detail and context behind each barrier and enabler.

- There were 37 documents reviewed in this part of the literature review. The number in the literature column below represents the prevalence in occurrence of the enabler or barrier; or in other words the number of sources that discuss it.
- There were seven semi-structured interviews in total. The number in the interview column below represents the prevalence in occurrence of the enabler or barrier; or in other words the number of interviewees that discussed it.
- The workshop column shows the prevalence in occurrence of the enabler or barrier; or in other words the number of workshop groups (five in total) that discussed it.
- The numbers on the left-hand side do not present a ranking but provide an easy point of reference to the order of analysis.

These enablers and barriers are illustrated throughout the text with supporting quotes and citations from interviews, workshops and literature. Further depth and interpretation is provided in the following paragraphs.

Enablers

#	Category	Enablers	Primary Source	Prevalence of occurrence		
				Literature	Interviews	Workshop
1	Market	Diversification of paper products	Workshop	1	2	3
2	Market	Lower consumer prices	Workshop	1	2	2
3	Market	Collaboration in the value chain	Interviews	1	2	
4	Legislation/Policy	Government policy	Interviews	1	4	2
5	Financial	Small incremental investments	Interviews		4	
6	Organisation	Senior management buy-in and formal business commitment	Interview	1	3	2

Table 4: Enablers

The first enabler –- **diversification of paper products** –- was identified by literature (CEPI, 2013) and a key discussion point both in interviews and the workshops. With some paper grades in decline, particularly magazine and newsprint in US and European markets, a number of global manufacturers are beginning to consider shifting their long-term strategy to alternative products as a response to changes in consumer habits, diversifying into recycled products, bio-products and paper-based hygiene products, all having a higher value added than commodity type paper.

In the long term, paper-based hygiene products will become more abundant and also more widely used in developing markets, while in mature markets they will remain essential for everyday life. Women are perceived by industry to become important drivers of consumption, both in emerging and mature markets, and the ageing population will also increase the demand for hygiene products. Such developments support the move towards high-tech or high value-added products and could lead to an increased profitability of the sector. This, in turn, could release more capital for other aspects such as energy efficiency and decarbonisation. The speed at which this change will happen is difficult to predict, but it is perceived by industry unlikely to happen in the short term. Companies shared that they will continue to produce commoditised paper grades, despite low profit margins and declining sales, using the capital to invest and diversify over the medium to long term. The risk to realising this enabler is that the paper industry as a whole fails to achieve or sustain higher prices for such value-added products, impacting the availability of capital to sustain investment in new technology. It is important to remember that there will always be a need for basic paper products in the UK. This enabler is relevant now, and will become increasingly important in the future.

One interviewee, responsible for environmental issues, stated: *"Our company's strategy positions it as complimenting the production of traditional fibre based products such as paper, with other value- added bio-based products in the long term. When we look at significant capital investment costs, there are often choices to be made regarding investing in products in mature or declining markets, products in growing markets, and investing in new innovative bio-based products"*

A second interviewee, a senior manager of a global company, stated: *"To get to where we need to be as an industry, we need greater technology. We are hitting a wall now, we need significant engagement. The UK is seriously missing from this conversation."*

This theme is particularly strong in the CEPI Two Team Project literature: *"New products could make a goal of creating 50% more value from the Sector's products achievable by 2050, but success would rely on significant breakthrough technologies being realised by 2030."*

The second enabler – **lower consumer prices** – was identified by literature (CSE and ECI, 2012) and confirmed in a lengthy debate during the workshops and in the interviews. Cost savings through lower energy consumption will lead to lower consumer prices and thus a higher demand. As the pulp and paper sector is energy-intensive, there is significant benefit in decreasing energy consumption in order to save costs. In the long run, any significant decrease in costs could be an enabler for not only a specific mill to remain in business, but for the growth and increased competitiveness of the sector as a whole. This is believed by industry to result in lower consumer prices which could lead to higher demand and again improved competitiveness of the sector. However, the industry historically has not demonstrated the ability to pass on energy costs to the consumer, largely due to the highly competitive nature of the sector. Prices are maintained to protect market share, particularly in the more commoditised paper grades such as newsprint and magazine papers. This is mostly a future enabler.

"The common and well-established driver in sectors such as the pulp and paper sector for driving lower energy use is cost." (CSE and ECI, 2012)

One interviewee, responsible for environmental issues, said: *"Shotton Mill gives a good example. Built in 1985, it produced virgin fibre pulp. The driver for investment was reducing the energy bill which used to equal the consumption of the city of Manchester. The foresight was in reducing energy requirements of the core process to secure the mill's future, initially converted to recycled fibre which reduced energy consumption by 60-70%. Then they looked at CHP for further reductions. Today, Shotton is not just a newsprint mill, it is a waste management, renewable power operation."*

However, one workshop attendee, representing the sector, conversely stated: *"We operate in a market of high competition with low ability to pass through costs of energy or investment to consumers. Customers are not interested in energy costs, we have to absorb it."*

The third enabler – **collaboration in the value chain** – was identified by literature (IEA, 2012) and confirmed in two interviews as a potential enabler that, if the sector can realise, will bring wide-reaching benefits. The pulp and paper supply chain is complex, with many interrelated specialist functions that do not fall into the boundaries of one single organisation, yet each has the opportunity to influence the performance of the other. Collaboration in the value chain includes closed-loop recycling and collaborating with machine suppliers. Collaboratively refining existing technologies and developing new technologies, will be able to catalyse decarbonisation. Waste streams for example offer the opportunity for further development: waste sludge provides raw material for other industry sectors, e.g. light-weight aggregates and road surfacing. This type of opportunity supports the overall need for greater consideration for collaboration across the sector and cross-industry, as well as with suppliers. This enabler is relevant now and will become increasingly important in the future.

One interviewed manager responsible for environmental issues stated: *"We only sell internally, because this is where the collaborative B2B relationships are, selling directly to retailers for example. We are always looking for ways to collaborate, find solutions for our customers and increase sales."*

Another senior manager stated: *"There are opportunities in how we obtain recycled content. Non-segregated recycling is problematic and costly; in other countries they are much better at sorting waste at source."*

"This reveals that the common driver in sectors such as the pulp and paper sector for driving lower energy use is cost". (IEA, 2012)

The fourth enabler – **government policy** – was identified by literature and confirmed both by interviews and discussions at workshops. Government policy can encourage companies to decarbonise, e.g. by removing barriers to entry, exit, and growth of new firms that are important for the low-carbon energy technology development, or by developing a common vision together with the industry to secure public support for spending and subsidies. Major UK investment in CHP has been enabled in the past through government policy. Two examples cited in interviews reference support from EU and Welsh Assembly funding, and Renewable Obligation Certificates as heavily influencing investment. Due to regulatory uncertainty, however, government policy could also become a barrier; this is addressed in the enabler/barrier 'current low-carbon prices and regulatory uncertainty' below.

The fifth enabler – **small incremental investments** – was identified during several of the interviews. This enabler applies to the implementation of incremental energy efficiency investments which can be applied at the mill level, rather than investment decisions being made at Head Office level. The level of budget for larger energy efficiency improvements depends on the budget available from the Head Office of the organisation, which is further discussed as the barrier 'global competition for funding from Group headquarters'. In general, the available budget is related to the overall profitability of the organisation, particularly in the case of more significant capital investments. Competition with other projects globally will only apply above a certain level of capital spend. There is a greater chance of implementation if the business case for investment can be linked to other operational benefits. This enabler applies now but the implementation of energy efficiency programmes may decrease in the future as the 'low-hanging fruit' has already been implemented.

One interviewee, a senior manager from a global organisation, stated: *"The industry can't save the world, we can't afford to have the most advanced technology tomorrow, it must be incremental to be commercially viable."*

The sixth enabler – **senior management buy-in and formal business commitment** – was identified by literature (CSE and ECI, 2012) and confirmed both by interviews and workshops. As with many industrial sectors we see today, senior management buy-in and formal business commitment, plus increasing willingness of top management to make climate change a priority, is an enabler for the level of support and prioritisation that a company's carbon strategy has compared to other aspects of the business strategy. This can create a cascade effect through the mill. Safety is an issue often cited by the sector as a success story: with senior management input in the sector in the 1990s, the European pulp and paper sector had improved its safety performance.

The maturity of business strategy varies across the sector and most companies have corporate-level objectives and targets in place, and an associated sustainability reporting process. Where the contribution of each mill is linked to the corporate target achievement and data collection as part of the overall sustainability, the reporting process may contribute towards this enabler. This focus is helpful, as it aligns those within the company to the importance of decarbonisation and provides the underlying business case for energy reductions. This enabler is applicable now.

One interviewee, responsible for environmental issues, stated: *"Currently we have carbon targets to 2020 and these are quoted publicly in our Annual Report. Management then passes these group targets down to unit level, which each unit expected to contribute."*

A second interviewee, responsible for energy stated: *"The closer an energy manager is to the CEO in the corporate hierarchy, the more likely the energy management activity will take place".*

Barriers

#	Category	Barriers	Primary Source	Prevalence of occurrence		
				Literature	Interviews	Workshop
1	Market	Competitive marketplace with lower profit margins	Workshop	2	2	3
2	Legislation/Policy	Regulatory uncertainty	Workshop		2	3
3	Organisation	Conservative industry	Workshop	2	1	2
4	Market	Uncertainty about return on capital	Interviews	1	5	5
5	Operations	Uncertainty regarding impact of new technology on machine operability	Literature	1		1
6	Organisation	Lack of awareness and information imperfections	Literature	3	2	1
7	Organisation	Lack of skilled labour	Workshops	2	1	1
8	Financial	Rising UK energy prices perceived as non-competitive	Interviews	1	4	
9	Market	Biomass availability	Interviews	1	2	
10	Financial	Global competition for funding from group headquarters	Workshop	1	3	4
11	Technology	Lifetime of machinery of 30-60 years	Workshop	1		3

Table 5: Barriers

The first barrier –- **competitive marketplace with lower profit margins** –- was identified in the literature (Thollander and Ottosson, 2007; Haydock and Napp, 2013) and had been confirmed both by interviews and workshops. This barrier is also linked to declining demand and over-capacity in certain subsectors. Caused by both the difficult economic climate and the decline in parts of the UK sector, it is difficult to obtain financial capital for large capital expenditures to finance decarbonisation in the pulp and paper sector. The competitive marketplace with lowering profit margins hampers any investments that are not critical from a production or operational perspective. In addition, according to many managers from the sector, the long-term future of mills might be uncertain which hampers investments even further. The competitive nature of the sector, coupled with the perceived lack of government assistance and the nature of long-term contracts between paper manufacturers and their most significant customers, makes the sector unattractive to new entrants.

One interviewee, responsible for energy management, stated: *"It's very difficult to talk about the UK in isolation. There is a 30-60 year life cycle for a paper machine, so for global groups they must consider where they place their mills. The danger for the UK would be that the UK is not competitive."*

"*Another barrier which may prohibit investments in energy efficiency technologies, even if the investment is cost-effective, is lack of access to capital.*" (Thollander and Ottosson, 2007)

The second barrier – **regulatory uncertainty** – was identified in several interviews and in both workshops. It makes it difficult for companies to take large investment decisions. Examples that were discussed during interviews include the changed support for CHP, and the cancellation of the Carbon Trust sector efficiency programme after the potential projects had been collaboratively identified and had been ready to be implemented. As mentioned before, government policy could also be an enabler for decarbonisation and will be discussed below in the enabler/barrier current low-carbon prices and regulatory uncertainty. This is a barrier now and is likely to continue to be a barrier in the future.

The third barrier – **conservative industry** – was identified in the literature and was confirmed both from interviews and the workshop. The pulp and paper industry prefers to use proven technologies that have been deployed before, and has a general resistance to changes. There is limited capacity for 'downtime' due to the tight margins and operating constraints of the mills linked to the low profitability of the sector. This is a barrier now and in the future as information is required on new technologies.

The fourth barrier – **uncertainty about return on capital** – was identified in the literature and was confirmed both from interviews and the workshops. This uncertainty deters companies from investing in the most energy-efficient technology. A more certain payback period would be an enabler, which is further discussed in the enabler/barrier 'payback time of one year or less' below.

The fifth barrier –- **uncertainty regarding impact of new technology on machine operability** –- was identified by literature (Haydock and Napp, 2013) and confirmed during the workshop. The potential impact of any changes in operations on machine operability, and any impact on production and quality, is perceived by industry as a barrier to decarbonisation that requires changes to machinery.

"The sector is under severe pressure on margins, so even if energy efficiency or fuel switching measures would reduce fuel costs, they may still not be taken up if they are accompanied by increases in maintenance costs for the equipment installed." And *"The 40 years ahead comprise only two investment cycles for a capital intensive industry, in other words, 2050 is two paper machines away."* And *'Mills and machines that have just been built will still be operating by 2050 or coming to the end of their life"* (Haydock and Napp, 2013)

The sixth barrier – **lack of awareness and information imperfections** – was identified from the literature (Thollander and Ottosson, 2007; Fleiter, 2012; DECC, 2013) and was confirmed both by the interviews and workshops, as a factor that could potentially lead to lower levels of investment in low-carbon technologies. The need for greater knowledge-sharing and R&D collaboration among countries to accelerate technology advancement along the curve from demonstration to commercialisation was also a theme mentioned during the interviews by some of the large manufacturers. A possible first step could be for the government, industry and the stakeholder community to develop a common vision at a sector level for the transition to low-carbon energy. The process of developing the vision could involve sharing information and views on the importance of using a portfolio of low-carbon technologies, the costs and benefits of various technology options, and the need for infrastructure and technology change. This shared vision is perceived as important in helping to secure public support for low-carbon technology spending and subsidies. The governments and the private sector will need to complement this with expanded community engagement. The risk to the pulp and paper sector is that it is not seen as 'sustainable' or 'high-tech' in the eyes of consumers, so will require more proactive engagement to drive public support to the sector. This is a barrier now and in the future as information is required on new technologies.

A senior manager for a global organisation stated: "*It's a cut-throat market and people are less willing to share, there is survival instinct that will always limit what can be shared.*"

A second interviewee, responsible for environmental issues, stated: *"A first priority should be for governments, industry and civil society to develop a common vision for the transition to low-carbon energy. The process of developing the vision should involve sharing information and views on the importance of using a portfolio of low-carbon technologies, the costs and benefits of various technology options, and the need for infrastructure and technology change."*

A third interviewee, representing the sector, stated: "*With mills being spread through the UK there is no cluster to support academic/supply chain or R&D support." And "Suppliers would help us to calculate potential energy savings, we have no specific procedure to check their claims but we listen to their technical advice. Potentially an area we need to improve, so that we understand more about what their equipment will achieve."*

"*Information on the technical solutions to decarbonise and the costs and technology readiness (for example on industrial CCS) is imperfect among industry players.*" (DECC, 2013)

The seventh barrier – **lack of skilled labour** – was identified in the literature (IEA, 2012; DECC, 2013) and was confirmed both by the interviews and workshops. A shortage of technically competent staff and a lack of funding for training prevent any further advancement of the sector. The general lack of industry-specific academic R&D in the UK follows the closure of undergraduate courses in pulp and paper technology at the University of Manchester, which closed to new entrants in 2001. For longer-term opportunities, it was perceived as extremely difficult to bring a share of the R&D back to the UK. There is also limited participation from UK mills in international R&D activities. The closure of the Paper Science Department at the University of Manchester will have other impacts, including reducing the availability of technically competent specialists into the sector. This is a particular barrier now, as the workforce in the sector is ageing, without sufficient succession planning in place, particularly in technical roles.

One interviewee, representing the sector, stated: *"We have little industry specific academic R&D in the UK following the closure of the UMIST facility."*

"The transition to low-carbon industrial heat will require specialised, highly skilled and experienced heat focused engineers. These skills are not readily available in the industry." (DECC, 2013)

"….the development of academic curricula and training of experts, including geologists to facilitate CO_2 storage, nuclear power technicians, and people with expertise in renewable energy and smart grids. There is also a need to adapt existing vocational and higher education institutions to develop the energy skills that will be needed." (IEA, 2012)

The eighth barrier – **rising UK energy prices perceived as non-competitive** – was identified in the literature (IEA, 2014; ICF International, 2012) and the opinion of those interviewed. Rising UK energy prices make it more attractive for paper companies to invest in energy-efficient technologies and for mills to justify any investments (and could therefore also be seen as an enabler), but high costs in the UK as a result of uncompetitive energy prices compared to key EU and global markets can also reduce investments. This is particularly a barrier for mills that form part of multinational organisations, where each site effectively competes against the others to secure long-term investment, which is heavily impacted by current and forecasted energy prices locally for each mill. The perception is that this further promotes a difficult economic climate and the decline of the sector, making it difficult to obtain financial capital for large capital expenditures to finance decarbonisation. It was stated specifically that the industry seeks overall reassurance on how the Government can ensure that paper manufacturers (and other energy-intensive industries) are not driven out of the UK by policy decisions or pricing around energy and carbon. In this discussion it is important to make the distinction between energy costs into these of electricity and fuel. It is true that for large energy-intensive industries, the UK has among the highest electricity prices in Europe and in the mid-range compared to G7 countries; a growing proportion of that cost is linked to climate change policy (ICF International, 2012). On the other hand, natural gas prices are amongst the lowest in Europe and are also low compared to G7 countries (DECC 2014). This is a barrier now and in the future.

"The cost of fuel is a big disadvantage for the UK." And *"Europe energy costs are growing, raising taxes on energy is affecting our competiveness."* (IEA, 2014)

The UK 2014 Budget reads: *"While UK electricity prices are currently close to the International Energy Agency (IEA) average, a typical energy-intensive industry in Britain currently pays almost 50% more for their electricity than they do in France, and the cost to businesses of policies to deliver new low-carbon energy infrastructure is set to increase by around 300% by 2020. This Budget announces a package of reforms to radically reduce the costs of energy policy for business, particularly in manufacturing."*

The ninth barrier – **biomass availability** – was identified in the literature (Haydock and Napp, 2013) and was confirmed by the interviews, but there was much discussion during the workshops on the potential impact of biomass and whether this is a future enabler rather than a barrier.

Biomass is potentially an alternative fuel for the pulp and paper industry. Feedstock availability could, however, be a significant challenge, since power generation, other industrial sectors, and domestic heating uses will be competing for the same, limited, resource. Although very much dependent on local market factors, the advantage of the pulp and paper sector is that the majority of sites are well linked, both geographically and through their supply chain to biomass sources, such as wood-based sources like saw mill waste and forest residues. The government position on biomass has changed in recent years and remains an area of uncertainty, a view expressed particularly in the workshop discussions. The issue is complex as the accountability of carbon emissions, how these are classified, and the definition of 'sustainable' biomass are still debated.

One interviewee, an energy manager, stated: ***"**A big area of opportunity must be through CHP and biomass, which offer a good opportunity to deliver target reductions over the next few years. However, there is clear potential for biomass demand to outstrip supply."*

"Barriers for biomass technology are feedstock availability (competition with industry and biofuels for feedstock, and with food and fibre production for arable land)." (Haydock and Napp, 2013)

The tenth barrier – **global competition for funding from group headquarters** – was identified in the literature (Thollander and Ottosson, 2007; Haydock and Napp, 2013) and was confirmed both by interviews and workshops. Funding for large capital expenditures, for most organisations, is obtained from the Group headquarters and especially for the pulp and paper industry as it is particularly global. There was a perception expressed by manufacturers that the UK mills may be in a weak position compared to their peers abroad because the UK is less competitive due to higher energy prices. Considering that UK natural gas prices are amongst the lowest in Europe, and below the median compared to other G7[12] countries, this perception could be either linked to electricity prices, where the UK has among the highest prices in Europe, or compared to developing countries, which in general have lower energy prices. Investor confidence was stated as a pre-requisite to give industry the background and confidence against which decarbonisation and energy efficiency related investments can be made. It was stated specifically that the industry seeks overall reassurance on how the government can ensure that pulp and paper manufacturers (and other energy-intensive industries) are not driven out of the UK by policy decisions around energy and carbon. Large upfront costs for pulp and paper mill related technologies were identified in the literature to be a significant disincentive to investment. To make these large investments, interviewed managers emphasised that UK mills are often competing for investment budget from groups overseas. Several factors were mentioned that influence decisions to invest in UK-based mills rather than mills overseas. It was expressed that, in the case of global mill groups with sites outside of Europe and the US, the growth projection in Europe (including UK) is lower than for businesses elsewhere, which could dis-incentivise the group to invest in the UK. This is a barrier now and in the future.

One interviewee, responsible for environmental issues, stated: *"Main considerations are ROI (needs to be less than four years) and projective gas/electricity prices."*

A second interviewee, responsible for energy management, stated: *"Cost is a barrier. At group level we need to consider all mills globally and their individual situation."*

A third interviewed environmental manager stated*: "We consider availability of resources, then list all projects that are suitable for investment and decide across the group. Rejected projects would remain in the queue until resources are available again."*

[12] The Group of 7 (G7) is a group consisting of the finance ministers and the central bank governors of seven major advanced economies as reported by the International Monetary Fund. The group includes Canada, France, Germany, Italy, Japan, the UK and the US.

The eleventh barrier – **lifetime of machinery of 30-60 years** – was identified in the literature (EC, 2011) and was confirmed during the workshops. This lifetime implies that there will only be one or, at most, two investment cycles to 2050 and limited opportunities for improvement. There are few newly built mills in the UK. The majority of the mills have equipment from different time periods and most of the equipment has been modernised at different times as well. As a consequence there are no publicly available key dates for when major equipment will be replaced; for major equipment, modernisation is more likely than replacement. This is a barrier now and in the future.

"The 40 years ahead comprise only two investment cycles for a capital intensive industry, in other words, 2050 is two paper machines away." And *"Mills and machines that have just been built will still be operating by 2050, or coming to the end of their life."* (CEPI, 2011)

As already briefly mentioned above, there are a number of areas that are regarded as both potential enablers and barriers.

Enablers/Barriers

The first enabler/barrier – **current low carbon prices and regulatory uncertainty** – was the view of interviewees and workshops with industry representatives. Government policy can encourage companies to decarbonise, but regulatory uncertainty remains a barrier, and the current low-carbon prices annul the incentive for companies to invest in low-carbon technologies. Uncertainty from the government on climate change policies was identified during the workshop as a hurdle for gaining capital for investments. This was reinforced during the interviews. For example, the uncertain UK position on renewable subsidies has caused one of the companies to cancel a large-scale decarbonisation project, which involved using locally sourced waste and wood as energy sources. They described that the case had significant buy-in from stakeholders, including environmental groups, local residents and local authorities. However, the uncertain UK position led external financers and, eventually, the company itself to cease the project.

A positive response from one interviewee, responsible for energy issues, stated: *"Renewable incentives in the UK were strong in 2011-12 compared to Sweden. We needed to invest in the mill anyway so it made sense to put the CHP in, so the UK got the investment. Security was key to our decision. One option of course was to stick with using gas and not invest at all."*

A more negative response from another interviewee, responsible for environmental issues, stated: *"There were many positive signs to our biomass project, e.g. wood availability. Technologically it would also be feasible. It became problematic with the government's policy with regards to renewables. The feed-in-tariff has changed at the last moment. It was just very uncertain. The company now suddenly needed a ten year contract to agree to purchase electricity or steam. The fact that government's policy was not fixed, made us pull out."*

A third interviewee, managing environmental issues, stated: *"Europe energy costs are growing. Raising taxes on energy is affecting our competiveness. Banning nuclear power in Germany is having an effect and we see the effect. We have energy costs 2-4 times higher than the US, so this affects the baseline cost of our operations."*

The second enabler/barrier – **payback time of one year or less** – was identified in the literature (Haydock and Napp, 2013) and was confirmed by both interviews and workshops. If the payback time for an energy efficiency and decarbonisation investment is one year or less, it makes it more likely for mills to receive funding from Headquarters. Haydock and nap, interviewed managers and workshop groups all agreed that one of the most important decision factors when making investments is the payback time. The maximum length before it causes a significant hurdle differed across information sources ranging from 12 months identified in literature, up to four years for other organisations, as mentioned during interviews. This is a barrier now.

