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 Appendices

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INDUSTRIAL DECARBONISATION AND ENERGY EFFICIENCY ROADMAP TO 2050 – PULP AND PAPER

APPENDIX A - METHODOLOGY

APPENDIX A METHODOLOGY

The overall methodology used in this project to develop a decarbonisation roadmap for the pulp and paper sector consists of four stages:

(1) Evidence gathering and processing based on literature, interviews and workshops
(2) Modelling of draft pathways, including scenario testing and sensitivity analysis
(3) Testing and developing final pathways
(4) Creating a sector vision for 2050 with main conclusions and recommendation of next steps

This methodology is illustrated in Figure 1 and summarised in the report. A detailed description is given in this appendix.

An important aspect of the methodology has been stakeholder engagement to ensure that all implicated parties have been invited to participate and contribute. We have worked closely with both CPI and PITA to identify and invite the right people from the sector. In addition we have worked with the Department of Energy and Climate Change (DECC) and the Department for Business Innovation and Skills (BIS) to identify appropriate academic and other stakeholders, such as financial industry personnel, to participate and contribute.

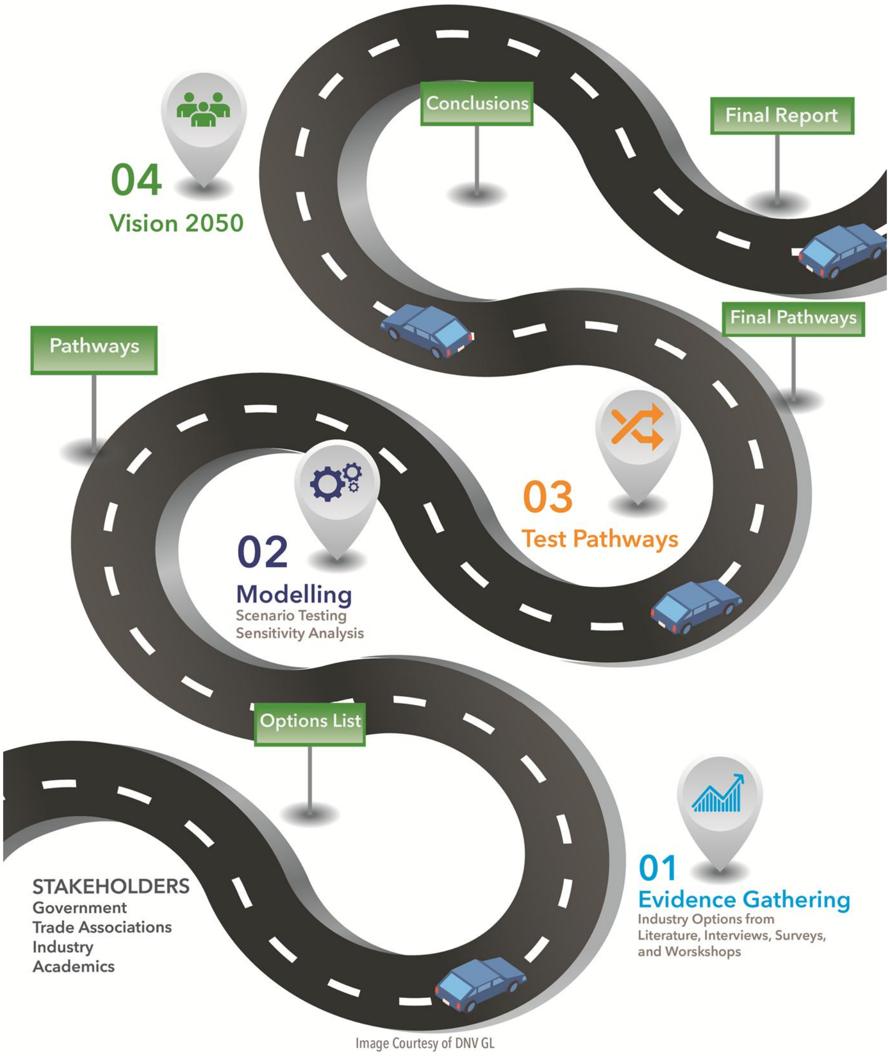

Figure 1: Roadmap methodology

1. Evidence Gathering

Evidence gathering focused on technical and social and business evidence, and aimed to acquire information about:

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

This evidence was required either to answer the principal questions directly, or to inform the development of pathways and the sector vision for 2050. The evidence was developed from the literature review, interviews and evidence gathering workshops. By using three different sources of information, the evidence gathered could be triangulated to improve the overall research. Themes that were identified during the literature review could subsequently be used as a focus or a starting point during the interviews and workshops. The data from the literature could be subjected to sensitivity testing by comparing it with information from the interviews and the workshops. In a similar way, information gaps during the interviews and workshops could be populated using literature data.

The three sources of evidence were used to develop a consolidated list of barriers and enablers for decarbonisation, and a register of technical options for the pulp and paper sector. This information was subsequently used to inform the development of a set of pathways to illustrate the decarbonisation potential of the pulp and paper industry in the UK.

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 members of DECC and BIS.

The evidence gathering exercise 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 literature review was not intended to be exhaustive and aimed to capture key documentation that applied to the UK. The companies interviewed represented over 80% of carbon emissions produced in the UK pulp and paper sector and captured 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. However, because many of the companies in the UK are globally owned, it was difficult to involve senior staff at a global corporate level. This also applied to workshop attendees.

The identification of relevant information and data was approached from a global and UK viewpoint. The global outlook examined dominating technologies and process types, global production and CO_2 emissions (in the EU-28) and the global outlook to 2050, including the implications for pulp and paper producers and consumers, and production and demand uncertainties. The UK outlook examined 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. The major UK pulp and paper producers and their key sites, dominant technologies and processes were also reviewed.

Options examined were relevant to fibre supply, the paper machine and the provision of utilities, as well as options that were applicable across the whole mill. Transformative options from the Confederation of European Paper Industry's (CEPI) Two Team Project were also included.

2. Literature Review

A literature review was undertaken on the pulp and paper sector. Its aim was to help to identify options, barriers and enablers for implementing decarbonisation throughout the sector. It seeks to answer the principal questions, determine the barriers and enablers for implementing decarbonisation and identify what are the necessary conditions for companies to invest and consider carbon management as a strategic issue to determine appropriate technical options for the sector.

The literature review covered over 150 documents. This was not a thorough literature review or rapid evidence assessment (REA) but a desktop research exercise deemed sufficient by the project team[1] in its breadth and depth to capture the evidence required for the purpose of this project. Based on the table of contents and a quick assessment (10 to 30 minutes per document), criteria were defined to identify which documents were to be used for the detailed analysis and evidence gathering (see 3 of APPENDIX A). Where

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

literature was deemed significant and of good quality, it was read and results were gathered on the principal questions.

The review has drawn on a range of literature (published after 2000), that examines energy efficiency and decarbonisation of the sector and also wider reviews, studies and reports deemed relevant to energy-intensive industries overall. Sector based and academic literature was also added. The documents are listed in section 6 of the main report.

The literature review was conducted in the following phases:

- Broad literature review and information or data collection
- Detailed literature analysis on technical points of note
- Identification of decarbonisation options and associated drivers or barriers
- Information on adoption rate, applicability, improvement potential, ease of implementation, capex, Return on Investment (ROI) and the saving potential for all options where available
- Construction of decarbonisation options list for short- (2015-2020), medium- (2020-2030) and long-term (2030-2050)
- Provision of information on strengths, weaknesses, opportunities, threats, enablers and barriers. This information was used in the evidence gathering workshop as a starting point for discussion. It provided evidence to support the development of a consolidated list of enablers and barriers for decarbonisation and, subsequently, to inform the list of the possible technological options and pathways that would lead to decarbonisation.

	Details
Main focus (all in the pulp and paper sector)	Energy efficiency improvements CO_2 and carbon reduction Fuel switching
Secondary focus	Drivers, barriers, policy Carbon capture and storage (CCS)
Excluded	Alternative trends in paper-making (e.g. paper based on plastics) District heating Technologies not applicable in UK pulp and paper sector (e.g. black liquor, gasification, chemical pulping, kraft)

Table 1: Scope of review

3. Criteria for Including Literature

As described earlier, the literature review followed a quick assessment process. General criteria used for including or excluding literature are shown in Table 2.

	Considerations	Final criteria
Literature value	Preference was given to official publications, such as academic papers or governmental publications. Information from paper machine constructors or pulp and paper suppliers (grey literature) was interesting as sector-related info. However, as there is no objective standard with which to compare this information, no extensive search in this domain was executed. The grey literature	Preference was given to published papers: the main source was ScienceDirect and published official reports.

	was used as input to the workshops.	
Time period to be covered	Given the fact that the European Energy Directive (end 2012) is a recent factor in the energy-related political landscape, preference was given to information which was (very) recently published. Some valuable, but older, information was included, as technology penetration is conducted at different speeds throughout the pulp and paper sector	No constraint was set on the date of the publication, but older information was given a lower quality rating, due to its lower relevance.
Geographical area	Preference was given to the UK industry, with a broader look to Europe (Scandinavia and Germany), as the technology competition in this area is the most prominent.	No geographical exclusion criteria were used, but information on the UK pulp and paper was given a higher quality rating, due to its higher relevance.
sector specifics	Given the specific nature of the UK pulp and paper sector, some technologies could be discarded, as there are no plants using them.	All information on black liquor was discarded, as of no importance to the UK. Similarly, not much focus was given to virgin pulping including chemical (kraft) and mechanical pulping.
Language	As the majority of information is in English, no special attention was given to publications in other languages.	The search was limited to papers in English, but where easily obtainable qualitative information was found in other languages, this was included[2].

Table 2: High-level selection criteria

For academic literature, the primary source was ScienceDirect. Of the documents that came on top in the search result (typically the first 25 papers), a skim-read of the abstract decided on the relevance of the paper.

A total of more than 150 papers, official publications and grey literature experts on pulp and paper were collected using this search methodology. The quality, source and objectivity of each document was analysed by reading the abstract (where present), followed by a skim-read of the document.

Each document was given a score on different aspects of relevance:

- Category: is the content of the document focusing on technology, drivers or barriers or policy-related aspects
- Affiliation: what is the source of the document: academia, governance or is it sector-based
- Financial-technical evaluation criteria present (YES/NO)
- Overall quality of the document (+/++/+++)
- Relevance for the UK pulp and paper sector (0/+/++/+++)
- Information on technological aspects (0/+/++/+++)
- Information on drivers and barriers (0/+/++/+++)
- Information on policy/legislation (0/+/++/+++)
- Document relevant for developing scenarios (0/+/++/+++)

Based on all these aspects, the document was given a relevance classification: ‘high’, ‘medium-high’, ‘medium-low’ or ‘low’.

[2] Some valuable references are in Dutch or German.

The approach to selecting and categorising literature is depicted in Figure 2.

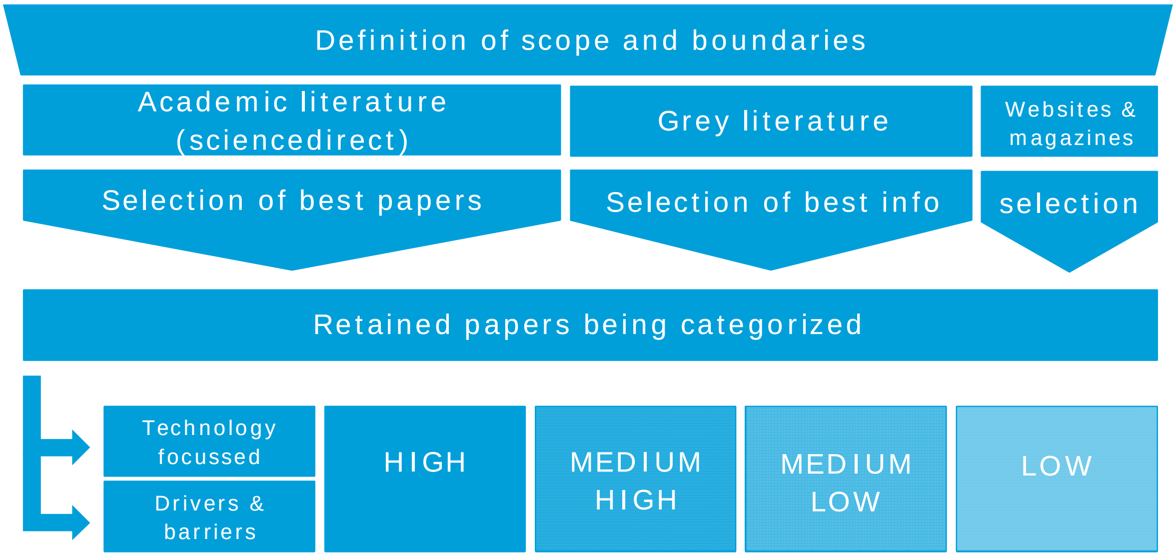

Figure 2: Diagram of the selecting and categorising process

All documents categorised as 'high' and 'medium-high' were read in detail, assessed and then included in the literature review process. The documents categorised as 'medium-low' and' 'low' were read and assessed in part and only included if a significant reason for inclusion was found.

Energy saving measures (if present) were listed from each document included in the review process and this list was used to construct a decarbonisation options list for short- (2015-2020), medium- (2020-2030) and long-term (2030-2050) timelines.

NOTE: Additional and specific information or data was added to the overall review process from e.g. stakeholder input datasheets and as a result of following citation trails, expert knowledge and further targeted searches and recommendations.

Method of Analysing Literature

The following method was used to go through the selected literature:

1. Reading and noting of the abstract (or summary) followed by review of the document in detail to extract any relevant information on sector description or outlook and information or data on energy and carbon reduction measures
2. Relevant information (if appropriate) was extracted from other sources (or referred to) and document citation trails (if appropriate) were checked for further relevant information or data
3. Incorporation of the documents into the literature review and collating of the most relevant information or data on energy and carbon reduction measures
4. Energy reduction, where possible, were preferably extracted as a percentage, or as a specific energy saving per relevant unit (e.g. kWh/tonne pulp or GJ/tonne paper)
5. For financial savings, the amounts were kept in their original currency

4. Technical Literature Review

Identifying Literature

The primary aim of the literature review has been to gather evidence on technical potential and options (under different timelines) in order to inform the opportunities and challenges associated with the decarbonisation of energy use and improved energy efficiency for the pulp and paper sector in the UK.

In parallel to the above review process, a number of key academics were identified to participate and provide perspectives on current research and to provide additional input and feedback. This was to ensure that the appropriate literature and research had been identified, screened and included.

Research Questions

The evidence review addressed the following research questions:

TECHNICAL POTENTIAL: What existing research is there on the technical potential for improving the energy efficiency and lowering the carbon footprint of the pulp and paper industry to 2050? What generic and specific technical measures exist and what is their potential?

TECHNOLOGY COSTS: What research is available on the costs of these technical measures, and what does it tell us?

DRIVERS or ENABLERS: What does research tell us about the drivers or enablers for organisations in the pulp and paper sector to decarbonise their energy use? What are the perceived benefits for industrial organisations to decarbonise their heat use?

BARRIERS: What does research tell us about the barriers for organisations limiting effective decarbonisation of their energy use?

PRINCIPAL QUESTIONS: Check for other links to issues raised by principal questions.

SWOT ANALYSIS: Check for any information using terms strengths, weaknesses, threats and opportunities.