"Increasing competition driven by imports and overcapacity has reduced the margins available to the manufacturers and has limited capital availability. This has led to a reluctance to undertake investment with a payback of more than 12 months." (Haydock and Napp, 2013)

3.5 Technologies to Reduce Carbon Emissions

The options distilled from the literature review, interviews, evidence gathering workshop, discussions with trade associations and input from academia are presented in appendix C (the data for these options are also listed). The energy saving and decarbonisation opportunities are classified into five categories:

- Across-mill options include energy monitoring and management, improved process control, waste-heat recovery and heat integration, maintenance, industrial clustering, heat networking, and lighting.
- Fibre supply options include de-inked pulp (DIP) and recycled fibres, screening, dispersers, sludge dryer, and improved quality of recycled paper.
- Paper machine options (a division is made into general savings, wet-end and dryer) include SAT steam and condensate systems, differential pressures for condensate evacuation, steam box, shoe press, improved dewatering, hot pressing, high-consistency forming, dry-sheet forming, impulse drying, infrared profiling, dew point set point, heat recovery on hoods, and closed hoods.
- Utilities options include vacuum systems, compressed air, pumps and motor systems, water system, and steam system.
- Two Team Project options (as proposed by the CEPI Team) include flash condensing with steam, superheated steam drying, dry pulp for cure-formed paper, supercritical CO_2, 100% electricity, functional surfaces, toolbox, and deep eutectic solvents.

These categories where then grouped in different groups reflecting their ease and timeliness of implementation:

- Existing SAT with wide deployment include existing and proven technologies, immediate deployment aligned with equipment replacement.
- Major investment technologies include proven technologies already implemented in some mills (but not all), proven technologies that are not yet widely accepted in industry (only a few UK demonstration projects), and some novel technologies.
- Two Team technologies only include 100% electricity from CEPI's project.

Biomass is an option that could have a big decarbonisation impact on the sector. The processes in a mill do not require energy supplied at a higher temperature than can be provided by steam. Today, on average, two-thirds of the energy used in a mill is steam and the rest is electricity. If the fuel used to produce the steam is replaced by a low carbon fuel, two-thirds of the carbon emissions could be reduced. Today, 17% of the fuel used in the sector is provided by biomass (CPI, 2014).

An interesting concept for the pulp and paper sector is the bio-refinery. A bio-refinery is a facility that integrates biomass conversion processes and equipment to produce fuels, power, and chemicals from biomass. The bio-refinery concept is analogous to today's petroleum refineries, which produce multiple fuels and products from petroleum (NREL, 2012). A bio-refinery could be integrated into a kraft pulp and paper mill, using the waste biomass that is produced in the process and produce pulp and paper, fuels, power and chemicals rendering the bio-refinery carbon negative. This is not considered a technical option in the modelling as there are no kraft pulp and paper mills in the UK today, but is considered in the conclusions.

3.5.1 Biomass Carbon Intensity

As well as providing the major raw material for production, the pulp and paper industry increasingly uses biomass to provide energy. This energy biomass is either a waste stream from production processes or purchased biomass (either waste or non-waste), often from closely associated forests or commercial waste streams. In 2012, 17% of the fuel used was biomass and due to the opening of new biomass-fired CHP in 2013 the biomass proportion of the fuel increased to 23% in 2013 (CPI, 2014).

Pathways including biomass (including residue fuels, sawmill dust, wood chips and pellets) reflect a biomass carbon intensity in this analysis unless the biomass in the pathway is assumed to be waste biomass (such as sludge or bark, or purchased waste biomass, such as timber waste). The carbon intensities (below) are applied to two scenarios to help reflect and bound the uncertainties around biomass carbon availability: these are (i) unlimited availability (as deployed in the Max Tech pathway) or (ii) no availability.

In all cases, combustion emissions are assumed to be zero (in line with EU Renewable Energy Directive methodology), on the basis that all biomass used is from renewable sources and thus additional carbon dioxide is removed from the atmosphere equivalent to that emitted on combustion. This means that all biomass is assumed to be sourced from material that meets published sustainability criteria.

Given the wide variation in pre-combustion emissions, a carbon intensity (based on pre-combustion emissions) derived from a low scenario from the DECC-commissioned Bio-Energy Emissions and Counterfactual Model report (2014). An emission value of 20 kg CO_{2e}/MWh_{th} has been used for solid biomass use.

Considering the increasing use of biomass in the UK, there is likely to be increased competition for waste biomass in the future. To estimate any future emissions from biomass, we are making the assumption that the amount of waste biomass available is constant and will not increase over time. As the base year is 2012, we've estimated the amount of waste biomass used in the sector for that year and this represents 53% of the biomass used in the sector. This includes both waste biomass used in CHP plants as well as waste biomass used for steam production only.

Since use of biomass in CHP increased in 2013, we already know the amount of biomass used in 2013 by the sector, including the proportion that is considered waste. So instead of fixing the amount of waste biomass in 2012, we are using the absolute amount of waste biomass used by the sector in 2013. This represents 48% of the biomass used in the sector.

When testing the sensitivity for future use of biomass, the assumption made is that any additional biomass used by the sector from 2013 and onwards will not be sourced from a waste biomass stream.

3.5.2 Costs

Limited information related to the capital cost of technologies was identified in this project as summarised in Appendix C. In gathering capital cost-related data, literature and/or engagement with stakeholders – together with expert judgement - were used to establish an initial order of magnitude dataset for use in the cost analysis assessment. The degree of stakeholder engagement in relation to the cost dataset was lower than for the decarbonisation pathways. To validate and complete the cost information, the investment costs were shared with stakeholders at the first workshop. After the workshop, CPI has broadly validated the range of investment cost data with their members. The cost data for each technical option is listed together with their technical details in appendix C. Results of cost analysis are provided in the pathways section of the report (section 4).

Operating costs such as energy use changes, energy costs and labour are not included in this analysis, although we recognise that operating costs will have a major impact on the decarbonisation pathways. For example some options (e.g. carbon capture and electrification of firing) will greatly increase energy use and costs of a process plant.

Costs analysis was carried out for the pathways, which is presented in section 4.6. There is a large degree of uncertainty attached to the cost analysis, especially for options which are still in the research and development stage. As well as costs of operation and energy use – other significant costs not included in the analysis are research, development, demonstration, civil works, modifications to plant and costs to other stakeholders, which are significant for many options. Great care must be taken in how these costs are interpreted.

The pathways described in Section 4 focus on the technical feasibility of emissions reduction from energy-efficiency and decarbonisation technologies; however, the modelling does not take into account the impact of the costs of these technologies.

Understanding the costs of the decarbonisation options is crucial as costs determine the viability of the business case that can be made for deploying them and therefore, what would actually be deployed.

4. PATHWAYS

4.1 Key Points

The pathways development and analysis shows that the maximum decarbonisation potential of the sector for the current trends scenario is a reduction to 0.06 Mt of CO_2 emitted in 2050 in the Max Tech 2 pathway, which corresponds to a reduction in emissions of 98% compared with emissions in 2012. Significant reductions of 86% and 97% could be achieved under challenging world and collaborative growth scenarios respectively. The reductions could be achieved through a range of options, the most significant being:

- The decarbonisation of heat by supplying heat with biomass (assuming a carbon emission factor for biomass of zero)
- The electricity currently produced by gas CHP being replaced by biomass CHP, delivering a significant percentage of low-carbon electricity

In addition, the decarbonisation of the electricity grid contributes greatly to the decarbonisation of the sector.

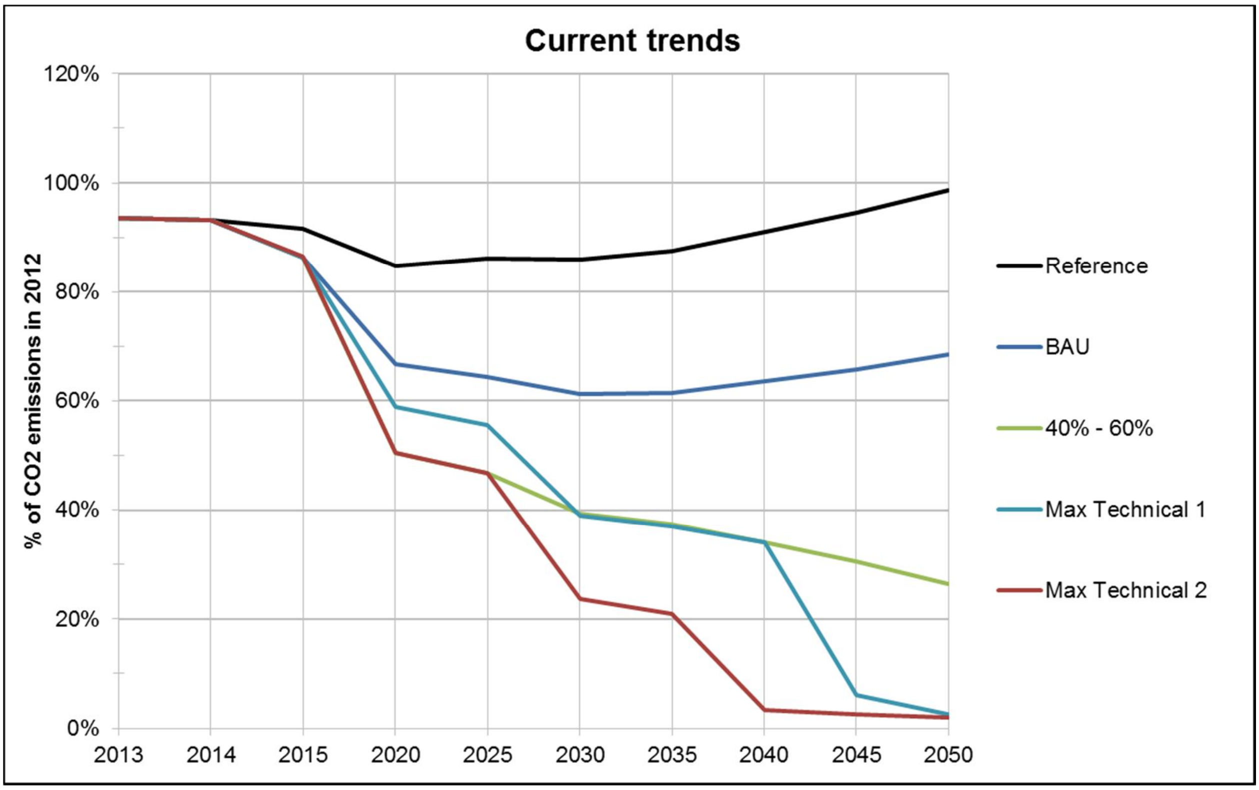

Figure 11: Performance of pathways for the current trends scenario

Figure 11 shows the wide range of decarbonisation and energy efficiency pathways that are possible for the current trends scenario.

- Business as usual represents a pathway where existing trends in energy efficiency and decarbonisation continue and current SAT are deployed starting in 2015 with most of them deployed to 100% by 2030.

- 40-60% CO_2 reduction pathway includes maximal deployment of all SAT equipment and some more advanced equipment requiring significant investment, referred to as 'major investment technologies'. In addition, biomass CHP is deployed to 25% of the sector.
- Max Tech 1 pathway includes all SAT and major investment technologies. In addition, the sector switches some heat use to electricity use and uses carbon-neutral steam provided through a heat network.
- Max Tech 2 pathway includes all SAT and major investment technologies and the replacement of fossil fuels with biomass-based CHP.

4.2 Pathways and Scenarios – Introduction and Guide

The pathways development uses evidence gathered, as set out in section 3, to create a set of decarbonisation pathways, which provide a quantitative component to the roadmap and help inform the strategic conclusions.

A pathway consists of decarbonisation options deployed over time from 2015 to 2050, as well as a reference emissions trend. The analysis covers three 'scenarios', with pathways developed under a central trend ('current trends' scenario) and alternative future outlooks ('challenging world' and 'collaborative growth' scenarios).

A scenario is a specific set of conditions that could directly or indirectly affect the ability of the sector to decarbonise. Examples of these are: future decarbonisation of the grid, future growth of the sector, future energy costs, and future cost of carbon. Since we do not know what the future will look like, using scenarios is a way to test the robustness of the different pathways. A detailed description of these scenarios is provided in appendix A.

The three scenarios were developed covering a range of parameters. They characterise possible versions of the future by describing assumptions relating to international consensus; international economic context; resource availability and prices; international agreements on climate change; general technical innovation; attitude of end consumers to sustainability and energy efficiency; collaboration between sectors and organisations; and demographics (world outlook). These scenarios were used during the workshop to help decide on deployment rate for the different options.

Quantitative parameters were also part of the scenarios, including production outlook (agreed sector-specific view) and grid CO_2 factors (DECC supplied) which both impact decarbonisation (assuming production and carbon emissions have a linear directly proportional relationship). Other quantitative parameters within the scenarios governed forward price forecasts and technology deployment.

The purpose of the model that underpins this pathways analysis is to bring together the data captured from various sources and to broadly reflect, using a simple 'top down' approach, how emissions might develop to 2050. The model is therefore capable of indicating magnitudes of emission savings that can be achieved, when various technology options are applied, and also how different deployment timings and high-level economic outlooks for a sector might change the results. A sector model was used to create pathways based on reference emissions and energy consumption in 2012. The model is not intended to give exact results and is not of sufficient detail to account for all mass, energy or carbon flows, losses and interactions in a sector (i.e. it is not 'bottom up' and does not use automatic optimisation techniques).

The methodology is summarised in Figure 12.

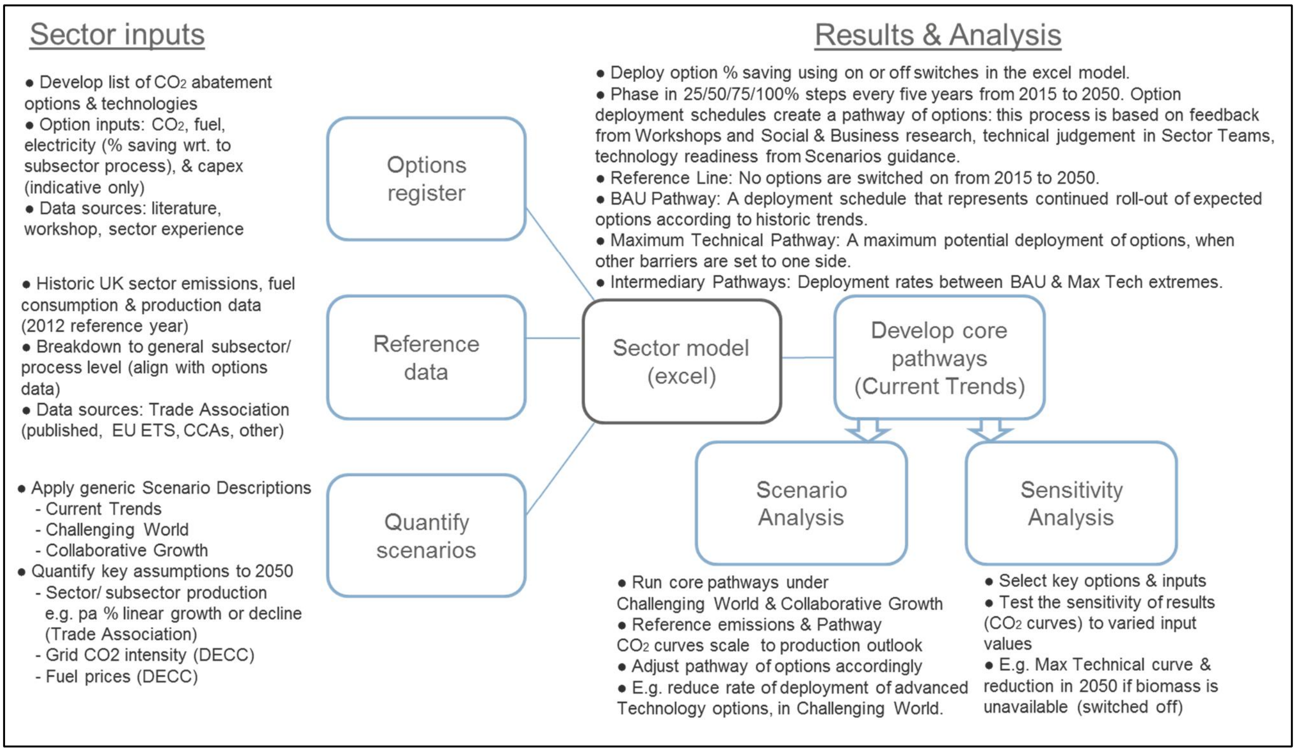

Figure 12: Summary of analysis methodology

This section of the report is structured to present the pathways in the current trends scenario (section 4.4), whilst also briefly describing how the pathways change when modelled under other scenarios. Table 6 illustrates this structure and acts as a guide to the section. Appendix D summarises the pathway analysis in the other two scenarios (challenging world and collaborative growth).

Pathway	Current Trends Scenario	Challenging World Scenario	Collaborative Growth Scenario
Reference Emissions Trend	*Scenario assumptions only linked to production outlook and grid decarbonisation No options deployed in the model*		
BAU	Builds on the reference line by deploying options from 2015 to 2050 in the model, to construct a BAU pathway. Run model under current trends.	Builds on BAU pathway current trends by adjusting option selections and deployment schedule, to reflect the scenario assumptions and technology constraints. Run model under challenging world.	Adjust BAU pathway current trends, i.e. option selections and deployment schedule, to reflect scenario assumptions and technology constraints. Run model under collaborative growth.
20-40% [13]	Builds on BAU for example by: deploying more advanced options, extending further across sector, deploying options earlier. Run under current trends.	Builds on 20-40% pathway current trends in the same way. Run under challenging world.	Adjust 20-40% pathway current trends in the same way. Run under collaborative growth.
40-60%	Builds on 20-40% in the same way. Run under current trends.	Builds on 20-40% pathway current trends in the same way. Run under challenging world.	Adjust 20-40% pathway current trends in the same way. Run under collaborative growth.
60-80%	Builds on 40-60% in the same way. Run model under current trends.	Builds on 40-60% pathway current trends in the same way. Run under challenging world	Adjust 40-60% pathway current trends in the same way. Run under collaborative growth.
Max Tech	Configure a schedule of options from 2015 to 2050 that broadly represents a maximum rate and spread across the sector. Run model under current trends.	Adjust Max Tech pathway current trends in the same way. Run under challenging world.	Adjust Max Tech pathway current trends in the same way. Run under collaborative growth.

Table 6: Pathways and scenarios matrix

Section 4.5 presents results from the sensitivity analysis, which aims to demonstrate the impact of key options and sensitivity of the pathways to critical inputs. Section 4.6 presents the analysis of pathway costs. Section 4.7 summarises the barriers and enablers to the options and pathways developed in the modelling, taking account of information gathered from literature and stakeholders.

4.3 Baseline evolution - Principal Question 3

This section provides assessment of the range of questions under Principle Question 3: 'How might the baseline level of energy and emissions in the sectors change over the period to 2050?'

[13] Intermediary pathways may or may not be developed for a sector, depending on the carbon reductions of the BAU and Max Tech pathways.

In the CEPI roadmap (CEPI, 2011), no growth is projected for the pulp and paper industry in Europe, but states that certain subsectors will either grow or decline.

As the UK pulp and paper sector is small compared to other countries in Europe, and the UK does import a large amount of its paper use, there is a potential to grow the sector. In addition, the population in the UK is expected to grow at a much faster rate than the rest of Europe (Eurostat, 2013), which would increase the market size for paper products.

When looking at the different subsectors in the UK, the following future scenarios are likely:

- **Tissue and hygiene**: This sector will likely grow, both due to population increase and an ageing population.
- **Printing and writing including newsprint**: There is still a considerable use of printing and writing paper but consumption continues to decline. There have been some recent investments in UK mills and the industry is moving towards more specialty papers rather than generic grades. Due to recent closures, there is no generic-grade production in the UK. Newsprint has probably been affected the most by the move from printed media to online. This decline is likely to continue especially considering UPM Kymmene's recent closure of one of its paper machines at the Sutton mill (UPM Kymmene, 2014) and Aylesford Newsprint being placed into administration.
- **Packaging**: This sector follows the overall economy very closely since it is used to package other products. There is a trend to move towards thinner and lighter grades, leading to an overall decline in tonnes produced but not necessarily a decline in economic performance.
- **Speciality**: This sector is very diverse and spread throughout the country. Due to this, it is very difficult to generalise. Part of the sector is performing well and, with a move towards a bio-based economy, it is likely that these specialty applications will continue and grow.

The pulp and paper industry is based on a renewable resource and there is more and more interest to base future products on sustainable resources such as wood fibre. There are a number of pilot projects around the world but none of them located in the UK. Attracting such investment to the UK would likely lead to growth of such bio-based products.

Based on the above assumptions and together with CPI, we have developed the following growth estimates for the different future scenarios affecting UK production:

- Current trends – 1% annual growth
- Challenging world – 0.5% annual decline
- Collaborative growth – 2% annual growth

4.4 Emissions Reduction Potential and Pathway Analysis – Principal Question 4 and 5

This section provides an assessment of the range of questions under Principal Question 4 and 5:

- What is the potential to reduce emissions in these sectors beyond the baseline over the period to 2050?
- What emissions pathways might each sector follow over the period to 2050, under different scenarios?

For a detailed description of the pathways development and analysis, please see appendix A.

The list of enablers and barriers has informed the list of technical options that are being deployed in the different pathways. They also informed the deployment of the different technical options both with regards to time and degree of deployment. For example the enabler 'small incremental investments', led to a faster deployment of current SAT that had a low or low-medium investment requirement.

In addition to the growth or decline projections for the different scenarios the following electricity grid emission factors were used in the modelling:

- Current trends: 100g CO_2 per kWh by 2030 and 26g CO_2 per kWh in 2050
- Challenging world: 200g CO_2 per kWh by 2030 and 150g CO_2 per kWh by 2050
- Collaborative growth: 50g CO_2 per kWh by 2030 and 25g CO_2 per kWh by 2050

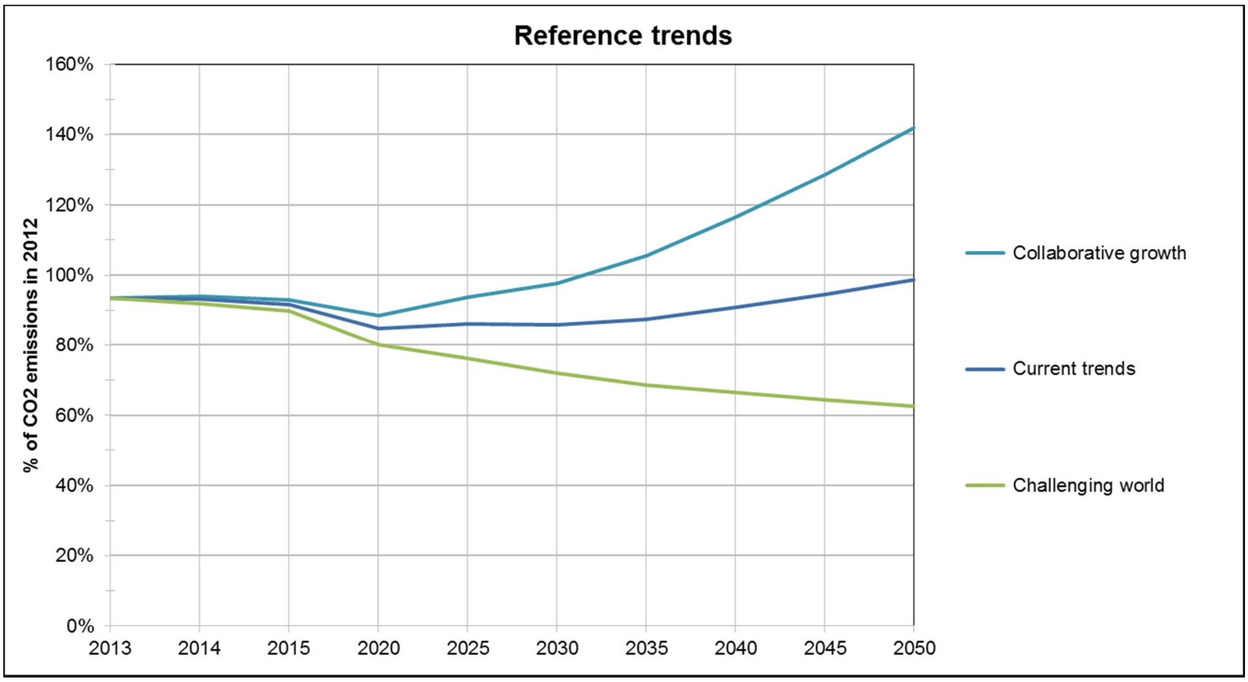

Figure 13: Reference trends for the different scenarios

For all of the pathways, to have the total CO_2 reduction, growth or decline of the sector, indirect (emissions from using electricity from the electricity grid) and direct emissions need to be accounted for. The indirect emissions and growth/decline of the sector is illustrated by the reference trends. In Figure 13 the reference trends for the different scenarios are shown. The shape of the line is linked both to growth or decline of the sector and the different levels of decarbonisation of the electricity grid.