Information Found by the Consortium during Technical Literature Review

A number of additional documents were identified during the course of the literature review. These documents were identified through Google or ScienceDirect[3] and through the pulp and paper sector team. The search terms used in ScienceDirect and Google were:

- “Pulp”
- “Pulp and paper”
- “Pulp” AND “UK”
- “Pulp and paper” AND “energy case study”
- “Pulp and paper” AND “energy (reduction)”
- “Pulp and paper” AND “recycle/recycling”
- “Pulp and paper” AND “UK”
- “Pulp and paper” AND “newsprint / tissue”
- “Pulp and paper” AND “carbon capture / CCS”
- “Pulp and paper” AND “refining”
- “Pulp and paper” AND “energy/energy consumption”
- “Pulp and paper” AND “CHP / cogen (eration)”
- “Pulp and paper” AND “driver(s)/barrier(s)”

[3] http://www.sciencedirect.com/

- “Pulp and paper” AND “policy/politics”

Other documents in ScienceDirect were found by checking the references of the papers found by the above searches.

The results of the technical literature review are summarised in Figure 3.

Summary of strength of evidence on energy efficiency in pulp and paper									
Division	Number of information sources reviewed					Strength of the evidence			
	Academic searches	Direct website searches	expert reviewer	grey literature	Total	HIGH	MEDIUM HIGH	MEDIUM LOW	LOW
General	28	29	29	0	86	15	31	30	10
Pulping	1	2	3	0	6		2	4	
Paper Machine	6	4	13	0	23	5	5	11	2
CO2 & CCS	12	8	4	0	24	1	9	13	1
Drivers/barriers	0	6	2	0	8	4	4		
Social and Business	16	6	3	12	37	3	10	11	13
Pathways	1	2	0	0	3	1	2		

Figure 3: Overview of literature review

A complete reference list is available in **Error! Reference source not found.** 6 of the main report.

5. Social and Business Literature Review

In addition to the work and processes described in the technical literature review, the social and business literature review key points and additions are:

- We reviewed over 37 documents (some of them the same as the technical literature review) to create a broad overview of the sector SWOT and identification of drivers and barriers to energy efficiency improvement and decarbonisation, and identification of main uncertainties in generic and business environment.

- The literature review included documents listed in the ITT (invitation to tender) as well as grey literature from trade associations, companies, DECC and BIS. Specific search terms were used which were agreed with DECC to identify the key enablers and barriers.

- We used a systematic and structured approach to the literature review. The criteria for assessing the relevance of the literature were defined to determine whether they address the key principal questions. The literature identified was analysed using a quick assessment process to identify the most relevant information on SWOT, enablers and barriers to decarbonisation.

- Based on table of contents and a quick assessment, we presented the results in a table as below. The analysis resulted in the identification of documents to be used for detailed analysis and evidence gathering. Where literature was deemed significant and of good quality (three stars or above), the literature was read and reviewed and results were gathered on the principal question areas.

	Year	Relevance	Quality	Characteristics	SWOT, Drivers and Barriers	Uncertainties future trends	options	pathways
Title 1		+++	++	0	++++	++	0	++++
…		++	+++	++	0	+++	+	+
…		+	++	+	0	++++	++	0
Title 10		++	++++	+++	++	+++	+++	++

Table 3: Literature review assessment process

0= very low, ++++ very high

The outcome of the literature review was a comprehensive list of strengths, weaknesses, opportunities, threats, enablers and barriers which were used in the evidence gathering workshop as a starting point for discussion and voted on to check which ones were most important.

6. Interviews

The evidence gathering stage of the project also involved a series of interviews. These aimed to obtain further details on the different subsectors within the pulp and paper industry and to gain a deeper understanding of the principal questions, including how companies make investment decisions, how advanced technologies are financed, the companies' strategic priorities are and where climate change sits within this.

Of the 17 biggest pulp and paper companies that represent 80% of the sector emissions, there are four subsectors: printing and writing (two), packaging (six), newsprint (three) and tissue (six). Although the sector is very heterogeneous, the different subsectors have similar manufacturing equipment and are facing the same type of challenges. It was agreed to undertake five interviews for the pulp and paper sector. We identified the proposed interviewees in liaison with CPI, DECC and BIS, and in accordance with the pre-defined criteria.

Five face-to-face interviews were completed and the following companies were interviewed:

- DS Smith - Procurement, EU Energy Manager (packaging)
- Arjo Wiggins - Mill Manager (printing and writing)
- KCC - Energy and Environment Manager (packaging and tissue)
- UPM - Head of Environment, UK and Ireland (newsprint, printing and writing, packaging)
- Smurfit Kappa - Energy Manager (packaging)

Comments collated via CPI, the workshop and subsequent email correspondence was also used as part of the evidence gathering process.

Interviewees were interviewed using the ‘interview protocol’ template, developed in liaison with DECC and BIS. The interview protocol was used to ensure consistency across interviews, to ensure that the interviews could be used to fill gaps in the literature review, identify key success stories of decarbonisation, and extract the key social and business barriers of moving to low-carbon technologies. The interview protocol can be found further in this section.

Evidence Gap

At the end of the evidence gathering process, it was recognised that a number of the UK mills are owned overseas and a key challenge with organising the interviews in this sector was that it was difficult to gain buy-in for the key investment decision makers outside the UK to participate in this project. It was also decided that further information was required on biomass. Therefore, two additional interviews were agreed with senior level decision makers:

- Smurfit Kappa – CEO
- Iggesund Paper and Board - Managing Director

These interviews helped to reaffirm the decision-making hierarchy and supported the enablers and barriers identified in this report. One interview focused heavily on the installation of a 100% biofuel based CHP plant and the decisions leading up to this investment, providing highly valuable insight for this report. It was also agreed to have an additional interview with CPI to help fill in any gaps in the evidence.

Assumptions

Going into each interview, a number of assumptions were made to refine the approach being taken:

1. Results from the literature review are available and partially well covered. Well covered areas are not addressed during the interview. Results may include:
    a. Options register of technical options
    b. Sector and subsector characteristic
    c. Sector SWOT analysis
    d. Main trends and drivers
    e. Some hurdles to and barriers for change, or energy or carbon reduction

2. Preparation of interviews includes rapid review of website and annual reports information related to business and energy and emissions reduction strategies.
3. The technical review covered any gaps in data or information (e.g. specifically related to that company's data) which may be appropriate to obtain during the interview process.
4. Interviewee role is reviewed prior to conducting the interview.
5. All interviews are conducted by interviewers in their own proficient way of dealing with issues around openness, consent, and follow-up.
6. Interviews are conducted by PB or DNV GL consultants (representatives from both technical and social and business disciplines), with their own proficient way of dealing with issues around openness, issues of consent, encouraging openness, and follow-up.
7. There might be follow-up with interviewees to obtain additional information discussed during the interview.

Interview Protocol

Preparation

1. Interviewee identification

Interviewees are identified in liaison with DECC and BIS in order to achieve good coverage of each sector. The steps taken to identify relevant candidates are:

- Identify the number of subsectors using SIC (standard industrial classification) codes listed in the ITT or another appropriate subsector division
- Where possible, subsectors were grouped based on similarities in products or production techniques to reduce the number of subsectors
- Identify which subsectors and/or organisations were most significant using the following criteria:
    - Size (e.g. by revenue or emissions)
    - Innovation level of companies
    - Whether headquartered in UK
    - Level of supply chain integration
- Select candidates best positioned to represent the views of the breadth of subsectors

***2.* Interview preparation**

The focus of each interview is to be informed by research of the key issues and challenges, successes and opportunities faced by each sector and an understanding of the specific knowledge held by the interviewee. The research incorporates:

- Social business literature review
- The findings of the technical review and decarbonisation options identified
- Review of company websites, annual reports and other materials relating business and emissions reduction strategies
- Assessment of the role of the interviewee and extensiveness of their knowledge
- Review of website, ONS data, IBIS data and annual reports information related to business and energy and emissions reduction strategies.
- Development of the options register

3. Interview format

Introductions

Interviewer sets out the project context and interview agenda.

Goals

Interviewer introduces the goals of the project as follows:

1. To determine the current state, ambitions or plans, successes and problems or challenges of each of the interviewee's organisation or sector with regard to energy use, energy reduction and carbon reduction:
    a. Identify and analyse examples of the implementation of energy and carbon reduction projects to deliver insight in the problems and barriers at a company level
    b. Develop an understanding of the decision-making processes
    c. Develop an understanding of the relationship between energy/carbon strategy and business strategy
2. To develop insight into the energy and carbon reduction options available to the organisations or sector and their potential:
    a. As currently deployed by organisations
    b. As an option to be deployed in the future
3. Understanding of the main drivers and barriers for change in general and with regard to energy and carbon reduction in the sector
4. To develop insight into the specific characteristics (strengths, weaknesses, opportunities and threats) of subsectors (where required)

Existing and future strategy for energy and carbon reduction

Interviewer to engage the interviewee on the focus of their organisations energy and carbon strategy using the following questions:

1. What is your organisations strategy for energy and carbon reduction? (If the strategy is clear, summarise and ask for confirmation). Cover the following sub-questions:
    a What are the main elements of the strategy?
    b How far in advance are you planning the company's energy efficiency strategy?
    c In your opinion, what are the enablers and/or challenges for the strategy?
        i) Please specify why:
            1. Constrained finance for funding for investments internally or externally
            2. Etc.
2. Do you consider your organisation as a leader (innovator or early adopter) or as a follower (early, late majority) on energy and carbon reduction? Cover the following sub-questions:
    a. Can you give one or more example(s) of actions undertaken by members of your organisation that fit with the stated market position?
    b. Do you expect the organisation's position with regard to energy and carbon reduction to change?

c. Please state why your organisation is or is not a leader.

3. What energy and carbon projects have you implemented the last five years and why? What energy and carbon projects have you not implemented the last five years and why?

   Guidance for interviewer: use the prepared options register (prepared by technical lead and sector team) to identify energy and carbon reduction options. For parts of the list that are not covered, challenge the interviewee to identify options that could be valuable. With front runners place emphasise on more innovative options.

4. How important is energy and carbon reduction for your organisation? Please address how the carbon and energy strategy fits into wider business strategy and the extent to which it is embedded.

Stories (interviewees not self-identified as leaders)

Interviewer to lead discussion of a story or example related to an energy or carbon reduction project that went well and another that did not

Stories: Questions for leaders (only for self-identified leaders)

Interviewer to lead discussion of a story or example related to an energy or carbon reduction project using the questions below:

1. What energy and carbon reduction options have been implemented, why, when and where?
2. Can you tell the story of a project from the initial idea generation until now? Ensure this covers how ideas were generated (i.e. the step before any appraisal of options takes place):
   a. What was the timeline, sequence of events?
   b. Cover: idea generation, feasibility study (technological, financial, and organisation), decision-making, board presentation, and implementation
   c. What was your process for making a case for an investment and who was involved? Consider: key factors during decision-making, required payback, main perceived or actual risks, influence of alternative options for investment, financial and non-financial factors
   d. What were the critical moments (breakthroughs, barriers)?
3. What was the original position of the main stakeholders to the energy carbon project? Did their attitudes towards the subject change? How?
4. Why do you consider this story as a success or an area for improvement?
5. What are the main conclusions you can draw from this story - positive and negative?
   a. Lessons for future action?
   b. Main drivers and barriers for energy and carbon reduction in your company?
   c. Lessons for the way of organising energy and carbon reduction options within you company?
   d. Conclusions regarding potential reduction targets on short-, medium- and long-term?
   e. How well did the carbon reduction option work in practice, in relation to the anticipated performance?
6. Can any reports or presentations on this innovation be supplied?

Business Environment: value chain and capacity for innovation

Interviewer to ask the following questions:

1. **1.** What do you consider to be the main drivers for energy and carbon reduction in the sector?
   - **a.** What are main characteristics of the main parts of the production process? Following the structure of the options register:
     - **i.** Ask specific questions on any elements not covered in the desk research
     - **ii.** Ask specific questions on the characteristics of the subsector (input, process, output, energy use, value chain, competitive forces)
   - **b.** What do you perceive as the strengths and weaknesses of your value chain?
   - **c.** What have been the main changes in the value chain over the last ten years?
   - **d.** What innovations do you expect to see in the value chain in the coming 10/20/30 years?
   - **e.** What are possible game changers for the value chain/ or sector?
2. **2.** Main innovators or early adopters in the sector:
   - **a.** Who influences action (whom or what are they listening to? Why?
     - **i.** Organisations and people within organisations (role or function)?
     - **ii.** Within or outside the sector (other sectors, academics, non-government organisations, politicians, etc.)?
3. **3.** Questions on the dimensions of innovations[4] . These questions will be on a multiple choice list (answer categories strongly disagree, disagree, neither agree or not agree, agree, strongly agree[5]). After filling the list, ask for clarifications and examples that underpin answers in the following areas:
   - **a.** Technical: networks with other companies, academics, knowledge of competitive and emerging technologies, participation in R&D, pilots, experiments
   - **b.** Human capital: improvement projects, multi-disciplinary teams, training on innovation/change/improvement
   - **c.** Organisation: horizontal communication lines, clear goals or responsibilities, customer focus
   - **d.** Management: clear performance criteria for projects, structural follow up of main improvement projects in management meeting, clear status information on projects
4. **4.** (Optional) Please set out a characteristic story of a (successful) sector and subsector that implemented a change/innovation related to energy or carbon reduction. This question should be asked if consortia or sector teams feel a need to get a better overview of success stories. The question is relevant because in most business environments managers are influenced most by their peers.

Enablers and barriers for sector change

Interviewer to lead a summary discussion of the main drivers and barriers for sector change (general and or specific for energy and carbon reduction) using the following questions:

1. **1.** What do you consider the main drivers for change in the sector?
   - **a.** Please state specific drivers in the following fields: social, policy, technical regulatory factors
   - **b.** Interviewer to review the pre-prepared list of main driver and check seek further detail from the interviewee
2. **2.** What do you consider the main barriers for change in the sector?
   - **a.** Please state specific barriers in the following fields: social, policy, technical regulatory factors
   - **b.** Interviewer to review the pre-prepared list of main barriers and seek further detail from the interviewee

[4] Questions are asked to get a better (and broad overview of space or possibilities for change (not only including investments but also the change that potential of option will materialise.

[5] This way of working is chosen to be able to just cover the field quickly and get a quick first idea what they consider the important aspects so we can spend as much time as possible on this. We normally don't use the survey results to collect quantitative answers to these.

Function of Interview Protocol

The interview protocol was designed to collect, build upon and collaborate specific answers to principal questions which are not covered by results of desk research. The general timeline of one interview is illustrated below:

Intro	5-10 minutes
Current state and plans energy and carbon reduction	20-30 minutes
Stories of energy or carbon reduction	30-45 minutes
Business environment and innovation power	15-20 minutes
Drivers and hurdles for sector change (to test survey or workshop questionnaire)	If time left

Table 4: General interview timeline

7. Evidence Gathering Workshop

The evidence gathering stage of the project also involved workshop 1, the 'evidence gathering workshop'.

We worked with CPI, PITA, DECC and BIS to identify the most relevant attendees for the workshop. The research work already undertaken as part of the literature review and interviews were used to inform the content of the workshop.

The workshop was divided into two key activities. The first activity focused on reviewing all potential technological options for decarbonisation and identifying adoption rate, applicability, improvement potential, ease of implementation, capex, ROI, saving potential and timeline for the different options. This was done through two breakout sessions, one focused on collecting more data and the other focused on the timeline under different scenarios. The second activity involved splitting participants into five groups to discuss and vote on the enablers and barriers. Participants were also asked if they had any other enablers and barriers to be included. The aim of this section of the workshop was to prioritise the enablers and barriers and begin to consider how to overcome them (so that this could feed into later work on the options register, pathways and next steps).