4.4.1 Business as Usual Pathway

Pathway Summary

The guiding principle for the BAU pathway was to outline a set of decarbonisation and energy savings options that would be expected if current rates of efficiency improvement in the UK pulp and paper industry continued, and no significant intervention or outside support was provided to decarbonise the sector by 2050. Options requiring no policy intervention (compared to today) and only minor changes within the sector were chosen.

Deployment for the Current Trends Scenario

Figure 14 shows the option deployment for the BAU pathway under the current trends scenario. This figure shows the different technical options on the left, followed by estimated adoption rate (ADOP.) in 2012, followed by the applicability rate. The applicability rate (APP.) indicates to what level this option is applicable to the sector. To the right of the applicability rate is the modelled deployment of the option over time to 2050. The CO_2 reductions are calculated by the model based on the adoption rate, applicability rate and deployment.

In the BAU pathway under current trends, current SAT were the only technologies deployed starting in 2015 with most of them deployed to 100% by 2030. This deployment was confirmed during the second workshop and by CPI's members. In practice, the deployment in a mill would be linked to its investment cycle.

Pathway: Business as Usual   Scenario: Current Trends (CT)

OPTION	ADOP.	APP.	DEPLOYMENT 2014	2015	2020	2025	2030	2035	2040	2045	2050
DIRECT											
Across Mill - General											
01 Energy management including installing meters for steam, electricity, air and gas to allow for online energy balances	76%	100%	0%	25%	100%	100%	100%	100%	100%	100%	100%
02 Improved process control across the entire mill (process & utilities)	42%	100%	0%	25%	50%	75%	100%	100%	100%	100%	100%
03 (waste) heat recovery and heat integration	64%	100%	0%	25%	75%	100%	100%	100%	100%	100%	100%
04 organic Rankine cycles, heat pumps and similar heat recovery technology	8%	80%	0%	0%	0%	0%	0%	0%	0%	0%	0%
05 Focus on maintenance	75%	100%	0%	25%	100%	100%	100%	100%	100%	100%	100%
06 Industrial clustering and heat networking	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Paper Machine - General											
08 State-of-the-art steam system: includes condensate system with stationary siphons and spoiler bars, with optimized differential pressures for condensate evacuation	76%	99%	0%	25%	50%	75%	100%	100%	100%	100%	100%
09 Use flash steam from condensate	35%	70%	0%	25%	100%	100%	100%	100%	100%	100%	100%
Paper Machine - Wet End											
10 steam box to increase sheet temperature and dryness	58%	80%	0%	25%	100%	100%	100%	100%	100%	100%	100%
11 Extended Nip Press: Tissue	0%	60%	0%	0%	100%	100%	100%	100%	100%	100%	100%
12 Extended Nip Press: Non-Tissue	39%	100%	0%	0%	100%	100%	100%	100%	100%	100%	100%
13 Improved dewatering in press section beyond extended Nip Press	0%	60%	0%	0%	0%	0%	0%	0%	0%	0%	0%
14 Hot pressing	1%	50%	0%	0%	0%	0%	0%	0%	0%	0%	0%
15 High consistency forming	15%	50%	0%	0%	0%	0%	0%	0%	0%	0%	0%
17 Impulse drying	0%	50%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Paper Machine - Dryer											
18 Infrared profiling	9%	50%	0%	0%	0%	0%	0%	0%	0%	0%	0%
19 Increase dew point in hood from 55°C to 70°C	63%	98%	0%	25%	100%	100%	100%	100%	100%	100%	100%
20 Heat recovery on hoods present	88%	98%	0%	25%	100%	100%	100%	100%	100%	100%	100%
21 Heat recovery on hoods future	0%	98%	0%	0%	0%	0%	0%	0%	0%	0%	0%
22 Closed hood (fuel)	86%	98%	0%	75%	100%	100%	100%	100%	100%	100%	100%
Utilities - Water											
23 Install anaerobic waste water treatment plant	7%	33%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Utilities - Steam System											
25 Biomass based CHP/boiler	16%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
27 Gasification of biomass for use in gas turbine	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
28 Oxygen trim control to adjust burner inlet air	70%	100%	0%	25%	75%	100%	100%	100%	100%	100%	100%
29 Economisers on steam boilers	78%	100%	0%	25%	100%	100%	100%	100%	100%	100%	100%
Two Teams											
30 Flash Condensing with Steam	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
31 Superheated steam drying	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
32 Drypulp for cureformed paper	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
33 Supercritical CO2	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
34 Functional surface	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
35 Toolbox	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
36 Deep Eutectic Solvents	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
37 100% electricity (heat saving)	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
INDIRECT											
Across Mill - General											
38 Replace lighting with high efficiency lighting	23%	100%	0%	75%	75%	75%	75%	75%	75%	75%	75%
Pulp - Pulp Production											
39 High consistency pulping	76%	100%	0%	25%	100%	100%	100%	100%	100%	100%	100%
40 Efficient screening	83%	100%	0%	25%	100%	100%	100%	100%	100%	100%	100%
41 Sludge dryer	12%	25%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Utilities - Pumps and Motors											
42 Match pumping capacity to duty, avoid oversizing pumps & motors, avoid throttling, use VSD and efficient motors where possible	80%	85%	0%	25%	100%	100%	100%	100%	100%	100%	100%
43 Use fans or blowers for low vacuum applications	17%	50%	0%	0%	50%	50%	75%	75%	100%	100%	100%
Utilities - Steam System											
44 Optimize steam turbine control	66%	100%	0%	0%	100%	100%	100%	100%	100%	100%	100%
Utilities -Compressed Air											
46 Review of system pressure, leak detection etc.	92%	100%	0%	25%	100%	100%	100%	100%	100%	100%	100%
47 Switch from compressed air to electric drives for activators	1%	50%	0%	0%	0%	25%	25%	50%	50%	75%	75%
Paper Machine - Wet End											
48 Only use necessary agitation (turn off agitators, slow down agitators, zone agitation where appropriate)	71%	100%	0%	25%	100%	100%	100%	100%	100%	100%	100%
Paper Machine - Dryer											
49 Closed hood (elec)	86%	98%	0%	75%	100%	100%	100%	100%	100%	100%	100%
Two Teams											
50 100% electricity (elec increase)	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Figure 14: Option deployment for the BAU pathway

In this pathway, the principal options that contribute to the emissions reduction in 2050 are (Figure 15):

- **Improved process control**, reaching 100% of potential in 2030, accounts for 20% of the total emissions reduction from deployment of options in 2050.
- **Extended nip press - non-tissue**, deployed to 100% in 2020, accounts for 12% of the total emissions reduction from deployment of options in 2050.
- **(Waste) heat recovery and heat integration**, deployed to 25% in 2015, 75% in 2020 and 100% in 2025, accounts for 9% of the total emissions reduction from deployment of options in 2050.
- **Energy management,** deployed to 25% in 2015 and 100% in 2020, accounts for 8% of the total emissions reduction from deployment of options in 2050.
- **Focus on maintenance**, deployed to 25% in 2015 and 100% in 2020, accounts for 6% of the total emissions reduction from deployment of options in 2050.
- **SAT steam system**, deployed in 25% increments increasing to 100% of potential in 2030, accounts for 6% of the total emissions reduction from deployment of options in 2050.

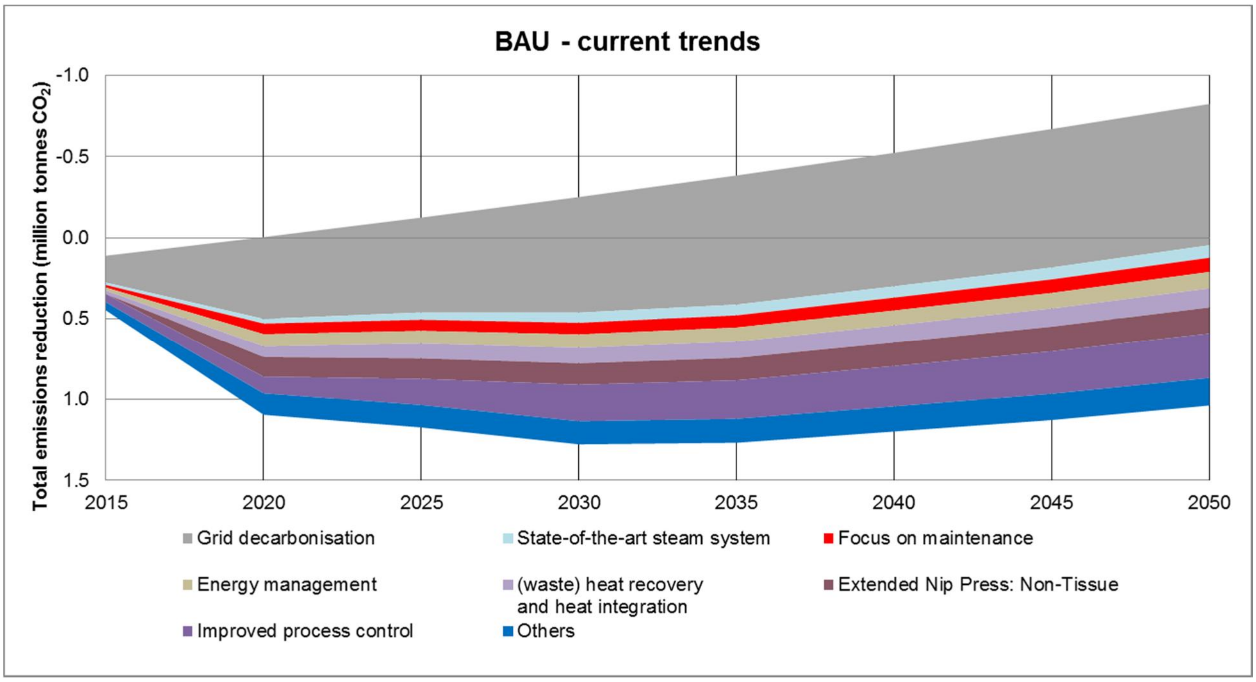

Figure 15: Contribution of principal options to the absolute emissions reduction throughout study period, for the BAU pathway, current trends scenario

For the current trends scenario, this pathway gives an overall reduction of 32% in 2050, compared to 2012. This includes the emissions reductions linked to the deployment of options and decarbonisation of the grid as well as the emissions increase linked to the growth of the sector.

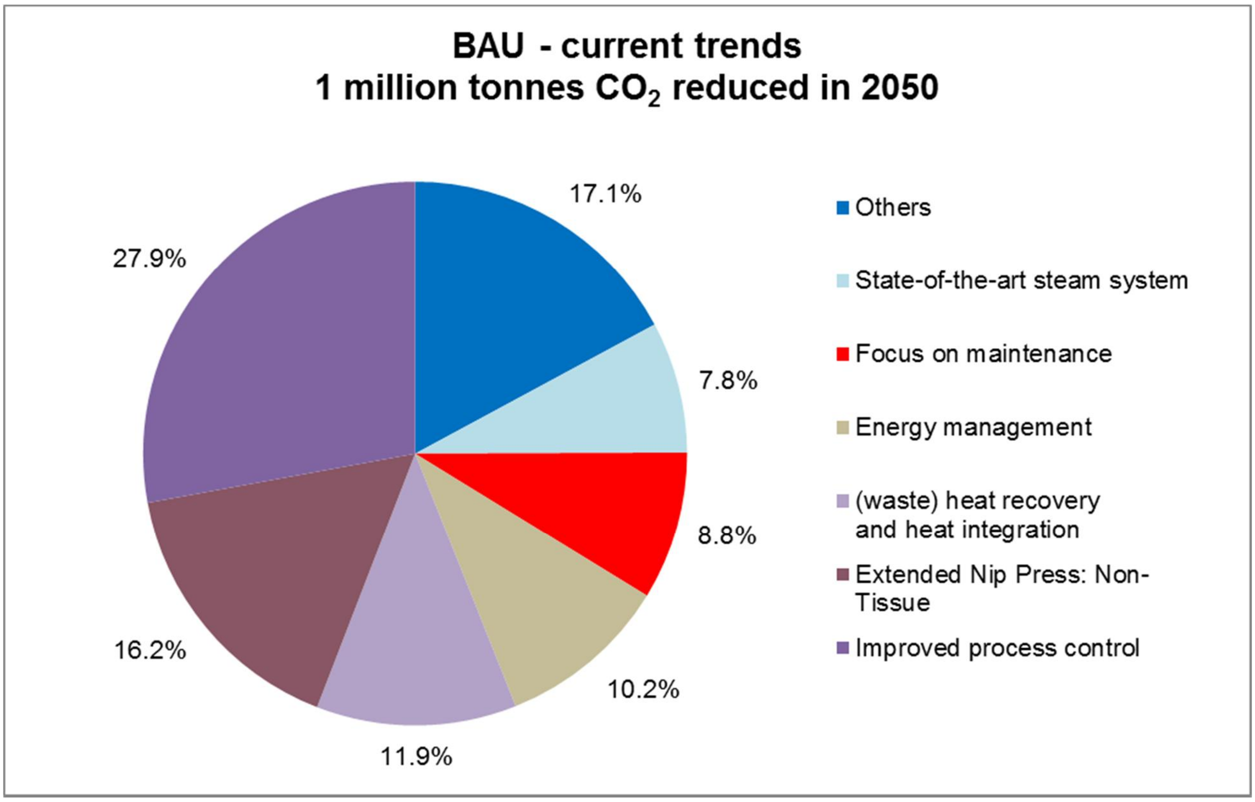

Figure 16: Breakdown of 2050 emissions reduction, for the BAU pathway, current trends scenario

The CO_2 reductions contribution in 2050 revealed that the biggest carbon savings in BAU came from a few key options[14] (Figure 16): improved process control across the entire mill (process and utilities); extended nip press; (waste) heat recovery and heat integration; and energy management including installing meters for steam, electricity, air and gas to allow for online energy balances.

Figure 17 shows the contribution of the low and low-medium cost options to the emissions reduction in 2050. As can be seen, the low and low-medium cost options contribute to 46% of the total emissions reduction in 2050.

[14] Grid decarbonisation is not considered to be an option, but a variable in the different scenarios, and is therefore not shown in the pie charts of emissions reductions.

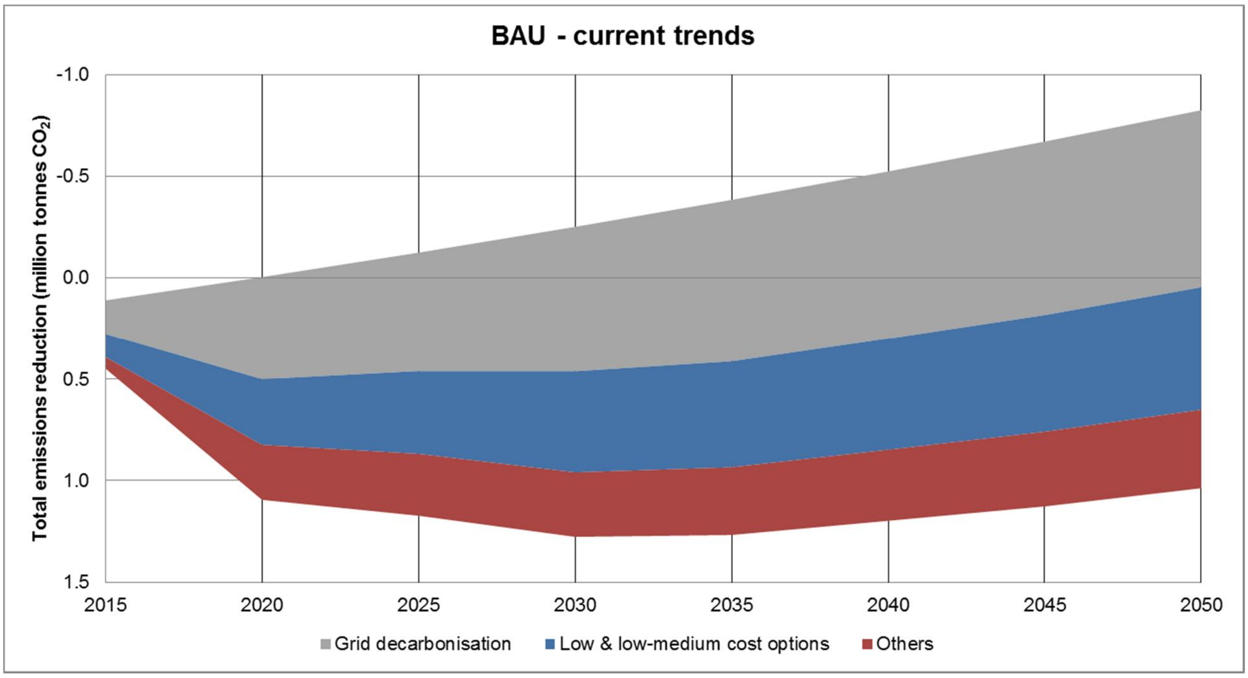

Figure 17: Contribution of low and low-medium cost options to the absolute emissions reduction throughout study period, for the BAU pathway, current trends scenario

Option Deployment for Other Scenarios

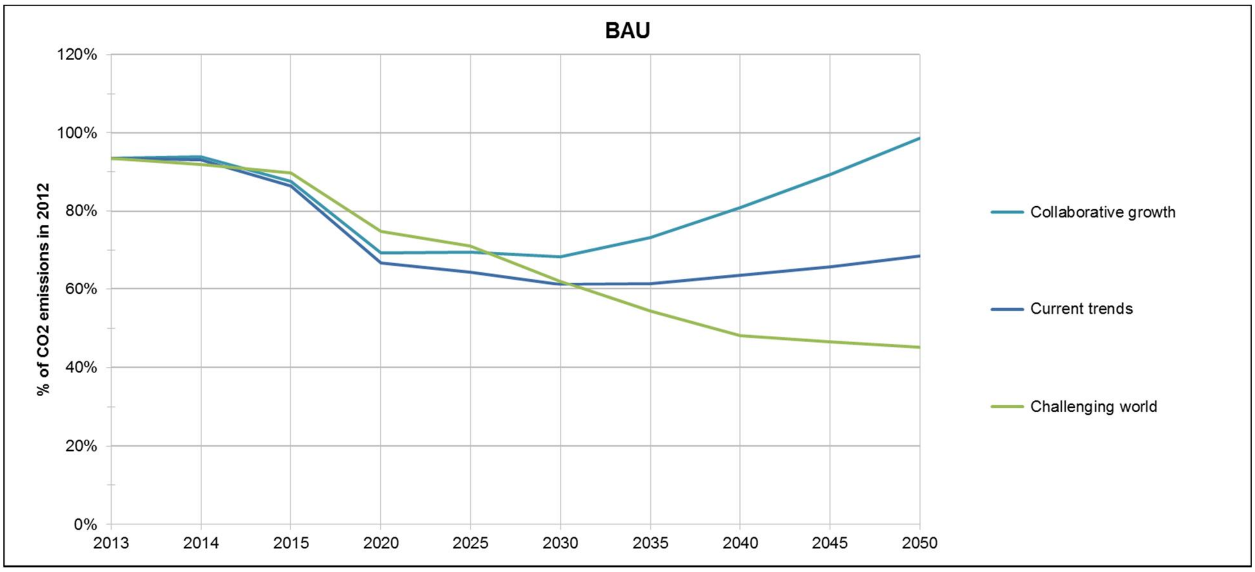

Figure 18: BAU pathways for the different scenarios

Figure 18 shows the BAU pathways for the different scenarios. As can be seen the current trends scenario delivers an overall CO_2 reduction of 34%, the challenging world scenario delivers an overall CO_2 reduction of 56% and the collaborative growth scenario delivers an overall increase in CO_2 of 5%.

For the challenging world scenario, all options included under the current trends scenario were deployed at a slower rate assuming that the challenging economic development reduces the rate at which the options will be deployed. The options reach full deployment between 2040 and 2050.

For the collaborative growth scenario, all options included under the current trends scenario were deployed at the same rate as in the current trends scenario. Because there is an increase in production, the pathway delivers an increase in CO_2 emissions.

Detailed information on the modelled deployment of options for the challenging world and collaborative growth scenario is shown in appendix D.

4.4.2 20-40% CO_2 Reduction Pathway

Pathway Summary

As the BAU pathway achieves a CO_2 reduction of over 20% in the current trends and challenging world scenario, it is only necessary to develop a 20%-40% CO_2 reduction pathway for the collaborative growth scenario. Under this scenario, it was assumed that the investment would happen at a faster rate, still only using technology available today. All SAT and major investment technologies were deployed to different levels in order to reach a CO_2 reduction of over 20%. The CO_2 reduction for this pathway was 18% in 2050 compared to 2012.

The deployment of options for the collaborative growth scenarios for this pathway is shown in appendix D.

4.4.3 40-60% CO_2 Reduction Pathway

Pathway Summary

The 40-60% CO_2 reduction pathway includes maximum deployment of all State-of-the-Art and Major Investment Technologies. In addition, biomass CHP is deployed to 25% of the sector potential in order to reach a CO_2 reduction of over 40%.

Biomass was chosen as it is a technology that is available today and already deployed at several mills.

Deployment for the Current Trends Scenario

Figure 19 shows the option deployment for the 40-60% CO_2 reduction pathway for the current trends scenario.

SAT have been deployed in the same way as in the BAU pathway, starting in 2015 with most of them deployed to 100% by 2030.

Major investment technologies are assumed to begin deployment in 2020 and to be largely deployed by 2050. Some sites may not implement some higher cost options or options that may be disruptive to the operation of the plant, so the deployment of these technologies has been assumed to only reach 75%.

Options such as extended nip press and heat recovery on hoods are ‘undeployed’ over time as they are being replaced by more advanced technologies.

Biomass CHP is assumed to be applied to 25% of the Sector by 2050.

Pathway: 40% - 60%   Scenario: Current Trends (CT)

OPTION	ADOP.	APP.	2014	2015	2020	2025	2030	2035	2040	2045	2050
DIRECT											
Across Mill - General											
01 Energy management including installing meters for steam, electricity, air and gas to allow for online energy balances	76%	100%	0%	25%	100%	100%	100%	100%	100%	100%	100%
02 Improved process control across the entire mill (process & utilities)	42%	100%	0%	25%	50%	75%	100%	100%	100%	100%	100%
03 (waste) heat recovery and heat integration	64%	100%	0%	25%	75%	100%	100%	100%	100%	100%	100%
04 organic Rankine cycles, heat pumps and similar heat recovery technology	8%	80%	0%	0%	25%	50%	50%	75%	100%	100%	100%
05 Focus on maintenance	75%	100%	0%	25%	100%	100%	100%	100%	100%	100%	100%
06 Industrial clustering and heat networking	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Paper Machine - General											
08 State-of-the-art steam system: includes condensate system with stationary siphons and spoiler bars, with optimized differential pressures for condensate evacuation	76%	99%	0%	25%	50%	75%	100%	100%	100%	100%	100%
09 Use flash steam from condensate	35%	70%	0%	25%	100%	100%	100%	100%	100%	100%	100%
Paper Machine - Wet End											
10 steam box to increase sheet temperature and dryness	58%	80%	0%	25%	100%	100%	100%	100%	100%	100%	100%
11 Extended Nip Press: Tissue	0%	60%	0%	0%	100%	75%	50%	50%	25%	0%	0%
12 Extended Nip Press: Non-Tissue	39%	100%	0%	0%	100%	75%	50%	50%	25%	0%	0%
13 Improved dewatering in press section beyond extended Nip Press	0%	60%	0%	0%	0%	25%	50%	50%	75%	100%	100%
14 Hot pressing	1%	50%	0%	0%	50%	50%	75%	75%	100%	100%	100%
15 High consistency forming	15%	50%	0%	0%	50%	50%	75%	75%	100%	100%	100%
17 Impulse drying	0%	50%	0%	0%	0%	25%	25%	50%	50%	75%	100%
Paper Machine - Dryer											
18 Infrared profiling	9%	50%	0%	0%	0%	0%	0%	0%	0%	0%	0%
19 Increase dew point in hood from 55°C to 70°C	63%	98%	0%	25%	100%	100%	100%	100%	100%	100%	100%
20 Heat recovery on hoods present	88%	98%	0%	25%	100%	100%	75%	75%	50%	25%	0%
21 Heat recovery on hoods future	0%	98%	0%	0%	0%	0%	25%	25%	50%	75%	100%
22 Closed hood (fuel)	86%	98%	0%	75%	100%	100%	100%	100%	100%	100%	100%
Utilities - Water											
23 Install anaerobic waste water treatment plant	7%	33%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Utilities - Steam System											
25 Biomass based CHP/boiler	16%	100%	0%	0%	25%	25%	25%	25%	25%	25%	25%
27 Gasification of biomass for use in gas turbine	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
28 Oxygen trim control to adjust burner inlet air	70%	100%	0%	25%	75%	100%	100%	100%	100%	100%	100%
29 Economisers on steam boilers	78%	100%	0%	25%	100%	100%	100%	100%	100%	100%	100%
Two Teams											
30 Flash Condensing with Steam	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
31 Superheated steam drying	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
32 Drypulp for cureformed paper	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
33 Supercritical CO2	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
34 Functional surface	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
35 Toolbox	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
36 Deep Eutectic Solvents	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
37 100% electricity (heat saving)	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
INDIRECT											
Across Mill - General											
38 Replace lighting with high efficiency lighting	23%	100%	0%	75%	75%	75%	75%	75%	75%	75%	75%
Pulp - Pulp Production											
39 High consistency pulping	76%	100%	0%	25%	100%	100%	100%	100%	100%	100%	100%
40 Efficient screening	83%	100%	0%	25%	100%	100%	100%	100%	100%	100%	100%
41 Sludge dryer	12%	25%	0%	0%	0%	0%	0%	75%	75%	75%	75%
Utilities - Pumps and Motors											
42 Match pumping capacity to duty, avoid oversizing pumps & motors, avoid throttling, use VSD and efficient motors where possible	80%	85%	0%	25%	100%	100%	100%	100%	100%	100%	100%
43 Use fans or blowers for low vacuum applications	17%	50%	0%	0%	50%	50%	75%	75%	100%	100%	100%
Utilities - Steam System											
44 Optimize steam turbine control	66%	100%	0%	0%	100%	100%	100%	100%	100%	100%	100%
Utilities -Compressed Air											
46 Review of system pressure, leak detection etc.	92%	100%	0%	25%	100%	100%	100%	100%	100%	100%	100%
47 Switch from compressed air to electric drives for activators	1%	50%	0%	0%	0%	25%	25%	50%	50%	75%	75%
Paper Machine - Wet End											
48 Only use necessary agitation (turn off agitators, slow down agitators, zone agitation where appropriate)	71%	100%	0%	25%	100%	100%	100%	100%	100%	100%	100%
Paper Machine - Dryer											
49 Closed hood (elec)	86%	98%	0%	75%	100%	100%	100%	100%	100%	100%	100%
Two Teams											
50 100% electricity (elec increase)	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Figure 19: Option deployment for the 40-60% CO_2 reduction pathway

In this pathway, the principal options that contribute to the emissions reduction in 2050 are (Figure 20):

- **Heat recovery on hoods future**, deployed to 22% in 2030 and increasing to 100% in 2050, accounts for 24% of the total emissions reduction from deployment of options in 2050.
- **Biomass-based CHP or boiler**, deployed to 25% of sector potential from 2020, accounts for 23% of the total emissions reduction from deployment of options in 2050.
- **Improved process control**, deployed in 25% increments increasing to 100% of potential in 2030, accounts for 10% of the total emissions reduction from deployment of options in 2050.
- **Impulse drying**, gradually deployed from 25% in 2025 to 100% in 2050, accounts for 5% of the total emissions reduction from deployment of options in 2050.
- **(Waste) heat recovery and heat integration**, deployed to 25% in 2015, 75% in 2020 and 100% in 2025, accounts for 4% of the total emissions reduction from deployment of options in 2050.
- **Energy management**, deployed to 25% in 2015 and 100% in 2020, accounts for 4% of the total emissions reduction from deployment of options in 2050.

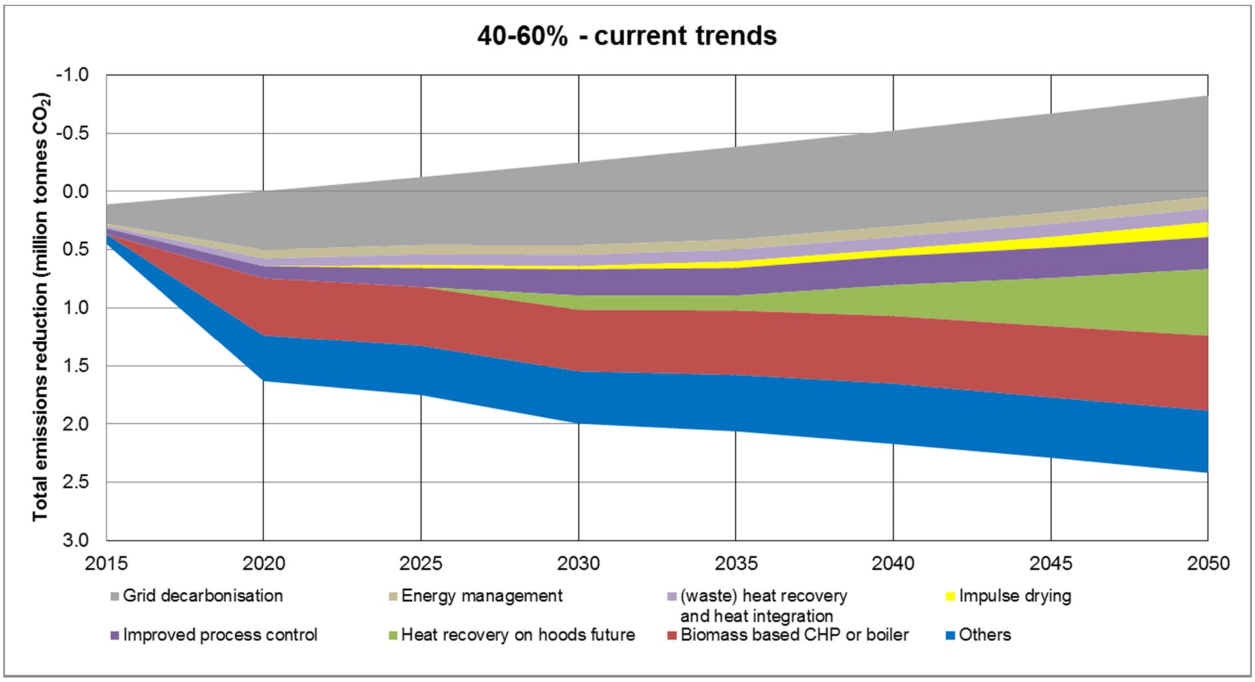

Figure 20: Contribution of principal options to the absolute emissions reduction throughout study period, for the 40-60% CO_2 reduction pathway, current trends scenario

For the current trends scenario, this pathway gives an overall reduction of 74% in 2050, compared to 2012. This includes the emissions reduction linked to the deployment of options and decarbonisation of the grid as well as the emissions increase linked to the growth of the sector.

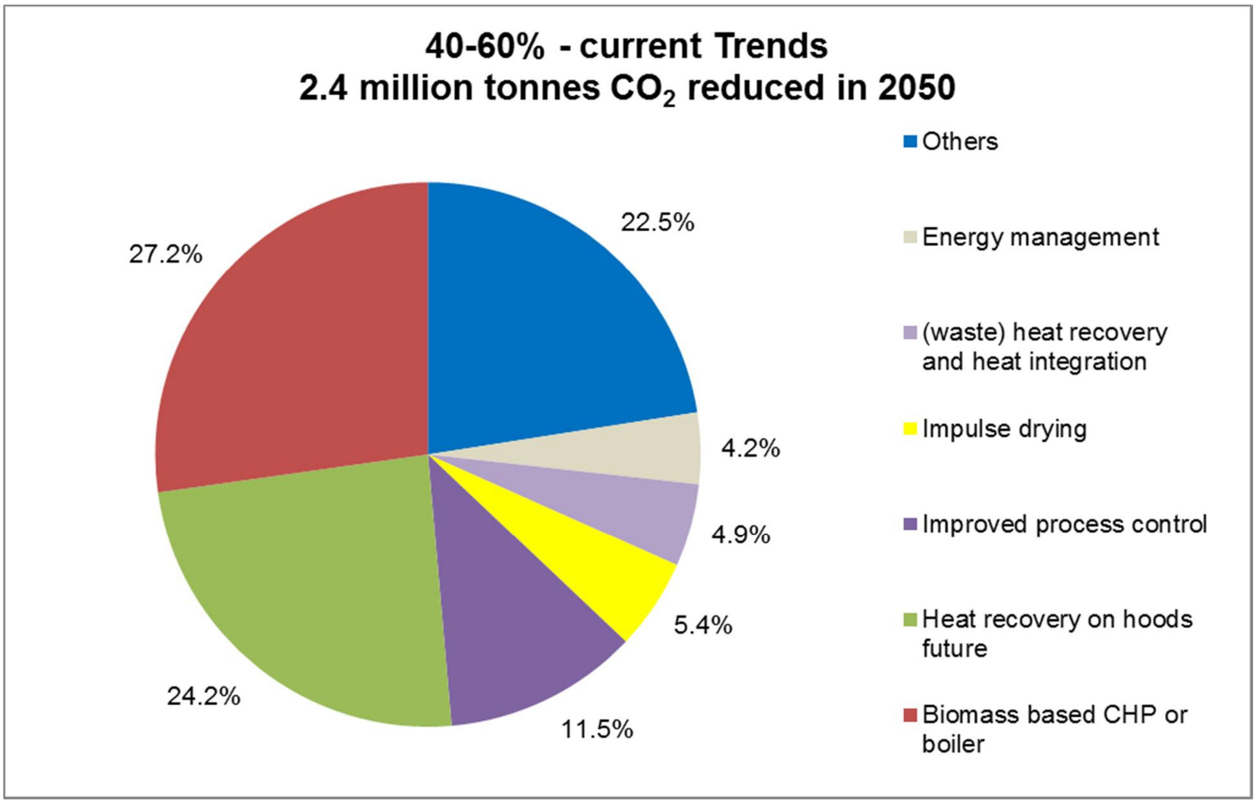

Figure 21: Breakdown of 2050 emissions reduction, for the 40-60% CO_2 reduction pathway, current trends scenario

The CO_2 reduction contributions in 2050 revealed that the biggest carbon savings in this pathway come from a small number of key options (Figure 21): biomass based CHP or boiler; heat recovery on hoods; and improved process control across the entire mill (process and utilities).

Option Deployment for Other Scenarios

The BAU pathway achieves over 40% reduction for the challenging world scenario so no additional 40-60% CO_2 reduction pathway was developed for that scenario.

In the collaborative growth scenario, all options included under the current trends scenario were deployed at the same rate as in the current trends scenario, except biomass CHP. Biomass CHP is assumed to reach a 50% deployment by 2050 compared to 25% for the current trends scenario, in order to reach an emissions reduction of above 40%. The total reduction of CO_2 emissions for this scenario is 41% in 2050 compared to 2012.

The deployment of options for the collaborative growth scenarios for this pathway is shown in appendix D.

4.4.4 Maximum Technical 1 Pathway

Pathway Summary

The Max Tech 1 pathway (Max Tech 1) for the current trends scenario includes all SAT and major investment technologies and the Two Team option 100% electricity applied to 25% of the sector and industrial clustering and heat networking applied to 75% of the sector. This Two Team option is also referred to by CEPI as recycle mill of the future. This pathway will decarbonise the sector by replacing equipment using heat today with equipment using electricity. This includes equipment using steam to be replaced by equipment using electricity and equipment using fuel to produce steam to equipment using electricity to produce steam. It will also replace steam produced by fossil fuels by net zero carbon steam. This net zero carbon steam is assumed to come from waste incineration in an industrial cluster and is referred to as industrial clustering and heat networking.

Deployment for the Current Trends Scenario

Figure 22 shows the option deployment for the Max Tech 1 pathway for the current trends scenario.

SAT are deployed in the same way as for the BAU pathway, starting in 2015 with most of them deployed to 100% by 2030.

Major investment technologies are assumed to begin deployment in 2020 and to be largely deployed by 2050. Some sites may not implement some higher cost options or options that may be disruptive to the operation of the plant, so the deployment of these technologies has been assumed to only reach 75%.

Options such as extended nip press and heat recovery on hoods are ‘undeployed’ over time as they are being replaced by more advanced technologies.

100% electricity is assumed to begin deployment in 2045, and is deployed to 25% by 2050.

Industrial clustering and heat networking is assumed to begin deployment in 2020 and is deployed to 75% by 2050.

Pathway: Max Technical 1 Scenario: Current Trends (CT)

OPTION	ADOP.	APP.	2014	2015	2020	2025	2030	2035	2040	2045	2050
DIRECT											
Across Mill - General											
01 Energy management including installing meters for steam, electricity, air and gas to allow for online energy balances	76%	100%	0%	25%	100%	100%	100%	100%	100%	100%	100%
02 Improved process control across the entire mill (process & utilities)	42%	100%	0%	25%	50%	75%	100%	100%	100%	100%	100%
03 (waste) heat recovery and heat integration	64%	100%	0%	25%	75%	100%	100%	100%	100%	100%	100%
04 organic Rankine cycles, heat pumps and similar heat recovery technology	8%	80%	0%	0%	25%	50%	50%	75%	100%	100%	100%
05 Focus on maintenance	75%	100%	0%	25%	100%	100%	100%	100%	100%	100%	100%
06 Industrial clustering and heat networking	0%	100%	0%	0%	25%	25%	50%	50%	50%	75%	75%
Paper Machine - General											
08 State-of-the-art steam system: includes condensate system with stationary siphons and spoiler bars, with optimized differential pressures for condensate evacuation	76%	99%	0%	25%	50%	75%	100%	100%	100%	100%	100%
09 Use flash steam from condensate	35%	70%	0%	25%	100%	100%	100%	100%	100%	100%	100%
Paper Machine - Wet End											
10 steam box to increase sheet temperature and dryness	58%	80%	0%	25%	100%	100%	100%	100%	100%	100%	100%
11 Extended Nip Press: Tissue	0%	60%	0%	0%	100%	75%	50%	50%	25%	0%	0%
12 Extended Nip Press: Non-Tissue	39%	100%	0%	0%	100%	75%	50%	50%	25%	0%	0%
13 Improved dewatering in press section beyond extended Nip Press	0%	60%	0%	0%	0%	25%	50%	50%	75%	100%	100%
14 Hot pressing	1%	50%	0%	0%	50%	50%	75%	75%	100%	100%	100%
15 High consistency forming	15%	50%	0%	0%	50%	50%	75%	75%	100%	100%	100%
17 Impulse drying	0%	50%	0%	0%	0%	25%	25%	50%	50%	75%	100%
Paper Machine - Dryer											
18 Infrared profiling	9%	50%	0%	0%	0%	0%	0%	0%	0%	0%	0%
19 Increase dew point in hood from 55°C to 70°C	63%	98%	0%	25%	100%	100%	100%	100%	100%	100%	100%
20 Heat recovery on hoods present	88%	98%	0%	25%	100%	100%	75%	75%	50%	25%	0%
21 Heat recovery on hoods future	0%	98%	0%	0%	0%	0%	25%	25%	50%	75%	100%
22 Closed hood (fuel)	86%	98%	0%	75%	100%	100%	100%	100%	100%	100%	100%
Utilities - Water											
23 Install anaerobic waste water treatment plant	7%	33%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Utilities - Steam System											
25 Biomass based CHP/boiler	16%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
27 Gasification of biomass for use in gas turbine	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
28 Oxygen trim control to adjust burner inlet air	70%	100%	0%	25%	75%	100%	100%	100%	100%	100%	100%
29 Economisers on steam boilers	78%	100%	0%	25%	100%	100%	100%	100%	100%	100%	100%
Two Teams											
30 Flash Condensing with Steam	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
31 Superheated steam drying	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
32 Drypulp for cureformed paper	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
33 Supercritical CO2	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
34 Functional surface	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
35 Toolbox	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
36 Deep Eutectic Solvents	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
37 100% electricity (heat saving)	0%	100%	0%	0%	0%	0%	0%	0%	0%	25%	25%
INDIRECT											
Across Mill - General											
38 Replace lighting with high efficiency lighting	23%	100%	0%	75%	75%	75%	75%	75%	75%	75%	75%
Pulp - Pulp Production											
39 High consistency pulping	76%	100%	0%	25%	100%	100%	100%	100%	100%	100%	100%
40 Efficient screening	83%	100%	0%	25%	100%	100%	100%	100%	100%	100%	100%
41 Sludge dryer	12%	25%	0%	0%	0%	0%	0%	75%	75%	75%	75%
Utilities - Pumps and Motors											
42 Match pumping capacity to duty, avoid oversizing pumps & motors, avoid throttling, use VSD and efficient motors where possible	80%	85%	0%	25%	100%	100%	100%	100%	100%	100%	100%
43 Use fans or blowers for low vacuum applications	17%	50%	0%	0%	50%	50%	75%	75%	100%	100%	100%
Utilities - Steam System											
44 Optimize steam turbine control	66%	100%	0%	0%	100%	100%	100%	100%	100%	100%	100%
Utilities -Compressed Air											
46 Review of system pressure, leak detection etc.	92%	100%	0%	25%	100%	100%	100%	100%	100%	100%	100%
47 Switch from compressed air to electric drives for activators	1%	50%	0%	0%	0%	25%	25%	50%	50%	75%	75%
Paper Machine - Wet End											
48 Only use necessary agitation (turn off agitators, slow down agitators, zone agitation where appropriate)	71%	100%	0%	25%	100%	100%	100%	100%	100%	100%	100%
Paper Machine - Dryer											
49 Closed hood (elec)	86%	98%	0%	75%	100%	100%	100%	100%	100%	100%	100%
Two Teams											
50 100% electricity (elec increase)	0%	100%	0%	0%	0%	0%	0%	0%	0%	25%	25%

Figure 22: Option deployment for the Max Tech 1 pathway

In this pathway, the principal options that contribute to the emissions reduction in 2050 are (Figure 23):

- **Industrial clustering and heat networking**, deployed to 25% in 2020 and increased to 60% and 75% in 2030 and 2045 respectively, accounts for 26% of the total emissions reduction from deployment of options in 2050.
- **100% electricity**, deployed to 25% from 2045, accounts for 20% of the total emissions reduction from deployment of options in 2050.
- **Heat recovery on hoods future**, deployed to 25% in 2030 and increasing to 100% in 2050, accounts for 15% of the total emissions reduction from deployment of options in 2050.
- **Improved process control**, deployed in 25% increments increasing to 100% of potential in 2030, accounts for 7% of the total emissions reduction from deployment of options in 2050.
- **Impulse drying**, deployed to 25% in 2025 and increasing to 100% in 2050, accounts for 3% of the total emissions reduction from deployment of options in 2050.
- **(Waste) heat recovery and heat integration**, deployed to 25% in 2015, 75% in 2020, and 100% in 2025, accounts for 3% of the total emissions reduction from deployment of options in 2050.

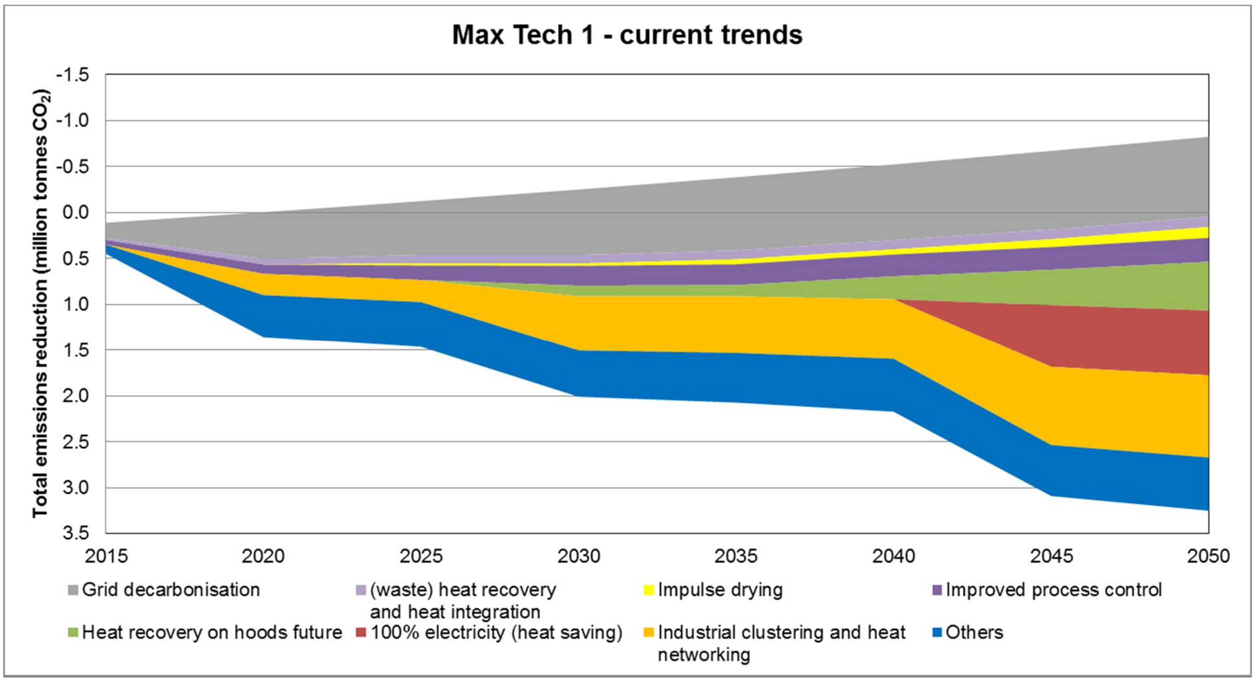

Figure 23: Contribution of principal options to the absolute savings throughout the study period, for the Max Tech 1 pathway, current trends scenario

For the current trends scenario, this pathway gives an overall reduction of 97.5% in 2050, compared to 2012. This includes the emissions reduction linked to the deployment of options and decarbonisation of the grid as well as the emissions increase linked to the growth of the sector. Despite the fact that the electricity consumption increases considerably for this pathway, the contribution of the decarbonisation of the grid is only decreased by 0.5% due to the low-carbon emissions from grid electricity in 2015.