We recognise that the voting process was based on initial reactions and that everyone voting may not have the expertise required on specific technical solutions to decarbonisation. In order to counter this limitation, CPI provided a validation of the options data after the first workshop.

The outcome of the evidence gathering workshop (and all evidence gathering stages of the project) was a consolidated list of enablers and barriers, and a more complete list of possible technological options with a suitable timeline for their implementation.

8. Pathways

A pathway is a combination of different decarbonisation options, deployed under the assumed constraints of each scenario that would achieve a decarbonisation level that falls into one of the following decarbonisation bands:

- 20-40% CO_2 reduction pathway
- 40-60% CO_2 reduction pathway
- 60-80% CO_2 reduction pathway

In addition, two purely technology-driven pathways were developed: a business as usual (BAU) pathway and a maximum technical (Max Tech) pathway. The BAU pathway consisted of the continued deployment of technologies that are presently being deployed across the sector. The Max Tech pathways - Max Tech 1 and Max Tech 2 - included a technology or technology combination that would achieve the maximum CO_2 reduction possible within the sector, given constraints of deployment rates and interaction. Two Max Tech pathways were developed because two potential avenues for reaching the maximum decarbonisation of the sector exist and it is presently not possible to determine which would be more likely. The pathways have not been optimised to achieve a certain decarbonisation level.

9. Pathways Development and Analysis

Overview

Pathways were developed in an iterative manual process in order to facilitate the exploration of uncertain relationships that would be difficult to express analytically. This process started with the data collected in the evidence gathering phase. This data was then challenged and enriched through discussions with the sector team and in the first workshop.

Logical reasoning (largely driven by option interaction and scenario constraints), sector knowledge and technical expertise were applied when selecting options for the different pathways under each scenario. For example, incremental options with lower costs and higher levels of technical readiness were selected for the lower decarbonisation bands, whereas more 'disruptive' options were selected for the higher decarbonisation bands in order to reach the desired levels of decarbonisation. These pathways were challenged by the sector team, modelled and assessed under the three scenarios and finally challenged 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 were detailed in the options register and relevant worksheets of the model.

It is important to keep in mind that the pathways results are the outcome of a model. As with all models the accuracy of the results is based on the quality of the input data. There are uncertainties associated with the input data and the output should therefore be seen as indicative and used to support the vision and next steps, not necessarily to drive it. Also the model was a simplification of reality, and there are likely to be other conditions which are not modelled.

The analysis only produced results (pathways) which were iterative inputs of the model operator, without any optimisation.

Process

1. The gathered evidence (from literature review, sector team discussions, stakeholder feedback and judgement) was consolidated into a condensed list of options.
2. Timing and readiness of options was developed by the sector team and during the first workshop, based on evidence from literature, sector knowledge and technical expertise.
3. Options were classified as SAT (incremental), major investment or Two Team.
4. BAU and Max Tech options were chosen and rolled out to the maximum level and rate allowable under the current trends scenario.
5. Options were added to the BAU pathway or reduced or taken out of the Max Tech pathway until each intermediary pathway band was reached.
6. Technical constraints and interactions across the list of options were taken into account when selecting options and deployment.

7. The deployment was adjusted to account for the output of the social and business research as well as current investment cycles.
8. pathways were modelled under the current trends scenario, accounting for changes in production and the carbon emissions of the electricity grid.
9. The results were reviewed and modifications made to the deployment, applicability and reduction potential for any options that appeared to be giving an unexpected or unusual result.
10. Further changes to option choices were made as required through iterations of points 5-9.
11. Revised pathways under current trends were produced for presentation at the second workshop.
12. Feedback on pathways was used to make any further necessary adjustments to the pathways under current trends.
13. The final pathways developed under current trends were used as a basis for the development of pathways under challenging world and collaborative growth scenarios.
14. Deployment of each option under challenging world and collaborative growth was adjusted according to the constraints of each scenario, including the removal of options that would not be likely under challenging world and the deployment of additional options that would become feasible under collaborative growth.
15. Deployment of each option was adjusted within the technical and scenario constraints in order to reach each pathway band where possible. Note that not all pathway bands are possible under some scenarios.

The options are listed in appendix C.

Deployment of Options

For each pathway, options were selected and deployed over time according to their readiness level, timing constraints, and those most likely to allow the pathway band to be achieved. This process occurred iteratively, involving the sector team, trade association and other Stakeholders (who contributed via the second workshop). The sector lead provided an expert view on whether the options identified in each pathway produced a feasible pathway.

As described within the pathways section of the report, the technologies included within each banded pathway under each scenario may differ in order to meet the pathway band under each scenario.

The selection and deployment of options accounted for evidence from the social and business research, for example which options could be deployed without any changes to policy and where the deployment of options may be slowed or curtailed by identified barriers or accelerated by enablers.

Option Interaction

There were a number of possible ways in which options could interact with each other. These interaction types, and how they were dealt with in the development of pathways, are described below:

- **One option excludes another:** This is taken into account by the user in the deployment inputs in the option selector by ensuring that no exclusive options are rolled out to a conflicting level in the same time period. For example, extended nip press and improved dewatering in press section beyond extended nip press are two options that are mutually exclusive in a paper machine. In the 40-60% pathway it can be seen that extended nip press and improved dewatering in press section beyond extended nip press are never deployed at more than 100% combined.
- **One option depends upon another being adopted:** This is taken into account by the user in the deployment section of the option selector by ensuring that if any option requires a precursor that this

precursor is rolled out to the appropriate level. In the BAU pathway it can be seen that closed hoods is a prerequisite to heat recovery on hoods.

- **Options are independent and act in parallel:** The ‘minimum interaction’ pathway curve assumes that all options are independent and their effect on energy or emissions are therefore incremental.
- **Options improve a common energy or emissions stream and act in series:** The ‘maximum interaction’ pathway curve assumes that the saving from each option reduces the remaining energy or emissions for downstream options to act upon.

The pathway curves included a ‘maximum interaction’ and a ‘minimum interaction’ curve. The actual pathway curve would lie between these two extremes.

Evidence Not Used in Pathways Modelling

Specific energy use of processes was considered constant in the modelling, whereas they are actually dependent on the load factor (production level) of the equipment. Increasing the production level of existing equipment would increase efficiency (in terms of kWh/tonne paper or Mt CO_2 per tonne paper), which should be taken into account when calculating emissions. However, a full bottom-up model would be needed, which was beyond the scope of this work.

The options were modelled with a fixed CO_2 and fuel saving as input values. As technologies mature, it is likely that these values would increase. This was not taken into account in the model, as the uncertainty of that development is high.

The adoption rates and applicability rates were used to inform deployment, but without a full bottom-up model implemented on a site-by-site basis, it was difficult to link these parameters directly to investment cycles.

10. Pathways Modelling

Scenarios

Modelling pathways starts with the development of scenarios. A scenario is a specific set of conditions external to the sector that would directly or indirectly affect the ability of the sector to decarbonise. An example of a condition in a scenario was the emissions factor of the electricity grid. Where appropriate, conditions were described qualitatively through annual trends. The scenarios analysis also included qualitative descriptions of exogenous drivers which were difficult to quantify, or for which analytical relationships to quantitative factors were indefinable.

For each pathway, the following three scenarios were tested: current trends, challenging world and collaborative growth. Scenario parameters are shown in Table 5 below.

Current Trends

The current trends scenario projected moderate UK and global growth. Alongside this, international policies on climate change were assumed to develop, gradually but effectively driving down emissions.

New low-carbon generation technologies were assumed to progressively decarbonise the electricity grid to 100 g/kWh by 2030.

Pulp and paper production was assumed to increase by 1% annually. It was assumed that the Pulp and paper business environment, the economic recession and the weak demand for paper may continue to limit revenues and thereby hamper the cash flow. An uneven playing field and carbon leakage was assumed to continue to be an issue, adding to the UK pulp and paper sector's lack of competitiveness on the global marketplace. Other governments were assumed to start taxing carbon.