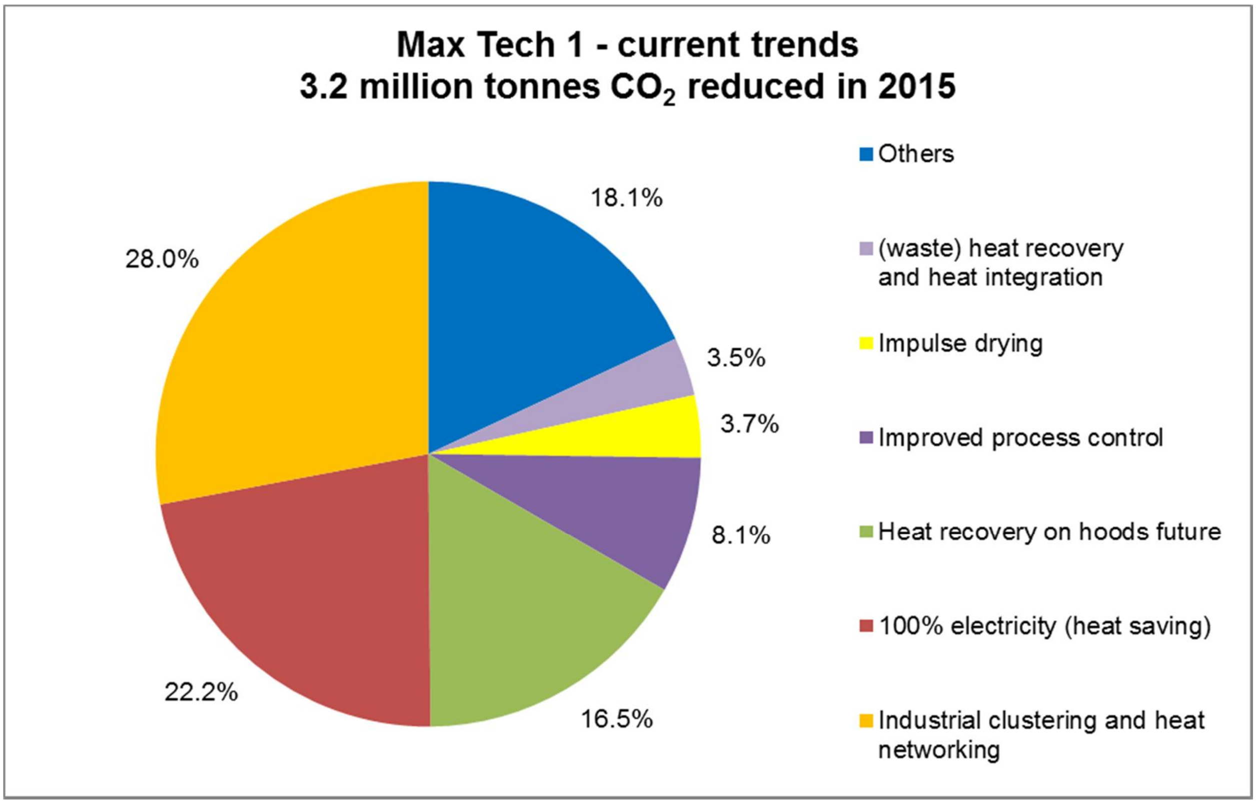

Figure 24: Breakdown of 2050 emissions reduction, for the Max Tech 1 pathway, current trends scenario

The CO_2 reductions contribution in 2050 revealed that the biggest carbon savings in this pathway come from a small number of key options (Figure 24): industrial clustering and heat networking; 100% electricity; and heat recovery on hoods.

This pathway would also have additional revenue streams by participating in demand response and capacity markets. The financial benefits and operational considerations of participation in such a market have not been considered here. The grid decarbonisation is a very important factor in this pathway.

Option Deployment for Other Scenarios

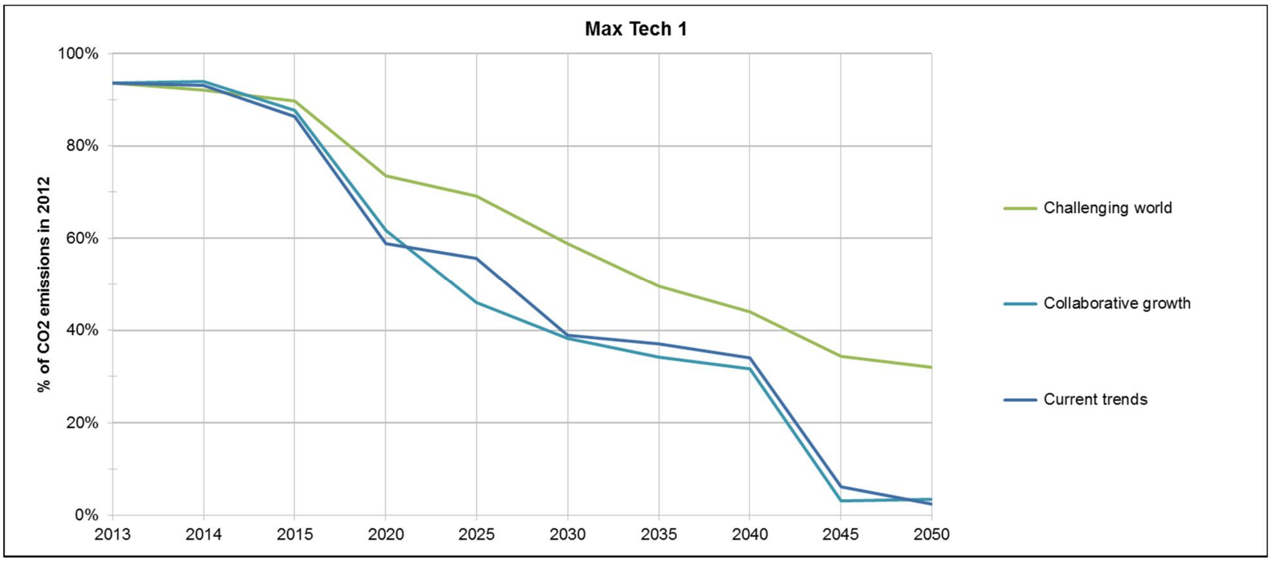

Figure 25: Max Tech 1 pathways for the different scenarios

Figure 25 shows the Max Tech 1 pathways for the different scenarios. As can be seen the current trends scenario delivers a CO_2 reduction of 98%, the challenging world scenario delivers a CO_2 reduction of 69% and the collaborative growth scenario delivers CO_2 reduction of 96%.

For the challenging world scenario, SAT and major investment technologies were deployed at a slower rate. Industrial clustering and heat networking was reduced to 25% of the sector as the lack of collaboration both within the sector and between industry would hinder the full deployment of this option.

In the collaborative growth scenario, all options included under the current trends scenario were deployed at the same rate as in the current trends scenario.

The deployment of options for the challenging world and collaborative growth scenarios for this pathway is shown in appendix D.

4.4.5 Maximum Technical 2 Pathway

Pathway Summary

The Max Tech 2 pathway for the current trends scenario includes all SAT and major investment technologies and the replacement of fossil fuels with biomass-based CHP. Biomass CHP is chosen as it is an existing technology in the sector that can achieve a maximum CO_2 emissions reduction under the assumption that biomass is carbon neutral. This pathway assumes sufficient availability of carbon-neutral biomass and is based on the UK Bio-Energy Strategy. The exception is for the challenging world scenario where the amount of available biomass is assumed to limit the deployment of biomass CHP to 50% of the sector.

Deployment under Current trends

Figure 26 shows the option deployment for the Max Tech 2 pathway for the current trends scenario.

SAT are deployed in the same way as for the BAU pathway, starting in 2015 with most of them deployed to 100% by 2030.

Major investment technologies are assumed to begin deployment in 2020 and to be largely deployed by 2050. Some sites may not implement some higher cost options or options that may be disruptive to the operation of the plant, so the deployment of these technologies has been assumed to only reach 75%.

Options such as extended nip press and heat recovery on hoods are ‘undeployed’ over time as they are being replaced by more advanced technologies.

The deployment of biomass CHP is assumed to begin in 2020, reaching 100% by 2050.

Pathway: Max Technical 2 Scenario: Current Trends (CT)

OPTION	ADOP.	APP.	2014	2015	2020	2025	2030	2035	2040	2045	2050
DIRECT											
Across Mill - General											
01 Energy management including installing meters for steam, electricity, air and gas to allow for online energy balances	76%	100%	0%	25%	100%	100%	100%	100%	100%	100%	100%
02 Improved process control across the entire mill (process & utilities)	42%	100%	0%	25%	50%	75%	100%	100%	100%	100%	100%
03 (waste) heat recovery and heat integration	64%	100%	0%	25%	75%	100%	100%	100%	100%	100%	100%
04 organic Rankine cycles, heat pumps and similar heat recovery technology	8%	80%	0%	0%	25%	50%	50%	75%	100%	100%	100%
05 Focus on maintenance	75%	100%	0%	25%	100%	100%	100%	100%	100%	100%	100%
06 Industrial clustering and heat networking	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Paper Machine - General											
08 State-of-the-art steam system: includes condensate system with stationary siphons and spoiler bars, with optimized differential pressures for condensate evacuation	76%	99%	0%	25%	50%	75%	100%	100%	100%	100%	100%
09 Use flash steam from condensate	35%	70%	0%	25%	100%	100%	100%	100%	100%	100%	100%
Paper Machine - Wet End											
10 steam box to increase sheet temperature and dryness	58%	80%	0%	25%	100%	100%	100%	100%	100%	100%	100%
11 Extended Nip Press: Tissue	0%	60%	0%	0%	100%	75%	50%	50%	25%	0%	0%
12 Extended Nip Press: Non-Tissue	39%	100%	0%	0%	100%	75%	50%	50%	25%	0%	0%
13 Improved dewatering in press section beyond extended Nip Press	0%	60%	0%	0%	0%	25%	50%	50%	75%	100%	100%
14 Hot pressing	1%	50%	0%	0%	50%	50%	75%	75%	100%	100%	100%
15 High consistency forming	15%	50%	0%	0%	50%	50%	75%	75%	100%	100%	100%
17 Impulse drying	0%	50%	0%	0%	0%	25%	25%	50%	50%	75%	100%
Paper Machine - Dryer											
18 Infrared profiling	9%	50%	0%	0%	0%	0%	0%	0%	0%	0%	0%
19 Increase dew point in hood from 55°C to 70°C	63%	98%	0%	25%	100%	100%	100%	100%	100%	100%	100%
20 Heat recovery on hoods present	88%	98%	0%	25%	100%	100%	75%	75%	50%	25%	0%
21 Heat recovery on hoods future	0%	98%	0%	0%	0%	0%	25%	25%	50%	75%	100%
22 Closed hood (fuel)	86%	98%	0%	75%	100%	100%	100%	100%	100%	100%	100%
Utilities - Water											
23 Install anaerobic waste water treatment plant	7%	33%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Utilities - Steam System											
25 Biomass based CHP/boiler	16%	100%	0%	0%	25%	25%	50%	50%	75%	75%	100%
27 Gasification of biomass for use in gas turbine	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
28 Oxygen trim control to adjust burner inlet air	70%	100%	0%	25%	75%	100%	100%	100%	100%	100%	100%
29 Economisers on steam boilers	78%	100%	0%	25%	100%	100%	100%	100%	100%	100%	100%
Two Teams											
30 Flash Condensing with Steam	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
31 Superheated steam drying	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
32 Drypulp for cureformed paper	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
33 Supercritical CO2	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
34 Functional surface	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
35 Toolbox	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
36 Deep Eutectic Solvents	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
37 100% electricity (heat saving)	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
INDIRECT											
Across Mill - General											
38 Replace lighting with high efficiency lighting	23%	100%	0%	0%	75%	75%	75%	75%	75%	75%	75%
Pulp - Pulp Production											
39 High consistency pulping	76%	100%	0%	25%	100%	100%	100%	100%	100%	100%	100%
40 Efficient screening	83%	100%	0%	25%	100%	100%	100%	100%	100%	100%	100%
41 Sludge dryer	12%	25%	0%	0%	0%	0%	0%	75%	75%	75%	75%
Utilities - Pumps and Motors											
42 Match pumping capacity to duty, avoid oversizing pumps & motors, avoid throttling, use VSD and efficient motors where possible	80%	85%	0%	25%	100%	100%	100%	100%	100%	100%	100%
43 Use fans or blowers for low vacuum applications	17%	50%	0%	0%	50%	50%	75%	75%	100%	100%	100%
Utilities - Steam System											
44 Optimize steam turbine control	66%	100%	0%	0%	100%	100%	100%	100%	100%	100%	100%
Utilities -Compressed Air											
46 Review of system pressure, leak detection etc.	92%	100%	0%	25%	100%	100%	100%	100%	100%	100%	100%
47 Switch from compressed air to electric drives for activators	1%	50%	0%	0%	0%	25%	25%	50%	50%	75%	75%
Paper Machine - Wet End											
48 Only use necessary agitation (turn off agitators, slow down agitators, zone agitation where appropriate)	71%	100%	0%	25%	100%	100%	100%	100%	100%	100%	100%
Paper Machine - Dryer											
49 Closed hood (elec)	86%	98%	0%	75%	100%	100%	100%	100%	100%	100%	100%
Two Teams											
50 100% electricity (elec increase)	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Figure 26: Option deployment for the Max Tech 2 pathway

In this pathway, the principal options that contribute to the emissions reduction in 2050 are (Figure 27):

- **Biomass-based CHP or boiler**, deployed to 25% in 2020 and increasing by 25% every ten years, accounts for 54% of the total emissions reduction from deployment of options in 2050.
- **Heat recovery on hoods future**, deployed to 25% in 2030 and increasing to 100% in 2050, accounts for 13% of the total emissions reduction from deployment of options in 2050.
- **Improved process control**, deployed in 25% increments increasing to 100% of potential in 2030, accounts for 6% of the total emissions reduction from deployment of options in 2050.
- **Impulse drying**, deployed to 25% in 2025 and increasing to 100% in 2050, accounts for 3% of the total emissions reduction from deployment of options in 2050.
- **(Waste) heat recovery and heat integration**, deployed to 25% in 2015, 75% in 2020, and 100% in 2025, accounts for 3% of the total emissions reduction from deployment of options in 2050.

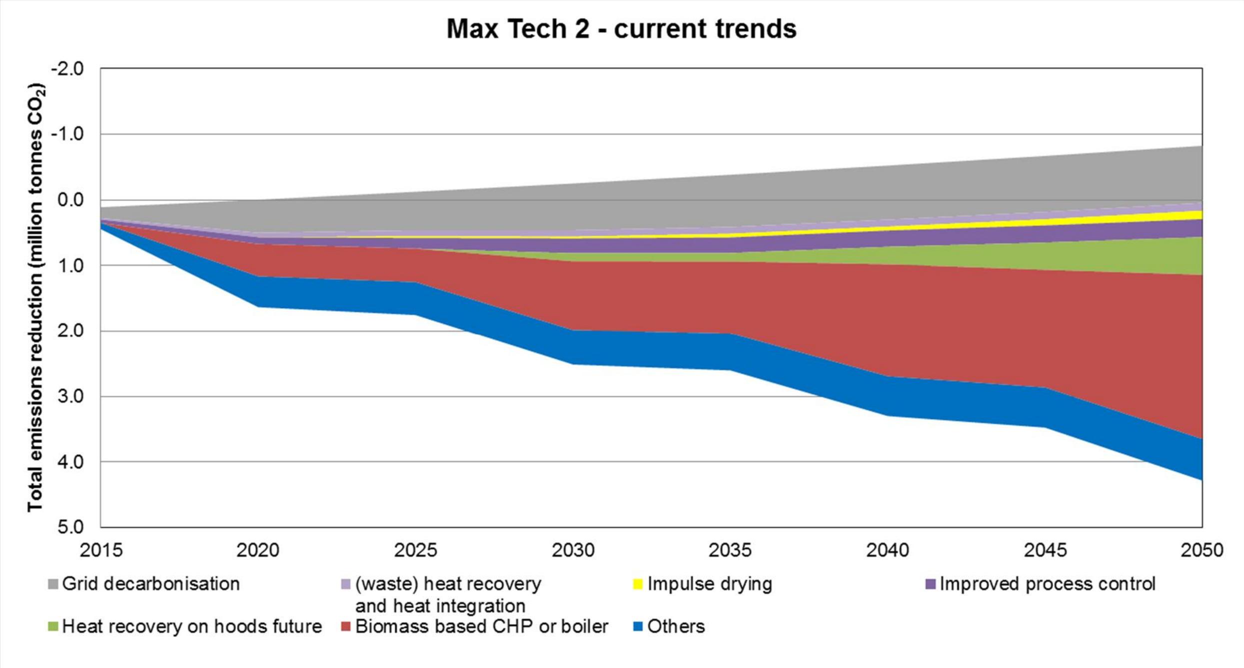

Figure 27: Contribution of principal options to the absolute emissions reduction throughout the study period, for the Max Tech 2 pathway, current trends scenario

For the current trends scenario, this pathway gives an overall reduction of 98% in 2050, compared to 2012. This includes the emissions reduction linked to the deployment of options and decarbonisation of the grid as well as the emissions increase linked to the growth of the sector.

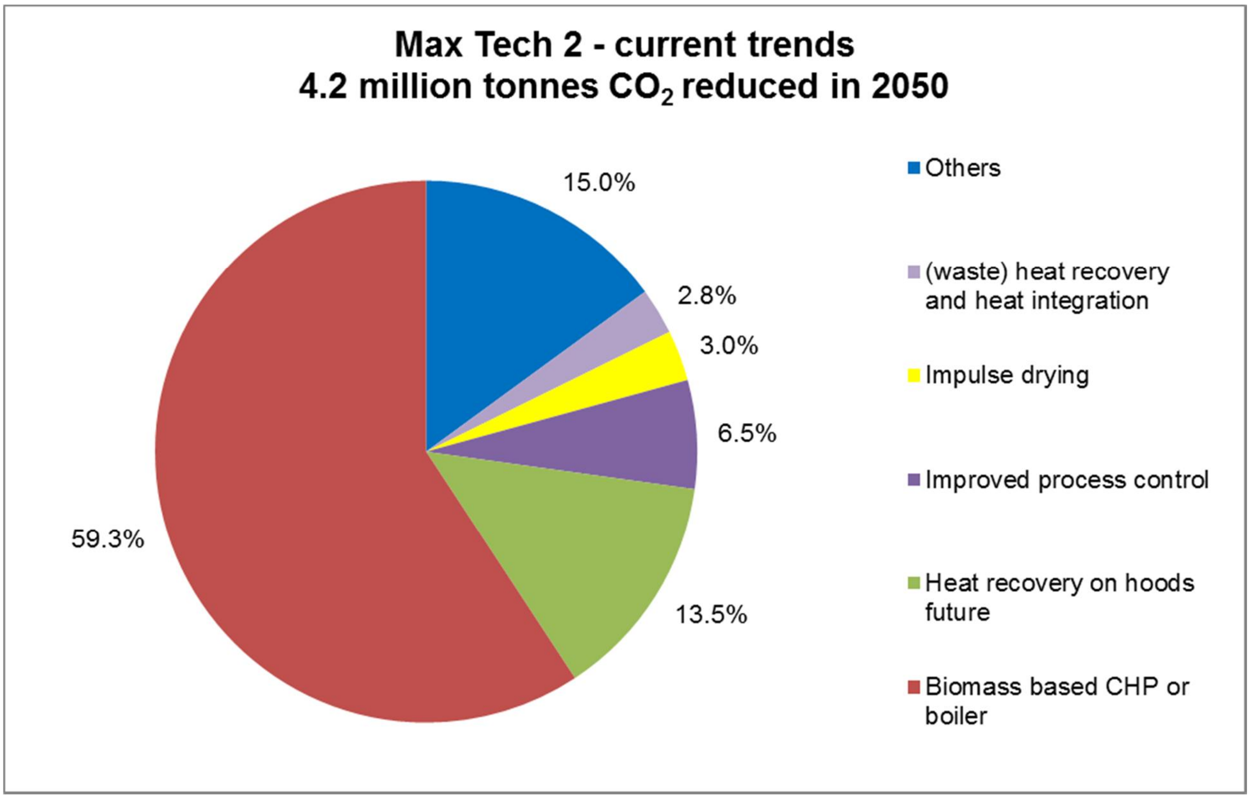

Figure 28: Breakdown of 2050 emissions reduction, for the Max Tech 2 pathway, current trends scenario

The CO_2 reductions contribution in 2050 revealed that the biggest carbon savings in this pathway come from a small number of key options (Figure 28): biomass based CHP or boiler; and heat recovery on hoods.

Option Deployment under Other Scenarios

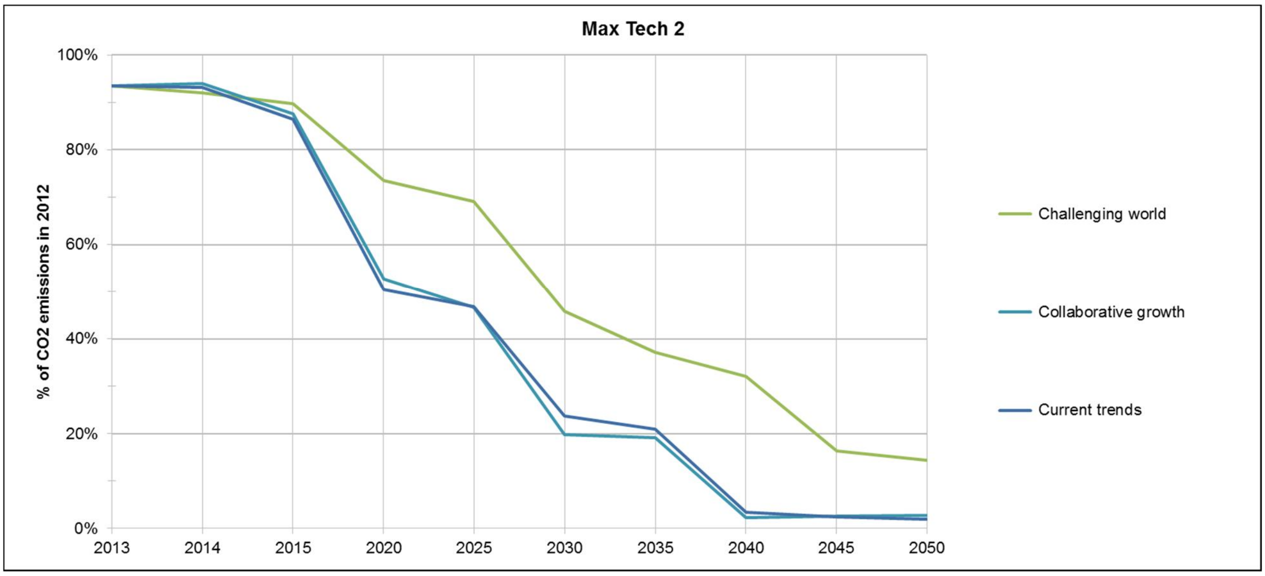

Figure 29: Max Tech 2 pathways for the different scenarios

Figure 29 shows the Max Tech 2 pathways for the different scenarios. As can be seen the current trends scenario delivers a CO_2 reduction of 98%, the challenging world scenario delivers a CO_2 reduction of 85% and the collaborative growth scenario delivers CO_2 reduction of 97%.

For the challenging world scenario, SAT and major investment technologies were deployed at a slower rate compared to the current trends scenario. Biomass CHP was only deployed to 50% assuming that the availability of biomass is restricted.

In the collaborative growth scenario, all options included under the current trends scenario were deployed at the same rate as in the current trends scenario.

The deployment of options for the challenging world and collaborative growth scenarios for this pathway is shown in appendix D.

4.5 Sensitivity Analysis

The Max Tech (no biomass) pathway described above illustrates the sensitivity of the pathways to the use of biomass.

In the option interaction calculation, the ‘no interaction’ case adds approximately 5% to the carbon reduction in 2050 in the Max Tech pathway.

4.6 Pathway Costs

4.6.1 Introduction

Estimates of the costs of new technologies or capital improvements with a time horizon to 2050 is fraught with difficulties. Any long-term forecasts should be treated with caution. The cost analysis presented in this report is intended to provide a high-level estimate of the total capital cost of each pathway to the UK as a whole, in a form that is consistent with the government’s approach to assessing the relative capital costs of alternative decarbonisation options from a social perspective (DECC, 2014). It is based on an analysis of ‘order of magnitude’ option capital costs. The purpose of developing and presenting this cost analysis is to provide an indication of the capital costs for the pathways, which could form a basis for further work.

In gathering capital cost-related data, literature or engagement with stakeholders was used to establish an initial dataset for use in the cost analysis assessment. Operating costs such as energy use changes, energy costs and labour are not included in this analysis, although we recognise that operating costs resulting from the decarbonisation pathways will have a major impact on any economic assessment. For example, some options (e.g. carbon capture and electrification of firing) greatly increase energy use or operating costs of a process plant.

4.6.2 Calculation of Pathway Costs

The pathway costs and carbon dioxide savings are measured with respect to the reference trend, i.e. they are calculated as the difference between costs and emissions under the decarbonisation pathway and those under the reference trend. This means the costs represent the additional capital costs for the pathway compared to a future in which there was no deployment of options. The pathway costs have been assembled from the estimated costs of the combination of decarbonisation and energy efficiency options, in accordance with each carbon reduction pathway including the selected deployment rates of each option. The methodology for calculating the total discounted capital costs which produce the CO_2 reductions for each pathway can be summarised as follows:

1. Capital costs of deployment for each decarbonisation and energy efficiency option are calculated based on the order of magnitude capital costs to deploy that option at one site (or installation or unit of equipment). This is then deployed to the applicable number of sites (or installations or units of equipment) for the (sub)sector in the pathway as defined by the model.
2. Capital costs reflect the additional cost of delivering the carbon dioxide and/or energy reduction options compared to continuing production without deploying the options. For a number of major investment options, including replacement of life-expired assets with BAT (for a list of options in this category see appendix C), only a proportion of the cost is assumed to be attributed to carbon dioxide emission or energy reduction, as a significant factor for the investment in this case would be to replace retiring production capacity and to recognise that options may be implemented for reasons other than decarbonisation or energy efficiency. In the absence of detailed information this proportion (attributed to the capital cost calculation in this analysis) is assumed to be 50%. For all other technology options the entire capital cost (i.e. 100%) is attributed to energy or carbon reduction. Capital costs are applied at the year of each deployment step (as modelled in the carbon reduction pathways), and adjusted in cases where the asset life defined in the option register would extend beyond 2050 to reflect their residual value on a linear depreciation basis.
3. The annual capital expenditure of each pathway is calculated from the capital cost and deployment of each of the options selected. Capital costs are presented in present day value (i.e. 2015) and assumed to remain constant throughout the period. The discount rate for costs has been chosen to be 3.5% to value the costs from a social perspective and in accordance with standard HM Treasury methodology for this type of assessment. In other words, all proposed capital expenditure on the various pathways are adjusted for the time value of money, so costs (which occur at different points in time) are expressed on a common basis in terms of their 'net present value' using the discount rate of 3.5%. The effect of this standard methodology is to reduce the apparent cost of large investments that are deployed in the pathways later in the study period.

The following specific assumptions apply:

i. Asset replacement is assumed to take place at the end of life of an existing asset. No allowance has been made for loss of production during the shutdown period associated with the implementation of major and/or disruptive technology options. Similarly no allowance has been made for loss of EU ETS allowances or civil works associated with a major shutdowns and plant rebuilds. Although costs may be incurred in a case where a plant is written off before the end of its life, this has not been taken into account in this analysis.
ii. It has been assumed that minor incremental improvements would be implemented in the shadow of other rebuild or maintenance work so that no additional costs for shutdown would be incurred.
iii. No allowance has been made for the costs of innovation and it is assumed that the costs of development of breakthrough technologies would be funded separately and not be charged to subsequent capital investments. Technology licensing costs are assumed to be included in the capital costs.
iv. No carbon price or other policy costs are included in the calculations.
v. Changes in other operating costs including labour, maintenance or consumables associated with the deployment of options have not been included (although it is noted these will be significant for many options).
vi. This analysis covers capital costs for carbon reduction: changes to energy use and energy costs (as a result of deployment of the options) have not been quantitatively included although it will be significant for many options.

4.6.3 Limitations

The project methodology for cost data collection and validation did not deliver a complete dataset for the capital cost of options, and where data was available, it was qualified at low confidence levels. Further, estimates based on expert judgement have been made where data gaps remained. Also, the degree of stakeholder engagement in relation to this cost analysis was lower than for the carbon reduction pathways.

The project cost methodology was agreed by DECC, BIS and Parsons Brinckerhoff / DNV GL. The methodology has not been agreed with stakeholders including trade associations.

All costs in the data input tables are subject to wide variation, for example between sites and sub-sectors and for technology options that have not been demonstrated at commercial scale. Hence, the cost data represent 'order of magnitude' estimates that require extensive further development and validation prior to any further use, including with sector stakeholders.

Moreover, the assumptions and constraints on confidence levels limit the valid uses for the results of this cost analysis, therefore the following applies to use of this analysis:

- The values are a starting point to help assess relative benefits of different technologies over the long term.
- The cost analysis results should not be used in isolation to compare decarbonisation technologies or decide on priorities for their development: additional techno-economic analysis should be carried out on individual options or groups of options.
- The cost analysis is part of a process of research and exploration and is being shared in a transparent way to support the development of broader strategy. The results are effectively provisional order of magnitude estimates which need to be developed further on the basis of thorough research before they can be used to inform decisions.

4.6.4 Cost Analysis Results

The results of the cost analysis of decarbonisation for the various pathways within the current trends scenario are summarised in Table 7 below.

Results can be used for relative comparison between pathways in a sector. No cost moderation process between the eight sectors has been carried out and therefore in the absence of further data validation and analysis comparison between sectors is not recommended.

The carbon dioxide emission abatement offered by each pathway has been totalled for each year to present a **cumulative** carbon abatement figure for the period from 2014-2050 compared to the reference pathway.

Although this analysis of discounted capital cost does not include energy costs, it should be noted that energy cost changes will be subject to the uncertainties of future energy cost projections and the significant divergence between energy costs applicable to the different levels of energy consumption. A high-level qualitative assessment of the impact of energy use and cost is presented in the table below.

Pathway	Total Discounted Capital Cost 2014-2050 (million £)[15]	Cumulative CO_2 Abated 2014-2050 (million tonnes CO_2)[16]	Projected Impact on Fuel or Energy use and Fuel or Energy cost
BAU	700	26	This pathway includes deployment of options that increase overall energy efficiency. In the study period 2014-2050, this pathway would result in a saving in energy used. The projected value of this saving will depend on the energy cost forecasts adopted.
40-60%	1,000	52	This pathway includes deployment of options that increase overall energy efficiency and also increased use of biomass. A saving in fuel costs is projected, the scale of which depends on the fuel cost forecast adopted.
Max Tech 1 (electrification and clustering)	1,000	54	The main characteristic of this pathway is a very significant transfer of energy use from natural gas to electricity coupled with deployment if advanced technology and clustering. An overall energy cost saving is projected, however, this is very sensitive to price forecasts.
Max Tech 2 (biomass)	1,000	71	This pathway is dominated by increased use of biomass plus advanced efficiency measures. An overall energy cost saving is projected, however, this is very sensitive to price forecasts.

Table 7: Summary costs and impacts of decarbonisation for the pathways

4.7 Implications of Enablers and Barriers

From the pathways described above, there are a number of options that will need to make significant contributions to decarbonisation under some or all of the pathways and scenarios. These are:

- Biomass CHP
- Reducing fuel use by switching to equipment using electricity instead of heat (100% electricity)
- Future heat recovery technology to recover more of the latent heat in the dryer section
- Improved process control
- Clustering
- Low and low-medium cost options such as energy management, focus on maintenance, etc.

From the evidence gathered during the project (from literature, interviews and workshops) there are a number of enablers and barriers associated with these options. These are discussed below.

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[15] Model output rounded to 1 significant figure to reflect 'order of magnitude' input data
[16] Model output rounded to nearest million tonnes of CO_2

4.7.1 Biomass CHP

This option relates to the use of biomass as fuel in a CHP, replacing natural gas or other fossil fuels. This option brings the absolute biggest emissions reduction assuming that the biomass used in the pulp and paper industry is carbon neutral. The industry is already using biomass that would be considered carbon neutral, even in the future (biomass waste, roots and branches, sludge, etc.), but will there be enough carbon-neutral biomass in the future? It is a very complex issue for this sector as its raw material is also biomass, with the associated benefits of storing carbon through tree growth. If there is an increased demand for biomass for other uses, such as electricity production, the Sector risks an increased cost of raw material. As many mills are already operating on the margin of profitability, this is a critical issue for the sector.

In addition to biomass availability, regulatory uncertainty, uncertainty about return on capital, and global competition for funding from group headquarters are barriers that could hinder this option. An example relating to regulatory uncertainty is the change in the CHP subsidy scheme, which has led to scepticism in the sector. For return on capital, this is also linked to regulatory uncertainty, if there were to be a subsidy scheme for biomass CHP; but also linked to the cost of biomass and how it will be regarded with regards to CO_2 emissions. As a biomass CHP requires substantial capital, competition for funding from group headquarters would be a barrier.

Having senior management buy-in for decarbonisation would be an enabler for this option as it has such a high impact on decarbonisation. The technology is also very well known in the sector. A new subsidy scheme for biomass CHP, guaranteed over the lifetime of the equipment, would enable this option as well.

For the current trends scenario, the biomass CHP option has the biggest impact on Max Tech 2 and the 40-60% CO_2 reduction pathways.

Enablers	Senior management buy-in and formal business commitment Government policy
Barriers	Biomass availability Regulatory uncertainty Uncertainty about return on capital Global competition for funding from group headquarters

4.7.2 100% Electricity

This option is to replace equipment using fuel with equipment using electricity and was the Two Team option retained in this roadmap. Replacing fuel-burning boilers with boilers using electricity would be a fairly non-intrusive solution that would have a very limited impact on the operation of machines. Future technology development might lead to process equipment using electricity instead of steam and then there would be a risk linked to productivity. The option would be very sensitive to electricity prices; given the UK's current and predicted electricity prices, this might completely hamper this option (ICF International, 2012).

One enabler would be appropriate policies to encourage such a switch; if it is a decarbonisation option, and decarbonisation is important to a company, senior management buy-in and formal business commitment would also enable this option.

The same policy that would be an enabler could also hamper the implementation of this option if there is regulatory uncertainty.

If only replacing fuel-burning boilers with boilers using electricity, barriers could include rising UK energy prices perceived as non-competitive, uncertainty about return on capital, and global competition for funding from group headquarters. The first two are linked to future electricity prices and, as it would be a high capital investment, it would also be competing with funding from group headquarters.

If we assume that future process equipment will use electricity instead of steam, there are additional barriers. Conservatism within the industry could hamper the deployment as it would be new or unproven technology. This is similar to the barrier regarding the impact of new technology on machine operability. Considering the lifetime of machinery of 30-60 years, if the sector has already invested in new equipment, or intends to do so in the near future, there might not be an opportunity to replace process equipment before 2050.

This option only impacts the Max Tech 1 pathway.

Enablers	Senior management buy-in and formal business commitment Government policy
Barriers	Regulatory uncertainty Conservatism within industry Uncertainty about return on capital Uncertainty regarding impact of new technology on machine operability Rising UK energy prices perceived as non-competitive Global competition for funding from group headquarters Lifetime of machinery of 30 to 60 years

4.7.3 Novel Heat Recovery Technology to Recover More of the Latent Heat in the Dryer Section

This option is a future technology option that assumes that more of the latent heat in the steam from the dryer could be recovered and reused. Currently, a large part of a paper machine's energy use results in a hot wet air stream containing energy that can be recovered. Recovering energy from this stream is already done today. More of the energy could be captured but would require considerable innovation to happen. This option would be linked to the barriers below, as it is likely to require changes to the dryer itself; as it is novel technology, the likelihood is that it would likely require considerable capital investment. In addition, if the dryer has been or will be replaced or retrofitted, the long lifetime of machinery would present another barrier to this option.

This option would impact all pathways except BAU.

Barriers	Conservative industry Uncertainty regarding impact of new technology on machine operability Global competition for funding from group headquarters Lifetime of machinery of 30 to 60 years

4.7.4 Improved Process Control

This option refers to improving the performance of existing equipment by increasing the ratio of production time of optimal energy consumption as a proportion of total running time. There is considerable variability in energy consumption in a mill and some of that is due to non-controllable parameters such as weather and type of product produced. A large part of the variability is linked to how the equipment is manipulated. Increased process control would lead to a less variable operation that can be fine-tuned to an optimal energy consumption. It would typically lead to many other non-energy benefits such as increased throughput, more consistent quality, etc.

This is an investment that can be spread out over time; it is likely to fall into the category of small incremental investments that the mill might be able to manage itself without having to request the funding from headquarters (an enabler for this option). Process control requires a thorough understanding of the functioning of the equipment and lack of awareness and lack of skilled labour are barriers to its deployment. In addition, improving process control can be a risk in the short term with regards to equipment operability.

This option impacts all pathways.

Enablers	Small incremental investments
Barriers	Uncertainty regarding impact of new technology on machine operability Lack of awareness and information imperfections Lack of skilled labour

4.7.5 Clustering

The clustering option refers to co-location of plants to optimise the use of energy and materials. This option was identified in the Workshops as a significant opportunity in the longer term, provided the barriers could be overcome such as difficulties with local planning systems and existing pulp and paper mills relocating. Collaboration in the value chain would be an enabler for this option as it is likely that companies that collaborate in the value chain would be more open to co-location. It would benefit from government policy encouraging such co-location. Senior management buy-in could be an enabler and lack of thereof would be a considerable barrier.

Just as government policy can be an enabler, uncertainty surrounding government policy could also be a barrier in this case as these are major investment decisions and would require a long-term approach. The sector is conservative and there is an inherent reluctance to rely upon an outside party for any material or utility.

Clustering only impacts the Max Tech 2 pathway.

Enablers	Collaboration in the value chain Government policy Senior management buy-in and formal business commitment
Barriers	Regulatory uncertainty Conservative industry

4.7.6 Low and Low-Medium Cost Options

This is a group of options that requires only low or low-medium capital investment. These are largely the current SAT such as energy management, focus on maintenance, leak detection etc. They have been grouped together for the purposes of this section as they have similar enablers and barriers. Small incremental investment was identified as an enabler as the mill typically has access to lower amounts of capital that it can control itself. The low capital cost option is likely to fall into that category. For the low-medium capital cost options, it is likely that the cost could be spread over several years.

Even lower investment costs are sensitive to the lower profit margins in the marketplace. Some of these options are more concerned with organisational changes rather than technical changes and would require awareness and skills to be properly implemented.

These options would have an impact on all pathways, but would influence the BAU the most.

Enablers	Small incremental investments
Barriers	Competitive marketplace with lower profit margins

	Lack of awareness and information imperfections Lack of skilled labour

4.7.7 Others

Sections 4.4.1 - 4.4.5 above focus on the options that provide the most significant decarbonisation potential. From the evidence gathered as part of this roadmap, other options share many of the same enablers and barriers such as:

- Major innovative technology changes require significant further development before they could be considered for deployment.
- The 100% electricity option is likely to result in higher overall energy use.
- Long-term stability in carbon pricing is needed in order to make major investments.

Finally, even though decarbonised grid electricity is included in all pathways and is not under the direct control of the sector, it is a major contributor to decarbonisation.

5. CONCLUSIONS – PRINCIPAL QUESTION 6

This section provides assessment of the questions under Principal Question 6: "What future actions might be required to be taken by industry, government and others to overcome the barriers in order to achieve the pathways in each sector?"

The section is structured as follows:

- Eight 'strategic conclusions' or themes have been developed by analysing the main enablers and barriers. Example next steps or potential actions are also included for each strategic conclusion.
- Five key technology groups are discussed, many of which link to the themes above. As described in section 4, a small group of technologies make a significant contribution to decarbonisation in 2050, especially for Max Tech savings[17]. Example next steps are included to assist with developing, funding and implementing the technologies.

It is intended that government and industry use the roadmap to develop and implement an action programme in support of the overall aim of decarbonisation while maintaining competitiveness in the sector.

5.1 Key Points

During the development of potential pathways to decarbonisation, the barriers to their implementation and enablers to promote them were summarised in section 4.5. Having cross-referenced the enablers and barriers through three different research methods, we have summarised the key points in key strategic conclusions (or themes) and key technology groups.

Strategic Conclusions

Strategy, Leadership and Organisation
It is critical that the pulp and paper sector, the government and other stakeholders recognise the importance of strategy and leadership in the context of decarbonisation, energy efficiency and general competitiveness for the sector.

Business Case Barriers
One of the most important barriers to decarbonisation and energy efficiency is lack of funding for such projects as the return of investment is not attractive enough or there is a lack of access to capital.

Future Energy Costs, Energy Supply Security, Market Structure and Competition
It is clearly critical to ensure that future decarbonisation and energy efficiency actions maintain the position with respect to overall cost-competitiveness of the UK sector compared to competing businesses operating in other regions of Europe, Asia and the US. This strategic conclusion links to a number of external factors that influence the business environment in which the sector operates. These include energy security and energy cost comparison to other regions (both reality and perception), as these factors are important when investment decisions are made.

[17] These technology groups apply to the pulp and paper sector and also the other seven sector roadmaps.

Industrial Energy Policy Context
Many in the sector have emphasised that the need for long-term energy and climate change policy is key to investor confidence. There is a need for incentive schemes to become long-term commitments, as changes in policy can be damaging, particularly when the business case for investment is marginal and is highly dependent upon factors such as (fluctuating) energy related costs.

Life-Cycle Accounting
As diversification of pulp and paper products continues the tools and methodologies for carbon accounting, to ensure comparability and full understanding of the impacts across the product value chain, is important. An example of this is the functional surface concept in the CEPI Two Team project. Improved standardised carbon accounting methodology can enable appropriate value to be put on carbon benefits and therefore easing the investment in decarbonisation.

Value Chain Collaboration
Partnerships with machine suppliers are needed to refine existing and develop new technologies, as well as collaboration between different paper companies. If customers put a premium on low-carbon paper products then a differential pricing approach would be possible. The challenge for the pulp and paper sector is that it rarely has a direct relationship with the end customer as it typically sells its products to a distributor of some sort. Bio-refinery refers to the conversion of biomass to high-quality products for the evolving bio-economy (bio-polymers, composites with new functionalities, etc.). Paper companies have the knowledge and part of the biomass that can be used to produce these bio-materials.

Research, Development & Deployment
There is a general lack of RD&D projects taking place in the UK pulp and paper sector, meaning that the sector could fall behind other regions with regards to strategy and leadership, knowledge, expertise, training and skills, technologies, and the supply chain. RD&D would form an important part of a vibrant sector in the future, including the contribution to increased decarbonisation and improved energy efficiency. Universities still include some research on pulp and paper, but mills have limited RD&D and do not tend to participate in pan-European projects (like the Two Team project). There is also little development or activity by equipment manufacturers in the UK, meaning the UK tends not to be chosen for pilot plants.

People and Skills
To implement advanced technologies, appropriately trained labour is needed to understand and implement complex new technologies to deliver the most energy and carbon efficient options. This is, and will continue to be, key to decarbonising the sector. While ad-hoc training has continued in the UK, the last graduates from the paper science programmes at the University of Manchester graduated in 2005 and it will be important to the sector to retain and develop appropriate skills. In addition, the current sector age profile means that increased efforts are required to facilitate the next generation of operators and plant managers. Advanced technologies are attractive to the younger generation so it is also an opportunity to attract more young people to start working in the sector.

Key Technology Groups

Electricity Grid Decarbonisation
Decarbonisation of the national electricity grid could provide a significant contribution to the overall decarbonisation of the sector. Very low-carbon electricity is a key part of any decarbonisation plan for the paper and pulp industry. But decarbonised electricity can only be used by industry if it is technically and financially viable to do so, and if there is a sufficient secure supply.

Electrification of Heat
To reach the decarbonisation potential in the Max Tech 1 pathway (applying switching to 100% electricity for heating), decarbonisation of the electricity grid is required, as illustrated above. Actions will be required to ensure that this takes place while maintaining cost-competitiveness.

Fuel and Feedstock Availability (Including Biomass)
Biomass clearly has significant potential as an alternative fuel for the pulp and paper industry, and provides an opportunity to decarbonise the sector (in the Max Tech 2 pathway, using biomass-based CHP). Feedstock availability and cost could, however, be a significant barrier, since power generation, other industrial sectors and domestic heating uses will be competing for the same, potentially limited, resource. There is significant added value to use biomass for heat and power (via CHP technology) compared to power generation only.

Energy Efficiency and Heat Recovery
Implementing current state of the art technology (SAT) has a significant decarbonisation potential for the pulp and paper sector. Many of these technologies have low or low-medium investment costs and could be implemented cost effectively in existing plants. Heat recovery with advanced technologies is required to reach the full decarbonisation potential of the sector. These technologies should be developed soon, which would require significant RD&D and sector collaboration including original equipment manufacturers (OEMs), and attention must be paid to the timing of investments (as they typically have long lifespans). Opening waste industrial heat to support regimes is likely to be required to deliver the full potential of this opportunity.

Clustering
To reach the decarbonisation potential in the Max Tech 1 pathway (using carbon-neutral steam provided through heat networks), clustering represents a significant opportunity to decarbonise the sector. Industrial symbiosis, energy integration and clustering are well-known approaches and much work is available addressing best practice. However in practice these opportunities are limited for existing installations and there can be significant local planning difficulties. Industrial clustering can provide a profitable use for pulp and paper waste or by-products like CO_2 (for CCS/U), recovered heat, etc. By clustering local industries, costs are shared, heat is used efficiently and total benefits increase

5.2 Strategic Conclusions

5.2.1 Strategy, Leadership and Organisation

Strategy is important in any industrial sector or company in that it provides long-term aims and a plan of action of how to achieve the aims. Leadership is required to drive programmes forward and involves developing solutions in response to evidence and analysis.

In order to take this agenda forward, it is considered critical that the pulp and paper sector, the government and other stakeholders recognise the importance of strategy and leadership in the context of decarbonisation, energy efficiency and competitiveness for the sector.

This links to all other conclusions below, including research, development and demonstration (RD&D), energy supply and business case barriers.

A possible action to address this issue is to set up a government-industry working group with responsibility for the pulp and paper sector strategic priorities. This group could bring:

- Leadership and vision to the UK sector, emphasising how pulp and paper production adds strategic value for the UK and why it is important to face the challenges and develop the opportunities for the sector. For example, the UK population is projected to grow significantly and there is currently a large proportion of paper used in the UK that is imported. There may be opportunities to increase the amount of pulp and paper production in the UK, but the industry would have to be willing to invest. A clear vision for the UK sector could encompass the ambition, drive, passion and creativity required to maximise future opportunities for the sector and also continue to spread a positive message and image. This links to a number of the other conclusions, for example, attracting and retaining skilled people.
- An approach to the need to drive forward the joint priorities of maintaining competitiveness of the existing pulp and paper operations (recognising the challenges of operating in the markets within which they reside) and also the need to increase RD&D activity and support technology and product innovation in the sector.
- A high-level link between industry, the government and the EU and a clear framework within which production, technology, energy efficiency and decarbonisation agendas can be taken forward. Members of the working group could engage with executives in corporate headquarters (both original equipment manufacturers (OEM) and pulp and paper production companies) to increase the level of activity and engagement between the UK and the international sector community (for example in RD&D).
- A means to take forward the roadmap agenda with shorter-term action plans, for example, in five-year intervals.

Given that the pulp and paper sector is not currently part of the government's published industrial strategies, the status of energy intensive industries (EII) including the pulp and paper sector within government should be investigated and reviewed periodically.

This 'leadership and strategy' conclusion is also applicable to individual companies, which have a key role in overcoming barriers and strengthening enablers – this links to a number of strategic conclusions, for example, value chain opportunities and shortage of skilled labour. As none of the companies interviewed has a strategy that looks further than 2025 in terms of carbon-reduction targets, it is important to link longer-term conclusions from this project into shorter-term company-level plans.

5.2.2 Business Case Barriers

One of the most important barriers to decarbonisation and energy efficiency, based on the literature, interviews and workshops, is lack of funding for such projects as the return of investment is not attractive enough or there is a lack of capital available. While this is not the only barrier to implementation of decarbonisation and energy efficiency projects (others include risk of implementing new technology, lack of skills, lack of management time, lack of certainty of business case), it is an important issue. With respect to external financing, the evidence suggests that this is not always available on terms (e.g. interest rates) that allow internal investment criteria to be met. Projects are then unable to progress.

A number of ideas were put forward by the stakeholders at the workshops to address this issue; these potential actions are described below:

- Investigate working with OEMs or energy saving companies (ESCO) and their financial support. For example, an external company could be employed to install a specific energy efficiency measure (which they would fund) in return for a share of the benefits. This is an action for industry and could start now for projects that are already defined and ready to implement
- Financial innovation – off balance sheet structuring of project finance

- Waste heat recovery incentive
- Establish an industrial energy efficiency dedicated fund which incentivises energy efficiency, in the context of the overall energy efficiency policy landscape
- Use of third-party funds, for example ethical investment funds
- Electricity Demand Reduction (EDR) programme (see also section 5.3.1)
- Use the full range of outputs from other actions in this Section to make the strongest possible business cases for decarbonisation investments. This would need to be an on-going activity by industry.