Challenging World

The challenging world scenario was characterised by lower global growth rates. Climate change was assumed to have a lower profile than at present, so that there would be less effective action to reduce emissions.

New low-carbon generation technologies were assumed to progressively decarbonise the electricity grid to 200 g/kWh by 2030.

The pulp and paper industry was subject to more intense competition, both for raw materials and sales, leading to a decline of 0.5% per year in UK production over the period. An uneven playing field and carbon leakage were an issue adding to the UK pulp and paper sector's lack of competitiveness on the global marketplace.

Collaborative Growth

The collaborative growth scenario was represented by higher levels of global growth and concerted action to reduce carbon emissions.

New low-carbon generation technologies were assumed to progressively decarbonise the electricity grid to 50 g/kWh by 2030.

The UK pulp and paper industry sees growth at 2% per year, with a shift towards more advanced processes, increased reuse and recycling in general, growth in higher added value and lower carbon footprint products. The business environment was assumed to be positive with increased demand for UK pulp and paper and plants are working at the optimum capacity. A favourable global carbon price was assumed to be in place.

	Challenging world	Current trends	collaborative growth
International consensus	National self-interest	Modest	Consistent, coordinated efforts
International economic context	More limited growth, some unstable markets, weakening of international trade in commodities	Slow growth in EU, stronger in world, relatively stable markets	Stronger growth in EU, stable markets, strong international trade.
Resource availability and prices	Strong competition, High Volatility High price trends.	Competitive pressure on resources. Some volatile prices Central price trends.	Competitive pressure on resources. Some Volatile prices Central price trends.
International agreements on climate change	No new agreements. Compliance with some agreements delayed	Slow progress on new agreements on emissions reductions, all existing agreements adhered to.	Stronger worldwide agreements on emissions reductions, consistent targets for all countries
General Technical Innovation	Slow innovation and limited application	Modest innovation, incidental breakthroughs	Concerted efforts lead to broad range of early breakthroughs on Nano, bio, green and ICT technologies.
Attitude of end consumers to sustainability and energy efficiency	Consumer interest in green products only if price competitive. Limited interest in energy efficiency.	Limited consumer demand for green products, efficiency efforts limited to economically viable improvements	Consumer willing to pay extra for sustainable, low carbon products. Strong efforts to energy efficiency even where not cost effective.
Collaboration between sectors and organisations	Minimal joint effort, opportunistic, defensive	Only incidental, opportunistic, short term cooperation	Well supported shared and symbiotic relationships
Demographics (world outlook)	Declining slowly in the west Higher growth elsewhere	Declining slowly in the west Modest growth elsewhere	Stable in the west Slowing growth elsewhere

	Challenging world	Current trends	collaborative growth
World energy demand and supply outlook	Significant growth in demand with strong competition for resources. High dependence on imported fossil fuels	Balanced but demand growth dependent on supplies of fossil fuels from new fields.	Growing demands balanced by strong growth in supply of renewable energy, slowly declining importance of fossil fuels.
UK Economic outlook	Weaker OBR growth assumption.	Current OBR growth assumption	High OBR growth assumptions
Carbon intensity of electricity	Weakest trend of electricity carbon intensity reduction 200g/kWh at 2030	Stronger trend of electricity carbon intensity reduction 100g/kWh at 2030	Rapid decline in electricity carbon intensity 50g/kWh at 2030
CCS availability	Technology develops slowly, only becoming established by 2040	Technology does not become established until 2030	Technology becomes proven and economic by 2020
Low carbon process technology	New technology viability delayed by ten years	New technology economically viable as expected	New technology viability achieved early

Table 5: Summary of scenario context and specific assumptions applicable to the scenarios

11. Options

Classification and Readiness of Options

The options were divided into three groups reflecting the likely timing of their deployment:

- Existing state-of-the-art technologies (SAT) with wide deployment
- Major investment technologies
- Two Team Project technologies

SAT were assumed to begin to be deployed immediately as the technologies exist and are proven. They were assumed to be easy to implement. Adoption of these technologies aligned with equipment replacement to current SAT.

Major investment technologies were defined as technologies that have limited adoption today. The technology is proven but not widely accepted in industry. Few demonstration projects exist in the UK. These technologies would benefit from demonstration installations in the UK combined with training and other activities to spread the knowledge and reduce costs. Some novel technologies yet to be fully developed were included, such as improved dewatering in press section beyond the extended nip press. The deployment of these technologies was assumed to start in 2020 and be completely rolled-out by 2050. Some of these technologies would replace SAT. Therefore certain SAT were assumed to be decommissioned in line with the deployment of some major investment technologies.

The **Two Team Project technologies** originated from CEPI's Two Team Project. In the pathways, only one option from the Two Team project was considered: 100% electricity. This option was combined with carbon neutral steam supplied from an adjacent carbon neutral steam producer, such as a waste incineration plant (industrial clustering and heat networking). Assuming that the electricity grid would decarbonise, this option could achieve considerable decarbonisation of the sector. The deployment of this option was assumed to begin in 2040.

Options Processing

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 evidence gathering workshop which options they would consider to be viable, and through receiving detailed information packs from members of CPI. The technical team drafted the first list of options. However, each option had strengths, weaknesses, enablers, and barriers which needed to be taken into account to develop and refine the options register to feed into the model.

A comprehensive list of enablers and barriers identified from the literature review was refined and triangulated with the evidence gathering workshop and interviews. To find the most relevant enablers and barriers for incorporating into the options register and pathways, enablers and barriers that were not supported by the evidence gathering workshop and interviews were removed from the list.

The impact of social and business research was captured in the options register, under the individual technologies (where possible) and in the subsequent pathways selected.

We have used the decision tree below to determine whether the social and business findings should impact upon the options and pathways. The pathways represent a selection of options, and this determines when and to what extent the options become active.

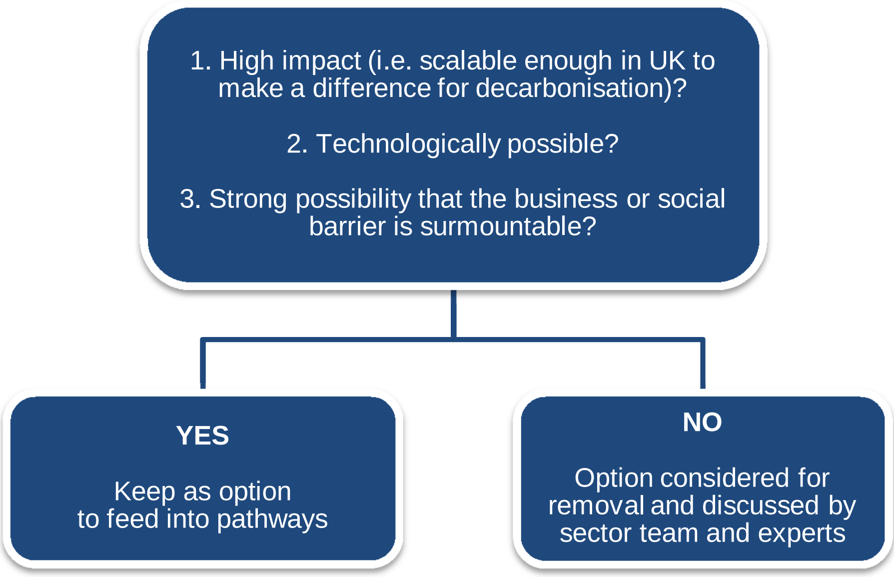

Figure 4: Social and business pathways impact tree

The options identified were further divided into the following subdivision (referred to as process factor): across mill, fibre supply, paper machine, utilities and Two Team Project.