It is also proposed that government, the pulp and paper sector and the finance sector continue to develop mechanisms to support energy efficiency and decarbonisation projects.

5.2.3 Future Energy Costs, Energy Supply Security, Market Structure and Competition

It is clearly critical to ensure that future decarbonisation and energy efficiency actions maintain the position with respect to overall cost-competitiveness of the UK sector compared to competing businesses operating in other regions of Europe, Asia and the US. This strategic conclusion links to a number of external factors that influence the business environment in which the sector operates. These include energy security and energy cost comparison to other regions (both reality and perception), as these factors are important when investment decisions are made (see barrier 8 in Table 5, section 3.4.5). There is a role for government in recognising the importance of and link between long-term plans on energy security to investment decisions made by companies in the UK pulp and paper sector. Moreover, the UK energy supply system will influence company decisions to invest in the sector (especially those investments that rely on secure competitive energy supply).

With respect to electricity and gas supply, a potential action is for representatives of the gas and electricity grids to meet with the sector to explore how the regulated utilities can better serve industrial customers – especially with regards to decarbonisation and energy efficiency projects. For example, how can grid connectivity be improved to export power? This could provide demand shifting and benefits to the industry, currently hampered by technical, commercial and regulatory issues. Ofgem should consider a significant code review to determine how industry can participate in the electricity market.

As the markets change, it is important that the sector response includes consideration of what opportunities are presented by product shifts in terms of decarbonisation and energy efficiency (see enabler 1 in Table 4, section 3.4.5).

With regards to the competitive markets in which the sector operates, as highlighted in section 3, this can be a barrier to collaboration on sharing best practice. Example actions to strengthen sharing of best practice are the use of benchmarking systems, pre-competitive joint funding of development projects and review of competition rules regarding decarbonisation and energy efficiency to overcome lack of investment in the development of new technologies.

5.2.4 Industrial Energy Policy Context

Many in the sector have emphasised that the need for long-term energy and climate change policy is key to investor confidence, according to literature and other evidence gathering sources (see section 3.4.5). They also believe that there is a need for incentive schemes to become long-term commitments, as changes in policy (around incentive schemes) can be damaging, particularly when the business case for investment is marginal and is highly dependent upon factors such as (fluctuating) energy prices. Incentives need to encourage energy efficiency and not just decarbonisation, currently, the balance is tipped in favour of decarbonisation (and provision of renewable electricity) which is often not the most cost-effective approach.

Possible actions as next steps to address this conclusion are as follows:

- As part of government's on-going carbon pricing policy, both through the EU ETS and the UK's own carbon pricing, government should consider carefully whether policies could be improved to assess how a price on CO_2 could incentivise investment. Work on this should start now on the assumption that it will take a number of years to implement and many of the decarbonisation options in the pathways depend on investment that needs this to underpin them.
- Government to explore alternative funding arrangements to recognise mid- to long-term decarbonisation benefits. This would allow the value of these benefits to be taken into account in investment decisions. A strong CO_2 price noted above would be one means of doing this, though if such a policy is only within the UK (or EU) wide it runs a real risk of causing carbon leakage by making installations that cannot secure low carbon investment uncompetitive.
- Government to establish a "level playing field" through a global carbon agreement (with regional breakdowns) before 2020. This could provide an alternative means to avoid carbon leakage.

5.2.5 Life-Cycle Accounting

As diversification of pulp and paper products continues the tools and methodologies for carbon accounting, to ensure comparability and full understanding of the impacts across the product value chain, is important. An example of this is the functional surface concept in the CEPI Two Team Project. Improved standardised carbon accounting methodology can enable appropriate value to be put on carbon benefits and therefore easing the investment in decarbonisation.

Example actions include:

- Wider dissemination of knowledge on carbon benefits of existing technologies. This could be an action for industry bodies and equipment manufacturers to take forward.
- Develop standard tools for evaluating life-cycle 'cradle-to-grave' carbon impacts, from original raw material and feedstock through to final product disposal (2015-2016). These should include defined, consistent boundary conditions to ensure results can be compared across sectors. This could be carried out in academia, with industry and government support. This would need to include means to account for the benefits of re-use and recycling.
- Implement policies and incentives that allow the value of carbon benefits to be realised at the appropriate point in the supply chain (by 2020). A global climate agreement would be one way to allow the market to price in these carbon benefits.

5.2.6 Value Chain Collaboration

Collaboration in the value chain includes collaboration with machine suppliers and between different companies to jointly refine existing and develop new technologies. Suppliers are often too optimistic about new technologies. A more balanced view on these new technologies is needed from an independent source.

Potential actions to support this conclusion are described below:

- An audit scheme could be set up to assess new technologies giving independent consultancy through audits and feasibility assessments. They can be assisted by external teams, independently reviewing technologies.

- A partnership or co-funding approach could be explored with the supply chain.

If customers put a premium on low-carbon paper products (see also section 5.2.5) then a differential pricing approach could be possible. This was brought up during the second workshop as a potential to finance energy efficiency and decarbonisation in the sector. The challenge for the pulp and paper sector is that it rarely has a relationship with the end customer as it typically sells its products to a distributor. The pulp and paper industry already have Forest Steward Council and Programme for the Endorsement of Forest Certification that are two certification bodies for sustainability, these schemes could be strengthened and developed – coupled with the following potential actions to support this conclusion:

- Marketing campaigns to increase public knowledge of the sustainability of products from the pulp and paper sector
- Collaborate more within the value chain: for example, co-develop new packaging material for the food and drink sector that is more sustainable and has a smaller carbon footprint than current packaging material, provided the value is recognised

5.2.7 Research, Development and Demonstration

As evidenced in the interviews and the workshops, and as evidenced by the Two Team project, there is a lack of Research, Development and Demonstration (RD&D) projects taking place in the UK. This means that the UK sector could fall behind other regions in a number of ways:

- Strategy and leadership
- Knowledge and expertise
- Training, skills
- Technology
- Supply chain

In short, RD&D would form an important part of a vibrant sector in the future including the contribution to increased decarbonisation and improved energy efficiency.

There is currently little research in the pulp and paper industry in the UK since the closure of the pulp and paper group at the University of Manchester's Institute of Science and Technology, though its School of Materials retains expertise in Paper Physics. The College of Engineering, Maths & Physical Sciences of the University of Exeter also still conducts research into cellulosic materials. UK pulp and paper mills do not have much research or development at their mills and they do not tend to participate in pan-European projects. For example, no one from a UK mill participated in the Two Team project. There is also very little development or activity by equipment manufacturers in the UK and they tend not to choose UK locations for their pilot projects. This is also linked to the topic of leadership and organisation. The fact that many mills are part of a global corporation that has its own research and that participates in European projects is not an excuse for the UK industry to not participate.

The UK pulp and paper industry has an opportunity to take a more leading role in both national and international research. Examples of next steps are described below.

The deployment of new manufacturing technologies is crucial. As companies often perceive the application of such technologies as putting at risk established processes, the pulp and paper industry and Government should work together to demonstrate the applicability and performance of such technologies.

As highlighted in CEPI's Two Team Project, *"as long as the industry continues to think in tonnes of product, new technologies producing different products with the same functionality will not be introduced, even if they* *would bring more value"*. CEPI therefore propose that the sector changes the way it conducts measurements and statistics and report in square meters as well as tonnes. It argues that such a change will be a huge driver for innovation, light-weighting and resource efficiency. The UK pulp and paper industry should work together with CEPI and relevant European standardisation body to move to measure statistics in new and more sophisticated ways, for example in square metres.

In the 'green economy', more and more products are being developed based on renewable resources. The pulp and paper industry is ideally placed to take a more leading role in the 'green' value chain and collaborate more with organisations trying to develop new products based on wood fibres (e.g. Centre for process innovation bio-refinery concept). Even though only 6% of the pulp used in the UK comes from wood, a number of mills are used to handling wood as a resource. The mills that do use wood as raw material have an even greater opportunity to increasingly participate in the 'green economy' value chain. For recycling mills, it is now possible to achieve 3D-printing based on wood fibres from recycled paper.

There are also opportunities to develop new products from material rejected by the mills, including potentially asphalt filler, MDF board and base chemicals. As this material is currently regarded as waste, it can be difficult to re-use it: the regulatory status of these materials should be assessed as part of future activity.

There has been, and continues to be, a considerable amount of research around the concept of the bio-refinery. This is typically related to the kraft pulp process and there are no such mills in the UK. There are other innovative ideas under development that are not reliant on the kraft pulp process that could be applicable to the UK, but the industry and others could collaborate more and actively engage. Research and development for large-scale demonstration projects could facilitate the deployment of such installations.

More potential actions to support these conclusions are described below:

- Support demonstration projects for example through funding and feasibility assessments.
- There is an opportunity for the UK to attempt to secure at least one of the pilot projects stemming from CEPI's Two Team project. It is likely that this would require input from the government as well as a proactive stance from one or more mills that would like to participate.
- It is recommended that the opportunity to collaborate and create higher value-added products (e.g. using the ink) in addition to producing paper is investigated through a programme of applied research.
- Environmental regulation would need to change to allow such 'waste stream' to be more easily recycled and reused. The industry could take a more active role in the development of new products and help create a new revenue stream for its waste.
- Research and development for large-scale demonstration bio-refinery projects could facilitate the development of such installations.
- Assist with or simplify the application processes to secure government and EU funding for research and deployment projects. Also, facilitate ideas exchange and provide improved, clear information on funding possibilities in order to link available research funds with industry and government priorities.

5.2.8 People and Skills

To implement advanced technologies, skilled labour is needed. To make the choice between 'standard' equipment and more energy efficient equipment when making investment, knowledge and time are needed. This is, and will continue to be, key to decarbonising the sector. The last graduates from the paper science programmes at the University of Manchester graduated in 2005 and it will be important to the sector to retain these skills. In addition, the current sector age profile means that increased efforts are required to facilitate the next generation of operators and plant managers.

Advanced technologies are attractive to the younger generation so it is also an opportunity to attract more young people to start working in the sector.

Potential actions to support this conclusion are described below:

- Share generic technical and engineering skills with other major industry sectors. The vast majority of this need can be met by co-operating with (and sharing resources with) other industry sectors (Engineering and Process Industries) sharing similar requirements. This need can already be met within the UK.
- Bring together the Training Resources from across Europe (the vast majority of the training is already delivered in English). Consider if it is possible to construct a comprehensive training programme covering all levels from apprentice to master's degree.
- Develop best practices for maintenance, behaviours, technical competence.
- The government and the sector engage with a wider society and school children in particular to address the perception of the pulp and paper industry, to make the industry more attractive for young people: CPI already provided curriculum linked educational materials to UK schools through the PaperWorks initiative. The government to continue to invest in STEM (science technology engineering mathematics) education – an interdisciplinary curriculum based on science, technology, engineering and mathematics – to attract high-school students to the industry.
- Increase awareness and understanding of all issues in this roadmap.

5.3 Key Technology Groups

5.3.1 Electricity Grid Decarbonisation

As shown in the pathway modelling (Section 4), the decarbonisation of electricity supply has an important contribution to make to overall sector decarbonisation. Trends for electricity decarbonisation in particular are assumed in the pathways model (through the use of the scenarios) and these will need to be achieved to deliver the levels of emissions reduction in the pathways. Decarbonisation of electricity supply is not within the direct control of the sector and so actions here are more likely to lie with government. The Government's reforms of the electricity market are already driving electricity grid decarbonisation, and this report uses assumptions of a future electricity decarbonisation trajectory that is consistent with Government methodology and modelling

Very low carbon electricity is a key part of any decarbonisation plan for the paper and pulp industry. But decarbonised electricity can only be used by industry if it is technically and financially viable to do so, and if there is a sufficient secure supply. It is imperative that the government and industry continue to implement a clear plan to deliver on its promise to decarbonise the national electricity grid. This will encourage industry to make investments in the UK because the long-term regulatory framework is clear.

With regards to the capacity market, the sector is sceptical that the capacity market design will encourage industry participation. One reason is the single calculation method to establish baseline load which does not take account of 'dynamic load'. Demand and load shifting can benefit the UK electricity sector by avoiding the need for new generating assets. In order to make this a success, flexible operation would be required and this might not always be possible.

DECC recently concluded that the sector could not participate in a permanent demand reduction pilot (Demand Side Response) as they are already benefiting from incentives under Climate Change Agreements (CCA). Industry would like to see this situation reviewed, given that permanent demand reduction will change payback times and bring more energy efficient projects into consideration. See also policy context (section 5.2.4) and electrification of heat (section 5.3.2 below).

On smart grids, to allow for electricity export and balancing, the government should continue to support the infrastructure for smart grids or future networks.

Example actions include:

- Continue incentives for electricity decarbonisation – these will need to be on-going to deliver the grid decarbonisation on which the pathways are based.
- Put in place measures to mitigate the cost-competitiveness impact of electricity and gas grid decarbonisation measures on the sector (links to section 5.2.4). It is important that these measures avoid perverse incentives that may inhibit switching to these decarbonised energy sources.

5.3.2 Electrification of Heat

As discussed in section 4, there are two Max Tech pathways, one of which includes a 100% electricity approach as proposed by the Two Team project. This would only provide emissions reduction where the use of electricity would be a lower carbon option than the current energy source – as the grid becomes more decarbonised over time, the list of processes to which this applies will grow, potentially providing a sequence of projects that could be deployed over time (see also section 5.3.1 above). A pulp and paper mill could also be a more active demand response participant as pulp could be used as 'storage' of electricity.

Example actions to enable delivery of this option include identifying those processes where electrification would be feasible, quantify how much potential energy use this represents and at what level of grid decarbonisation conversion to electricity would provide a carbon saving. Industry could take the lead here in identifying suitable processes and at what level of grid decarbonisation each could be deployed.

5.3.3 Fuel and Feedstock Availability (Including Biomass)

Biomass provides an opportunity for the pulp and paper industry to decarbonise as illustrated with the 60-80% CO_2 reduction and Max Tech 2 pathways. Biomass clearly has significant potential as an alternative fuel for the pulp and paper industry. Feedstock availability and cost could, however, be a significant barrier, since power generation, other industrial sectors and domestic heating uses will be competing for the same, potentially limited, resource. A hierarchy of use would be helpful. There is significant added value to use biomass for CHP compared to power generation only. The role of biomass in decarbonising the electricity grid should be carefully considered, the use of biomass in power generation not only adds competition for this resource but also using biomass for power generation only is far less efficient than using biomass for CHP.

Potential actions to support this conclusion are described below:

- Biomass policy needs to be developed taking account of potential impacts from use within (i) the power sector, (ii) industry for fuel (e.g. CHP), (iii) industry as a raw material or feedstock – in addition to other uses and other demands in relation to land use. The pulp and paper sector's requirements are stable supply and prices and so it is recommended that the sector (companies, supply chain) continue to work together with government to assist with facilitating sustainable use of biomass while benefitting the sector in terms of competitiveness and decarbonisation.

In the European vision of 2020 and the EU bio-economy, the term bio-refinery refers to the conversion of biomass to high-quality products for the chemical industry (bio-polymers, composites with new functionalities, etc.). Paper companies are well positioned in terms of knowledge and biomass feedstock to be part of this vision and produce these bio-materials. In several European companies (Netherlands, Germany and France), clusters of companies are combining waste streams and there are opportunities in terms of the large amounts of minerals that can be re-used. In order to be successful, companies are needed whose core business is running the value chain (pooling, logistics, product development, and marketing). Establishing kraft bio-refineries in the UK would be a way to maximise the value of biomass. Not only would this produce a high-quality pulp, it could also produce new product streams that could serve as raw material to the chemical (and other) industries. At the same time, the bio-refinery could be carbon negative as it would be a net exporter of electricity and would offset petroleum-based raw material for the chemical industry. There would need to be a major push to make that investment happen, both from the government and the sector.

Potential actions to support this conclusion are described below:

- Successful initiatives in other EU countries, as well as the applicability for the UK market, should be assessed.
- The industry, working in partnership with the Government, should carry out a feasibility study on the potential of the bio-refinery concept. Interested parties could form a consortium to develop, test or implement the concept. This consortium could be led by CPI or PITA. In this consortium, close cross-sector cooperation with other sectors that can deliver input or technology is key to success.

This links to a number of conclusions including collaborative RD&D, policy and future markets or products.

5.3.4 Energy Efficiency and Heat Recovery

As seen in section 4.4.1, implementing current SAT options would lead to a 29% reduction of CO_2 emissions and as such it has an important potential for decarbonisation of the sector. Many of the SAT have low or low-medium investment costs and could be implemented without requesting investment funds from headquarters. Several of the interviewees acknowledged that if the investment sum was low, it could be made at the discretion of the mill as part of a continuous improvement process in order to stay competitive. Example actions are provided below:

- With increasingly lean organisations and the lack of skilled labour there is a risk that, when improving the mill, decarbonisation is not considered in the investment decision. In order to overcome this barrier, the pulp and paper sector could organise events to encourage companies to share and promote good practice in energy, based on real case studies and examples. Environment Agency engagement is recommended here, with PITA, CPI or another organisation providing the necessary studies. CPI or PITA could also participate in an EU benchmarking programme, collecting information and data from other pulp and paper sectors throughout Europe. UK plants would be able to see what is happening in the EU and improve their own energy efficiency accordingly.
- Another way to overcome the lack of skills in the mills is to develop fact sheets for new State-of-the-Art Technology. The fact sheets could include a list of critical success factors or lessons learnt, for a successful implementation and deployment with different types of mills or production processes.

The production and exact content of fact sheets or other means of sharing information should take account of the specific characteristics of the UK pulp and paper industry. For example, larger UK companies may already be knowledgeable on the technology landscape and are relatively good at sharing information because of commonality in production processes. Smaller companies may have less experience or information on technology scoping. The content should be at an appropriate technical level, with deployment data and business case and ROI details included.

As heat recovery with advanced technologies impacts all pathways, it is an important technology. It is assumed to start to be deployed by 2030, which does not leave much time to develop a technology. As one of the workshop participants said, "*If we could recover all the heat that leaves the dryer, we would achieve significant CO_2 reductions in the sector*". It would require significant RD&D and sector collaboration including OEMs.

This technology option is a continuation of closed hoods, heat recovery on hoods, and traditional heat recovery technology; careful attention must be paid to the timing of these investments as they typically have long lifespans.

5.3.5 Clustering

As shown in the pathways analysis, clustering represents a significant opportunity with regards to decarbonisation in the sector (see Max Tech pathway including the use of heat from a cluster). Industrial symbiosis, energy integration and clustering are well-known approaches and much work is available addressing best practice. Clearly, there are a number of enablers and barriers which apply specifically to clustering.

Industrial clustering can provide a profitable use for pulp and paper waste or by-products like CO_2 (for CCS/U), recovered heat, etc. By clustering local industries, costs are shared, heat is used wisely and benefits increase. It is recognised that changing the location of a mill is likely to be challenging for the pulp and paper industry due to the scale of its operations and size of sites, but this should still be periodically investigated as opportunities may occur depending on company investment cycles.

Potential actions to support this conclusion are described below:

- Energy from waste: Assess the feasibility of installing 'Energy from Waste' facilities on existing mills sites and displace gas CHPs. The majority of the UK pulp and paper industry is based on paper for recycling and typically has strong links with the resource recycling sector. In addition the mills are typically not in Residential Areas and already have Combustion Plants. High pressure steam could be produced to generate electricity to the grid and the paper machine would serve as 'condensing load'. This would not only help decarbonise the grid and the mill but also liberate biomass for the development of new products instead of burning it to produce electricity. An organisation such as WRAP could participate in this activity.
- Heat customers: Investigate the possibility of linking heat consumers and paper mills; for example, new mills near to existing heat opportunities (e.g. energy-from-waste plants) and new heat providers close to existing paper mills. Hence, assess the possibilities on stimulating industrial clustering with taxes and permits, for example focus on growing industries with a big demand for low-grade heat or use of CO_2 and other measures (food and beverage, pharmaceuticals, new bio materials, etc.).
- Bio clusters: The development of a 'green economy' could support a cluster of bio-based industries: see also section 5.3.3 which puts forward the benefits of a bio refinery concept.
- Recovered heat incentive: Review the incentives for heat to enable waste heat recovery and re-use projects.
- Industrial clusters: The sector or trade organisation jointly executes a high-level feasibility study on possibilities for industrial clustering around pulp and paper mills. This study includes a forecast of possible market or customers for the pulp and paper by- or waste-products and also energy opportunities. The study also includes a sensitivity analysis for (several combinations of) governmental actions or measures. Based on the results of the sensitivity analysis, government policies, regulation and an implementation plan are developed and targeted project outcomes are developed.

5.4 Closing Statement

This roadmap report is intended to provide an evidence-based foundation upon which future policy can be implemented and actions delivered. The way in which the report has been compiled is designed to ensure it has credibility with industrial, academic and other stakeholders and is recognised by government as a useful contribution when considering future policy.

It will be successful if, as a result, the government and the pulp and paper sector are able to build on the report's evidence and analysis to deliver significant reductions in carbon emissions, increased energy efficiency and a strong competitive position for the UK pulp and paper industry in the decades to come.