12. Pathway and Action Plan Workshop

The second workshop, the 'pathway and action plan' workshop, focused on reviewing the draft decarbonisation and energy efficiency pathways and identifying potential actions for delivering them. This included presenting and discussing draft pathways in groups and then asking the question, "Taking into account the identified barriers and enablers, what next steps would assist in delivering the pathways?"

The outputs of the second workshop were used to validate the pathways and to inform the conclusions of the roadmap, which include example next steps and actions.

13. Next Steps

The output of the pathway development and social and business research included identification of barriers to and enablers for:

- Implementation of the pathways
- Decarbonisation and energy efficiency in the pulp and paper sector more generally

To draw conclusions, the analysis of barriers and enablers is taken further by describing a list of possible next steps to be implemented by a combination of industry, government and other organisations. These actions can take the form of strategic conclusions which are high-level or longer term, or more specific, discrete activities which can lead to tangible benefits.

The development of conclusions and next steps has considered the following:

- Actions from other pulp and paper decarbonisation projects

- Necessary changes in future markets, product features, business environment to enable the different pathways
- The outputs of workshops held as part of this project covering decarbonisation and energy efficiency pathways and next steps

- Actions that help maximise the success of a pathway under a range of scenarios
- options within the pathways that are necessary for success, e.g. if a particular technology option is necessary for the success of a number of pathways, or an option has a very high decarbonisation potential, actions to implement this option are included
- Policy and regulations that could contribute to the removal of barriers or enhancement of enablers

INDUSTRIAL DECARBONISATION AND ENERGY EFFICIENCY ROADMAP TO 2050 – PULP AND PAPER

APPENDIX B – FULL SOCIAL AND BUSINESS FINDINGS

APPENDIX B FULL SOCIAL AND BUSINESS FINDINGS

1. SWOT Outcomes

The table below highlights the top strengths, weaknesses, opportunities and threats in relation to decarbonising the pulp and paper sector in the UK.

STRENGTHS	WEAKNESSES	OPPORTUNITIES	THREATS
Inherently sustainable product life cycle	Declining phase of the sector, impacts investor confidence	Commercial driver behind lowering energy costs impacting cost of sale	Regulatory uncertainty
Energy investment and RD&D are a well-established discipline	Challenging payback criteria for investments	Increasingly attractive positioning for the industry around recycled, bio-based, and paper based hygiene products	Underinvestment in training and resources
Positioned well as bio-renewable product industry grows	Energy intensive process largely influenced by grid carbon intensity	CHP, biomass	Competitive market with low margins
Mill groups setting global decarbonisation targets	Imperfect information and visibility of Best Available Technology	Heat recovery and integration	Short-term thinking and risk aversion
Established recycled fibre supply chain			Reliance on ‘breakthrough technology’
Senior management buy-in			

Table 6: SWOT analysis for pulp and paper sector

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. In order to understand the inter-linkages between the SWOT analysis for the sector and the key enablers and barriers we identified from the literature review, interviews, and workshop, we analysed the root causes of the enablers and barriers and linked it back to the market environment and internal decision-making. The top SWOT outcomes were identified from the literature review, reinforced in the interviews and voted on by workshop participants as the most important.

Other social and business research methods used include elements of system analysis, root cause analysis, causal mapping, Porter's Five Forces analysis, and storytelling. **System analysis** can be used to help decision makers identify a better course of actions and make better decisions. It is a process of studying a procedure or business in order to identify goals and purposes, and to create systems and procedures that will achieve those goals most efficiently. It uses an experimental approach to understand the behaviour of an economy, market or other complex phenomenon. **Root cause analysis** is a method of problem solving that tries to identify the root causes of a problem. A root cause is a cause that - once removed from the problem - prevents the final undesirable event from recurring. **Causal mapping** is a visual representation, showing causalities or influences as links between different nodes. These maps can be used to aid strategic planning and thinking. **Porter's Five Forces** is a framework to analyse the level of competition within an industry and business strategy development. **Storytelling** is a technique that uses a clear and compelling narrative to convey a message or provide context to a conversation with the aim to engage the interviewee and encourage openness.

2. Market Structure

Subsector	Industry Definition	Market share major companies	Key external drivers
Paper and paperboard manufacturing	Firms in this industry manufacture paper and paperboard products from pulp and recycled materials. The bulk of the industry's output is intended for further processing by downstream manufacturers (e.g. cardboard packaging and tissues) although the industry also supplies finished products such as newsprint, writing paper and paperboard liner.	1. UPM-Kymmene (UK) Ltd 20.6% 2. DS Smith plc 18.1% 3. Aylesford Newsprint Holding Ltd 5.3%	• IT and telecommunications adoption • Demand from cardboard packaging and paper bag manufacturing • Demand from printing • Demand from newspaper printing • World price of wood pulp
Printing	Companies in this industry print books, magazines, brochures, labels and tags, posters, diaries, calendars, maps, stamps, security papers, cheques, banknotes and other products. This industry excludes the printing of newspapers and periodicals that appear at least four times a week.	1. De La Rue plc - 3.4% 2. St Ives plc - 2.7%	• Retail sales index • Percentage of households with internet access • Producer price index for paper and paperboard • Demand from book publishing
Cardboard packaging and paper bag manufacturing	Operators in this industry manufacture cardboard packaging and paper bags and sacks. Cardboard packaging includes corrugated and solid cardboard boxes, folding cartons and customised cardboard containers.	1. DS Smith Packaging Ltd - 17.2% 2. Smurfit Kappa UK Ltd 13.5%	• Demand from plastic packing goods manufacturing • Real effective exchange rate • Real private consumption expenditure • Producer price index for paper and paperboard
Sanitary products manufacturing	Industry operators convert sanitary paper stock or wadding, as well as pulp and paper, into sanitary paper products such as facial tissues, handkerchiefs, table napkins, kitchen towels, toilet paper, disposable nappies, sanitary towels and tampons. The final products are sold to wholesalers for distribution, straight to retailers or directly to large commercial customers.	1. Kimberly-Clark Ltd - 24.5% 2. SCA Hygiene Products UK Ltd - 23.7%	• Real private consumption expenditure • World price of wood pulp • International tourist numbers • Demand from takeaway and fast-food restaurants
Paper stationary manufacturing	Firms in this industry are principally involved in the manufacture of paper stationery products used in commercial, educational and household applications. This includes ready-to-use office paper, envelopes, folders, binders, diaries and manifold business forms.	1. Adare Group Ltd - 7.7% 2. Paragon Group UK Ltd - 7.0% 3. Hamelin Brands Ltd - 6.9% 4. Encore Envelopes Ltd - 5.6%	• IT and telecommunications adoption • Demand from newsagents and stationery stores • Percentage of households with internet access • Producer price index for paper and paperboard • Demand from printing

Table 7: Market structure – subsector definition, market share and external drivers within the pulp and paper sector

Subsector	Revenue (£M)	Profit (£M)	Wages (£M)	Annual Growth	Imports/ Demand (%)	Exports/ Revenue (%)	Revenue/ Employee (£"000)	Wages/ Revenue (%)	Employees/ establishment (nr.)	Average wage (£"000)	Share of economy (%)	Number of establishments
Paper and paper board	3,000	119.9	405	-4.10%	63.52%	30%	324	13.51%	34.77	43.78	0.05%	266
Printing	8,900	471.9	2374	-6.9%	5.79%	5.99%	115.07	26.66%	7.24	30.68	0.21%	10,690
Card board and paper bag	4,000	326.5	811	1.2%	15.51%	5.09%	151.54	20.12%	32.84	30.49	0.09%	810
Sanitary products	2,500	94	227.6	-1.8%	24.85%	13.23%	34.42	9.20%	61.15	34.46	0.03%	108
Paper stationary	564	24.3	105	-0.9%	16.54%	3.81%	184.92	18.62%	8.97	34.43	0.01%	340

Table 8: Market structure – subsector data within the pulp and paper sector

3. Assessing Enablers and Barriers

The first stage in our 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 evidence and whether the findings were validated via more than one information source. If the strength of the evidence was deemed high or medium high, then for the social and business research the enabler and/or barrier was included and information was used to support the answer to the principal question '*What are the main business enablers and barriers to decarbonisation?'*. If the strength of the evidence was deemed high or medium high for the technical options, the uncertainties in the modelling were reduced. The evidence was given a relevance classification of: 'high', 'medium-high', 'medium-low' or 'low'. The classifications are defined in Table 9 below.