6. REFERENCES

A. Bru, T. Bye, J. Larsson, K. Telle, Technological changes in the P&P industry and the role of uniform versus selective environmental policy, *Statistics Norway*, October 2003

ABB, Paper tech - untapped trends, June 2010

ABP, Branchenleitfaden für die Papierindustrie, *Arbeitsgemeinschaft Branchenenergiekonzept Papier, prepared by IUTA, PTS, LTT and Eutech,* November 2008

Aden N., Bradbury J., Tompkins F., Energy efficiency in US Manufacturing - the case of Midwest pulp and paper mills, *World Resources Institute*, July 2013

AF-engineering AB, Energy consumption in the P&P industry - model mills 2010; integrated fine paper mill, *Market area Forest Industry, Stockholm,* January 2011

Afshar P., Brown M., Austin P., Wang H., Breikin T., Maciejowski J., Sequential modelling of thermal energy: new potential for E optimisation in papermaking, *Manchester and Cambridge Universities*, October 2010

Ahman, M. et al., Decarbonising industry in Sweden, *Lund University,* January 2013

Allwood J.M., Cullen J.M., Carruth M.A., Cooper D.R., McBrien M., Milford R.L., Moynihan M., and Patel A.C.H., Sustainable materials: With both eyes open*, UIT Cambridge, pp. 180,* 2012

Asblad A., Franck P. A., Berntsson T., Learning from experiences with energy conservation in the pulp and paper industry, *CADDET Energy Efficiency*, March 2001

Austin P., Reducing Energy Consumption in Paper Making using Advanced Process Control and Optimisation, *University of Wellington*, February 2010

Aylesford Newsprint ltd., *available online from http://aylesford-newsprint.co.uk.*, consulted on November 2013

Bajpai, P., Biorefinery in the P&P industry, *Elsevier*, 2013

Bajpai, P., Process steps in recycled fibre processing, *Advances in recycling and deinking of recovered paper, Chapter 4*. Elsevier, January 2014

Balser T., Higher quality plus energy savings. *Voith twogether magazine*, November 2012

Barkemeyer R., Figge F., Liesen A., Müller F., Sustainable value creation by pulp & paper companies, *University of Leeds, Euromed & IZT Berlin*, January 2011

BBC, Aylesford newsprint to enter administration, *available online from http://www.bbc.co.uk/news/uk-england-kent-31587533, 23 February* 2015

Bergman, M. A. et al., Large investments in the P&P industry: a count data regression analysis, *Journal of Forest Economics, Vol. 8, Number 1, pp. 29-52(24),* May 2002

Berkeley Lab, Energy efficiency improvement and cost saving opportunities for the Pulp and Paper Industry, *Ernest Orlando Lawrence Berkeley National Laboratory*, *Kramer K.J., Masanet E., Xu T. and Worrell E.,* *Environmental Energy Technologies Division, sponsored by the US Environmental Protection Agency*, October 2009

Berkeley National Lab, Opportunities to improve energy efficiency and reduce greenhouse gas emissions in the US P&P industry, *Ernesto Orlando Lawrence Berkeley National Laboratory*, *prepared by Martin N., Anglani N., Einstein D., Khrushch M., Worrell E. and Price L.K.,* July 2000

Blomberg J., et al., Energy efficiency and policy in Swedish P&P mills: a data envelopment analysis approach, *Energy Policy, 42, pp. 569-579*, December 2011

Blum O., Maur B., Öller H.J., Revision of Best Available Technologies for Pulp and Paper industry - report n°2: use of energy saving techniques, *Federal Environmental Agency Germany and TU Darmstadt - PTS München*, September 2007

Bobu E., Iosip A., Ciolacu F., Potential Benefits of recovered paper sorting by advanced technology, *Technical University of Iasi, Faculty of Chemical Engineering and Environmental Protection,* July 2010

Bobu E., Iosip, A., Advanced sorting of recovered paper: key solution to improve environmental credentials of paper recycling, *Vrancart Presentation,* September 2011

Boyd G. and Fang Guo, Y., Development of Energy Star energy performance indicators for pulp, paper and paperboard mills, *Energy Star*, May 2012

Breitholtz C., The biomass gasification plant to Vaskiluodon Voima in Vaasa, *Metso*, January 2011

Brown, T. et al., Reducing CO_2 emissions from heavy industry: a review of technologies and considerations for policy makers, *Imperial College London*, February 2012

Buckman Green, Transparency (Commercial Folder), October 2013

Buckman Laboratories, Sustainability Report, 2012

Bunse, K. et al., Integrating energy efficiency performance in production management - gap analysis between industrial needs and scientific literature, *Journal of Cleaner Production Vol. 19, Issues 6–7, Pages 667–679*, October 2010

CAN Europe, Horizon 2050 - Steel, Cement & Paper, *Climate Action Network Europe,* July 2010

Carbon Trust, How to implement oxygen trim control, January 2005

Carbon Trust, Industrial Energy Efficiency Accelerator - guide to the paper sector, 2011

Carbon Trust, Industrial renewable heat – Insight paper, May 2014

CCC, Annual report & accounts 12/13, *Committee on Climate Change*, June 2013

CCC, Meeting Carbon Budgets, *Climate Change Committee 2013 progress report to Parliament*, June 2013

CEPI, CEPI sustainability report, *Confederation of European Paper Industries*, 2013

CEPI, Key statistics European Pulp and Paper industry, *Confederation of European Paper Industries,* January 2012

CEPI, Papermaking process, *available online from http://www.cepi.org/system/files/public/static-pages/WEB_paper%20making%20infographic.pdf, consulted on 7 March* 2014

CEPI, The Forest Fibre Industry 2050 Roadmap to a low-carbon bio-economy, *Confederation of European Paper Industries,* 2011

CEPI, Unfold the future: The Two Team Project, November 2013

Chen, H.W., Hsu C.H. and Hong G.B., The case study of energy flow analysis and strategy in pulp and paper industry, January 2012

Chimack, W. M., Energy Conservation Opportunities in the Pulp and Paper Industry: an Illinois Case Study, January 2003

CII, National Best Practices Manual P&P industry, *Confederation of Indian Industry*, January 2010

Collins, L., Environmental performance and technological innovation: the P&P industry as a case in point, *University of Illinois*, January 2013

Collins, L., Renewable energy from wood and paper: technological and cultural implications, *University of Edinburgh*, January 1998

Commonwealth of Australia, Pulp & Paper - Final report, *P&P Industry Strategy Group*, March 2010

Consolato R., et al., Less steam in the boiler, *Voith Twogether magazine 34*, January 2013

Cortés E., Rivera W., Exergetic and exergoeconomic optimization of a cogen P&P mill plant including the use of a heat transformer, *Universidad de Mexico*, May 2009

CPI, CPI Review 2012-2013, *Confederation of UK Paper Industries*, January 2013

CPI, Interviews and evidence gathering from CPI members, *Confederation of UK Paper Industries,* 2014

CPI, UK Paper: Strength through Unity, *Confederation of UK Paper Industries*, January 2013

Croezen H., A long-term view of CO_2 efficient manufacturing in the European Region, *CE Delft*, June 2010

CSE and ECI, What are the factors influencing energy behaviours and decision-making in the non-domestic sector?, *Centre for Sustainable Energy and Environmental Change Institute, University of Oxford report for DECC*, November 2012

de Alda O., Feasibility of recycling P&P mill sludge in the paper and board industries, *Segovia University*, January 2013

De Beer J., Worrell E. and Blok K., Long-term energy-efficiency improvements in the paper and board industry, *Energy, Vol. 23, Issue 1, pp. 21–42*, February 1997

DECC, Energy consumption in the UK, *Department of Energy and Climate Change, available online from https://www.gov.uk/government/statistics/energy-consumption-in-the-uk, September* 2014

DECC, Estimated impacts of energy and climate change policies on energy prices and bills, *UK Department of Energy and Climate Change,* 2012

DECC, RHI evidence report: direct application of renewable heat, *Department of Energy and Climate Change,* October 2014

DECC, The carbon plan: Delivering our low-carbon future, *Department of Energy and Climate Change,* 2011

DECC, The future of heating: meeting the challenge, *Department of Energy and Climate Change*, March 2013

DECC, Valuation of energy use and greenhouse gas emissions: Supplementary guidance to the HM Treasury Green Book on Appraisal and Evaluation in Central Government, *Department of Energy and Climate Change, September* 2014

EC, A roadmap for moving to a competitive low-carbon economy in 2050, *European Commission,* March 2011

EC, BATREF for Energy Efficiency, *European Commission,* February 2009

EC, BREF for the production of pulp, paper and board, *Best available technology Reference document, European Commission Institute for Prospective Technological studies*, July 2013

EC, Development of a model of the world P&P industry, *European Commission JRC Institute for Energy and Transport*, November 2006

EC, Methodology for the free allocation of emission allowances in the EU ETS post 2012 - Sector report for the pulp and paper industry, *report for the European Commission*, *prepared by Ecofys, Fraunhofer Institute, Öko-Institut,* November 2009

EC, Technology Map of the European Strategic Energy Technology Plan, *European Commission JRC Institute for Energy and Transport*, 2011

Eknor C., Reduction of Wet-End rewetting using super absorbents, *Lulea University of Technology*, January 2010

Element Energy, Ecofys, Imperial College, The potential for recovering and using surplus heat from industry and appendix, *report for DECC, pp. 51, 170*, December 2013

Energetics Inc, Energy and environmental profile of the US pulp and paper industry, *report for US DOE*, December 2005

Energietransitie Papierketen, Best EE practices in Dutch paper and hardboard industry, April 2013

ETSAP, IEA and OECD, Global Energy Systems and Common Analyses, *Energy Technology Systems Analysis Programme*, *International Energy Agency, Organisation for Economic Co-operation and development*, June 2008

Eurostat, Energy, transport and environment indicators, January 2013

Fleiter T., Fehrenbach D., Worrell E. and Eichhammer W., Energy efficiency in the German pulp and paper industry - a model-based assessment of saving potentials, *Energy, 4°(1), pp. 84-99,* April 2012

Fleiter T., Schloman B., Arens M., Hirzel S., Rohde C., Eichhammer W., Cebulla F., Idrissova F., Reitze F., Toro F. and Jochem E., Where are the promising energy-efficient technologies? A comprehensive analysis of the German energy-intensive industries, *Proceedings from ECEEE 2011 Summer Study, Toulon (France),* January 2011

Fleiter T., The adoption of energy efficient technologies by firms - an integrated analysis of the technology, behavior and policy dimensions, *Fraunhofer Institute for Systems and Innovation Research ISI*, January 2012

Fracaro G., Vakkilainen E., Hamaguchi M., Nelson Melegari de Souza S., Energy efficiency in the Brazilian P&P industry, *Energies, 5, pp. 3550-3572*, September 2012

Francis, D. W., Energy Cost Reduction in the P&P Industry - an energy benchmarking perspective, *Pulp and Paper Research Institute of Canada*, December 2005

Gasbarro F. et al., The mutual influence of environmental management systems and the EU ETS: findings for the Italian P&P, *European Management Journal, Vol. 31, Issue 1, pp. 16–26*, January 2012

Ghosh A. K., Ahsan A., Fundamentals of Paper Drying – Theory and Application from Industrial Perspective, Evaporation, Condensation and Heat transfer, *AKG Process Consulting*, January 2011

Grossmann H., Exploration of new scientific ideas for significant electricity savings in mechanical upgrading of pulp fibres for papermaking, *Study coordinated by Papiertechnische Stiftung*, January 1997

Gulbrandsen, S., Comparison of a Swedish and a Norwegian P&P company, *Energy Policy, Vol. 56, pp. 516-525,* January 2013

Häckl M., et al., Drying more efficiently, *Voith Twogether magazine 34*, January 2013

Haikola M., Enhancing the EE of PM drives, *ABB, available from www.ipwonline.de*, January 2010

Haydock H. and Napp T., Decarbonisation of heat in industry: a review of the research evidence, *Ricardo-AEA*, July 2013

Hektor, E. et al., Future CO_2 removal from pulp mills - process integration consequences, August 2007

Henriksson E., Industrial electricity demand and EE policy, *Lulea University of Sweden*, January 2010

Holmberg, K. et al., Global energy consumption due to friction in paper machines, *Energy Conversion and Management, Vol. 48, Issue 11, pp. 3025–3033*, November 2007

Hurmekoski E., Hetemäki L., Studying the future of the forest sector: review and implications for long-term outlook studies, *EFI & UEF, Forest Policy and Economics, Elsevier*, May 2013

IBIS, Paper and paperboard manufacturing in the UK, *IBIS World Industry Report C17.120, March* 2013

ICF International, An international comparison of energy and climate change policies impacting energy-intensive industries in selected countries, *London (UK)*, 2012

IEA, Energy Technology Perspectives 2010: scenarios & strategies to 2050, *International Energy Agency,* September 2012

IEA, OECD, Tracking industrial energy efficiency and CO_2 emissions, *International Energy Agency, Organisation for Economic Co-operation and development*, January 2007

Ikonen E., Immonen T., Measurement forms the basis for energy efficiency, *Results Pulp & Paper 2/13*, February 2013

Intelligent Energy Europe, Energy Efficiency trends in industry in the EU - Lessons from the Odyssee Mure Project, September 2012

Isaksson J., Asblad A., and Berntsson T., Influence of dryer type on the performance of a biomass gasification combined cycle, *Biomass & Bio-energy, Vol. 59, pp. 336-347*, April 2013

Isaksson J., Pettersson K., Mahmoudkhani M., Asblad A. and Berntsson T., Integration of biomass gasification with a Scandinavian mechanical P&P mill - consequences for mass and energy balances and global CO_2 emissions, *Energy, 44, pp. 420-428,* August 2012

Jacobs & Institute of Paper Science and Technology, Pulp and Paper Industry - Energy Bandwidth Study, *Report for AIChE and DOE*, August 2006

Jonhston, K. et al., SolarSoft increases speed and saves energy, *Voith Twogether magazine*, January 2010

Jönsson J., Berntsson T., Analysing the potential for implementation of CCS within the European P&P industry, *Chalmers University Göteborg*, May 2012

Kong, L., Price L., Hasanbeigi A., Liu H. and Li J., Potential for reducing paper mill energy use and CO_2 emissions through plant-wide energy audits: a case study in China, *Applied Energy, Vol. 102, pp. 1334–1342*, February 2013

Köpenick M., Pulp & Paper International, Setting a high standard, *RISI*, November 2013

Kriechbaum, G., Energy on two counts: energy savings and energy recovery, *Voith Twogether magazine*, January 2010

Laes E. et al., A low-carbon roadmap for Belgium / Industry sector, *presentation for Health, Food Chain Safety and Environment*, July 2005

Lamminen S., The world's largest biomass gasification plant supplied by METSO, *Results Pulp & Paper 2/13*, February 2013

Laurijssen, J., De Gram F., Worrell E. and Faaij A., Optimizing the energy efficiency of conventional multi-cylinder dryers in the paper industry, *Energy, Vol. 35, Issue 9, pp. 3738–3750*, May 2010

Laurijssen, J., Faaij A. and Worrell E., Benchmarking energy use in the paper industry - a benchmarking study on process unit level, *Energy Efficiency, Vol. 6, Issue 1, pp. 49-63*, June 2012

Laurijssen, J., Marsidi M., W~estenbroeck A., Worrell E. and Faaij A., Paper and biomass for energy: the impact of paper recycling on energy and CO_2 emissions, *Resources, Conservation and Recycling, Vol. 54, Issue 12, pp. 1208–1218*, August 2009

Lehtinen M., Sahlsten H., Bio-oil production offers an extra revenue source for CHP plant, *Results Pulp & Paper 2/2013*, February 2013

Liew, J. P., More effective dryer fabrics thanks to synstron, *Voith Twogether magazine*, January 2011

Lipponen, J. et al., The IEA CCS Technology Roadmap: one year on, *International Energy Agency*, October 2010

Marechal F. and Perin-Levasseur Z. P., Efficient energy conversion in the P&P industry - Annual report, École polytechnique fédérale de Lausanne (*EPFL)*, November 2005

Marshman et al., Energy optimization in a P&P mill cogen facility, *2010 American Control Conference*, April 2010

Marsidi, M. et al., Maximum value from paper for recycling, *Confederation of European Paper Industries (CEPI),* August 2011

Matias S., Silva C., Raventos A., Roadmapping renewable energies: uncertainties review and assessment, *Institute of Mechanical Engineering, Instituto Superior Técnico and WavEC - Wave Energy Centre*, October 2012

McKenna, Industrial energy efficiency, *University of Bath*, March 2009

Mensink M., Presenttaion given at the first workshop of the pulp and paper sector decarbonisation project, *Manchester*, 2014

Metso, A comparative study of new steambox design and performance, November 2013

Metso, Board machine dryer sections, January 2005

Möllersten K., Yan J. and Westermark M., Potential and cost-effectiveness of CO_2 reductions through energy measures in Swedish pulp and paper mills, *Energy, 28, pp. 691-710,* 2003

Müller, W., 20% energy savings due to intensapulper IP-R, *Voith Twogether magazine*, January 2010

NCASI, Environmental footprint comparison tool - effects of recycled fibre use, *National Council for Air and Stream Improvement*, January 2009

NIFES, Drying in the Paper industry, *NIFES Consulting Group for the European Commission*, January 1998

NN., Viability of biomass-fuelled cogen plants in paper mills, *The Bulletin on Energy Efficiency, Vol. 2 issue 4*, February 2002

Notenboom, J. et al., Climate and Energy Roadmaps towards 2050 in NW Europe, *Netherlands Environmental Assessment Agency*, September 2012

NREL, JI Network, Broadening the appeal of marginal abatement cost curves: capturing both carbon mitigation and development benefits of clean energy technologies, *National Renewable Energy Laboratory (NREL)*, *prepared by Cowlin S., Cochran J., Cox S., Davidson C., van der Gaast W*., May 2012

OECD, IEA, World Energy Model 2013, *Organisation for Economic Co-operation and Development*, January 2013

Osara M., Energy-saving solutions for the paper machine, *Metso*, January 2010

Ostle, G., Innovative ways of handling steam lead to energy efficiency, *In Paper 360°, pp. 12-14*, July 2012

Ostle, G., Today's new and improved chemicals, minerals, starch industry, *In Paper 360°, pp. p20-26*, July 2012

Persson J., Berntsson T., Influence of seasonal variations on energy-saving opportunities in a pulp mill, *Chalmers University of Technology*, August 2009

Popp D. et al., Environmental policy vs. public pressure: innovation and diffusion of alternative bleaching tech, *Research Policy, Vol. 40, Issue 9, pp. 1253–1268,* January 2013

Pulp and Paper Technology, *from www.pulpandpaper-technology.com.,* retrieved November 2013

Pulp, paper & logistics magazine, Recycling technology recognized in Brussels, November 2013

Reese D., Update on paper machine energy conservation, *In Paper 360°, pp. 16-20*, July 2012

RISI, PPI Europe, November 2013

Ruohonen P., Hippinen I., Tuomaala M., Ahtila P., Analysis of alternative secondary heat uses to improve EE - Case study of a Finnish mechanical P&P mill, *University of Helsinki,* July 2009

Schock B., Available and emerging technologies for reducing greenhouse gas emissions from the pulp and paper manufacturing industry, *US Environmental Protection Agency,* October 2010

SETIS, Energy efficiency and CO_2 reduction in the P&P industry, *Strategic Energy Technologies Information System*, January 2011

Siitonen, S., Implications of energy efficiency improvement for CO_2 emissions in energy intensive industry, *Aalto University*, September 2012

Spachman J., Not just hot air, *ABB, pp. 30-32*, May/June 2007

Stawicki B. and & Read B., The future of paper recycling in Europe: opportunities and limitations - final report of COST action E48: "The limits of paper recycling", *COST*, January 2010

Stepan P., Jones D., Feasibility study on improving the evidence base for industrial EE - phase 1 report, *Verco report for DECC* November 2013

Swagelok, Combustion trim for boilers, January 2005

Thollander P. and Palm J., Improving EE in industrial energy systems - an interdisciplinary perspective on barriers, energy audits, energy management, policies and programs, *Springer Verlag,* January 2013

Thollander, P. and Ottosson M., An energy efficient Swedish pulp and paper industry - exploring barriers to and driving forces for cost-effective energy efficiency investments, *Linköping University*, October 2007

Thorp B., Seamans H. and Akhtar M., Cellulosic Bioproducts will be important to P&P, *In Paper 360°, pp. 18-19*, November 2013

Tyagi, Thaphliyal, Mathur, A review on developments in paper machine clothing for achieving higher energy savings, *IPPTA, Vol. 25, No. 4, pp. 103-107*, January 2005

UNIDO & MITI, Manual P&P Industry, *Output of a seminar on EC in P&P industry, Energy Conservation Center Japan, United Nations Industrial Development Organization and Malaysian Ministry of Trade and Industry*, January 1993

UNIDO, Carbon Capture and storage in industrial applications, *United Nations Industrial Development Organization*, November 2010

UPM Kymmene, Press release, *available online from http://www.upm.com/EN/MEDIA/All-news/Pages/UPM-introduces-a-new-profit-improvement-target-of-EUR-150-million-%E2%80%93-UPM-Paper-EN-001-Thu-13-Nov-2014-09-31.aspx, 13 November* 2014

US DOE, An efficient and environmentally benign technology for papermaking, *US Department of Energy*, September 2001

US DOE, Oregon Mill uses model-based energy assessment to identify energy and cost savings opportunities, *US Department of Energy Industrial Technologies Program*, April 2004

US DOE, Replace pressure-reducing valves with backpressure turbogenerators, *US Department of Energy – Energy Efficiency and renewable Energy, Advanced Manufacturing Office, Steam Tip Sheet #20,* January 2012

US DOE, Save Energy Now, *US Department of Energy,* March 2008

US EPA, Available and emerging technologies for reducing greenhouse gas emissions from the petroleum refining industry, *US Environmental protection Agency,* October 2010

Usher, W., Strachan. N., Crucial mid-term uncertainties in long-term decarbonisation pathways, *Energy Policy, Vol. 41, pp. 433–444*, November 2011

Utlu, Z., Kincay O., An assessment of a pulp and paper mill through energy and exergy analyses, *Istanbul University*, May 2013

Van Deventer H. C., Industrial superheated steam, *TNO Environment*, January 2004

Voith magazine, Saving energy with LEDs, *Voith Twogether magazine*, January 2011

Voith, 33% Less Energy thanks to Low Energy Flotation, *Voith Twogether magazine 32/2011, pp 12*, January 2011

Voith, Less energy, water & waste worldwide, *Voith Twogether magazine*, January 2011

Williamson, M., Where there's steam, there's energy to be saved, *Dans Paper 360°*, pp. 8-10, July 2012

Worrell E. et al., World Best Practice Energy Intensity Values for Selected Industrial Sectors, *Ernest Orlando Lawrence Berkeley National Laboratory*, February 2008

7. GLOSSARY

Adoption

The percentage of sector production capacity to which a carbon reduction option has already been applied. Therefore, of the list of options being assessed, this is a measure of the degree to which they have already been deployed in the sector.

Applicability

The percentage of the sector production capacity to which a particular option can be applied. This is a measure of the degree to which a carbon reduction option can be applied to a particular part of the sector production process.

Barrier to Decarbonisation or Energy Efficiency

Barriers are factors that hinder companies from investing in and implementing technologies and initiatives that contribute to decarbonisation.

Business as Usual (BAU)

A combination of carbon abatement options and savings that would be expected with the continuation of current rates of deployment of incremental improvement options in the sector up to 2050 without significant intervention or outside support.

Decarbonisation

Reduction of CO_2 emissions (in $MtCO_2$) – relative to the reference trend for that scenario. When we report carbon dioxide, this represents CO_2 equivalent. However, other greenhouse gases were not the focus of the study which centred on both decarbonisation and improving energy efficiency in processes, combustion and indirect emissions from electricity used on site but generated off site. Also, technical options assessed in this work result primarily in CO_2 emissions reduction and improved energy efficiency. In general, emissions of other greenhouse gases, relative to those of CO_2, are very low.

Carbon Reduction Band or Bin

The percentage ranges of CO_2 reduction achieved for a given pathway in 2050 relative to the base year, e.g. 20-40% of the base year emission.

Carbon Reduction Curve or Profile

A quantitative graph which charts the evolution of sector carbon emissions from 2014 to 2050.

Competition Law

The UK has three main tasks:

- Prohibiting agreements or practices that restrict free trading and competition between business entities. This includes in particular the repression of cartels.

- Banning abusive behaviour by a firm dominating a market, or anti-competitive practices that tend to lead to such a dominant position. Practices controlled in this way may include predatory pricing, tying, price gouging, refusal to deal and many others.
- Supervising the mergers and acquisitions of large corporations, including some joint ventures. Transactions that are considered to threaten the competitive process can be prohibited altogether, or approved subject to 'remedies' such as an obligation to divest part of the merged business or to offer licences or access to facilities to enable other businesses to continue competing.

Deployment

Once the adoption and applicability of an option has been taken into account, each option can be deployed to reduce part of the sector's CO_2 emissions. Hence, the deployment of the option from 2015 through to 2050 is illustrated in our analysis by the coloured matrix on the pathway presentations.

Enabler for Decarbonisation or Energy Efficiency

Enablers are factors that that make an investment feasible or would either help mitigate a barrier.

Grid CO_2 Emission Factor

A specific scenario assumption relating to the average carbon intensity of grid electricity and projection(s) of how this may evolve to 2050

Maximum Technical Pathway (Max Tech)

A combination of carbon abatement options and savings that is both highly ambitious but also reasonably foreseeable. It is designed to investigate what might be technically possible when other barriers are set to one side. Options selected in Max Tech take into account barriers to deployment but are not excluded based on these grounds. Where there is a choice between one option or another, the easier or cheaper option is chosen or two alternative Max Tech pathways are developed.

Option

A carbon reduction measure, often a technical measure, such as a more efficient process or technology.

Option Register

The options register was developed jointly by the technical and social and business research teams. This was achieved by obtaining the list of potential options from interviews, literature, asking participants at the information gathering workshop which options they would consider viable, and through engagement with members of the relevant trade associations.

Pathway

A particular selection and deployment of options from 2014 to 2050 chosen to achieve reductions falling into a specific carbon reduction band.

Projection of Production Changes

A sector specific scenario assumption which defines the changes in production as an annual percentage change to 2050.

Reference Trend

The carbon dioxide emission trend that would be followed if the 2012 base year emissions were affected by production change and grid decarbonisation in accordance with the sector specific scenarios.

Scenario

A specific set of conditions external to the sector which will affect the growth and costs of production in the sector and affect the timing and impact of options on carbon emissions and energy consumption.

Scenario Assumptions

A set of specific cost and technical assumptions which characterise each scenario. These include forward fuel and carbon price projections, grid CO_2 factor projection and background economic growth rate. The assumptions may include sector forward production projections.

Sensitivity case

The evaluation of the impact of changes in a single assumption on a pathway, e.g. the availability of biomass.

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