It should be noted that the nature of the interview and workshop discussion process means that these represent the opinions and perceptions of the interviewees and workshop participants which could not always be backed up with evidence from other information sources.

The evidence was analysed and interpreted using a variety of evidence analytical techniques such as SWOT analysis, system analysis and root cause analysis or causal mapping where possible.

Classification	Definition
High	High relevance for the UK pulp and paper sector Good financial-economic decarbonisation data Recent information (after 2000) Provides a good example or story of decarbonisation Validated across all evidence gathering methods
Medium-high	Relevance for the UK pulp and paper sector Financial-economic data not always complete or clear-cut and only generic decarbonisation data Provides a good example or story of decarbonisation Validated by more than one evidence gathering method
Medium-low	Information that is or too general or too specific Relevant grey literature Old information but still relevant If only mentioned via one evidence gathering method
Low	Background information No or low applicability for the UK pulp and paper sector Grey literature of limited value Old information Lack of relevance or only mentioned once

Table 9: Evidence classification definition

The following tables provide a summary of raw data collected relating to enablers and barriers.

4. Detailed Analysis of Enablers and Barriers

Enablers

#	Category	Enablers	Literature review	Interviews	Workshops	Analysis and Interpretation
1	Market and economy	Diversification into recycled products and services, and bio-products with higher value added than paper, as well as paper-based hygiene products due to growing consumer demand.	**1 literature source** **O22** *CEPI, 2013, The Two Team Project, 42* According to CEPI, new products could make a goal of creating 50% more value from the sectors products achievable by 2050, but success would rely on significant breakthrough technologies being realised by 2030.	**2 Interviews** One company's strategy sees it moving away from commoditised paper grades towards value added bio-based products. The paper mill processes over 600,000 tonnes of recovered paper every year with the introduction of its new materials recovery facility, it is able to process plastics, cans and household waste For each tonne of recyclable material that are sorted at the facility, over 100,000 tonnes are newspapers and magazines that are used at the mill as raw material. It has partnered with external waste management experts, for a new product. This is a pellet that constitutes mainly paper fibre retrieved from wet waste, which is then shipped back to the mill to be burned for clean energy.	3 groups in the workshop identified this enabler.	A number of global manufacturers are beginning to shift their long term strategy to alternative products. We identified bio-products, biomass, and hygiene products as particular enablers for the industry. One example is the strategy, which sees the company moving away from commoditised paper grades towards value added bio-based products. The sector has existing expertise in the processing of biomass – one possible vector for the industry could be diversification into bio products with higher value added than paper products. '*It is not just a newsprint mill, it's waste management, renewable power operation too, the mill innovates and this approach to waste is unique as far as I know'* The most successful projects joined up different kinds of low-carbon behaviours (energy, waste, transport etc.); In the long term paper-based hygiene products serving basic human needs will become more and more available and used also in developing markets, while in mature markets they will remain essential for everyday life. Women will be important drivers of consumption, both in emerging and mature markets and the ageing

#	Category	Enablers	Literature review	Interviews	Workshops	Analysis and Interpretation
				Another interviewee stated that responding the customer needs is something that drives the business case for investment, in particular where it offers the opportunity for differentiation.		population will also increase the need for hygiene products. Such developments support the move towards high tech or high value added products and stimulate further enablers as the sector becomes more competitive which releases more capital for other aspects such as energy efficiency. This enabler is relevant now and will become increasingly important in the future.
2	Market and economy	Cost savings through lower energy consumption will lead to lower consumer prices and thus a higher demand	1 literature source CSE, ECI, 2012, What are the factors influencing energy behaviours and decision-making in the non-domestic sector? This reveals that the common and well established driver in sectors such as pulp and paper sector for driving lower energy use is cost.	2 interviews At one of the Mills, the driver for approving capital investments was reducing energy bill of the site (which used to equal consumption of a large city centre). This reduced the energy requirements of the core process which was stated that it also helped secure the mills future, the decision. This reduced energy consumption by 60-70%. Another interviewee confirmed that energy is a significant cost in the mills and there is a commercial drive to reduce energy consumption.	2 groups in the workshop identified this enabler.	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 that specific mill to remain in business but for growth and increased competitiveness of the sector as a whole. This could impact on lower consumer prices which could lead to higher demand and again improved competitiveness of the sector. One interviewee stated "*Energy is a significant cost to our mills, so there is a commercial drive too. This runs through all decisions, from small to large*" This is mostly a future enabler.
3	Market and economy	Collaboration in the value chain, including:	1 literature source	2 interviews	-	The pulp and paper supply chain is complex, with many interrelated specialist

#	Category	Enablers	Literature review	Interviews	Workshops	Analysis and Interpretation
		closed loop recycling, collaborating with machine suppliers, collaboratively refining existing technologies and developing new technologies, will be able to catalyse decarbonisation	**O10:** IEA, 2010, Energy Technology perspectives 2010 - SCENARIOS and STRATEGIES 2050. This reveals that the common driver in sectors such as pulp and paper sector for driving lower energy use is cost.	Segregated waste, as found elsewhere in Europe could remove cost and energy through efficiencies in sorting and pulping process. The closure of the Paper Science department and the University of Manchester has reduced the potential for RD&D in the sector		functions that do not fall into the boundaries of one single organisation, yet have the opportunity to influence performance. For example, the quality of recycled waste streams. Segregated waste, as found elsewhere in Europe could help improve efficiencies in sorting and pulping process. pulp and paper waste streams also offer the opportunity for further development. Waste sludge is viewed as waste, but can provide raw material for other industry sectors, e.g. lightweight 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. . Consideration should also be given on how to strengthen international collaboration. The closure of the Paper Science department and the University of Manchester has reduced RD&D and collaboration in the sector and resulted in other impacts such recruitment of new talent. There is a need for greater knowledge sharing and RD&D collaboration across countries to accelerate technology advancement along the curve from demonstration to commercialisation. This enabler is relevant now and will become increasingly important in the future.

#	Category	Enablers	Literature review	Interviews	Workshops	Analysis and Interpretation
4	Legislation	Government policy can encourage companies to decarbonise, for example removing barriers to entry, exit and growth of new firms that are important for the low-carbon energy technology development; developing a common vision together with the industry to secure public support for spending and subsidies.	1 literature source **O10:** IEA,2010, Energy Technology perspectives 2010 - SCENARIOS and STRATEGIES 2050, - Government steps to remove barriers to the entry, exit and growth of new firms may have an important part to play in low-carbon energy technology development in general	4 interviews One organisation stated that the Renewable Observation Certificates (ROCs) were a key factor in the decision to invest in a biomass powered CHP plant on site. Without these the 100% biomass fuelled CHP plant would have not gone ahead. All of the major investments in the mill has had assisted funding through national, EU or Welsh Assembly funding. As part of a global mill group, investment decisions consider a range of options, including investment outside of the UK, With clear and significant financial support major investments can be encouraged in the UK market. Other interviewees stated that the principle of subsidising energy savings will help to drive investments in the UK paper industry. CHP incentives would make a lot of sense, given the nature of our industry and	2 groups in the workshop identified this enabler.	The government can play a major role in encouraging the industry to decarbonise. Interviewees felt that successful energy efficient projects had been supported by funding from the European Union or the UK government. In one case, government backed incentives, such as the Renewable Observations Certificates (ROCs) were the single most important factor in going ahead with the investment. This can also be supported by keeping energy prices competitive with the rest of Europe, while at the same time incentivising low-carbon technologies. It was also mentioned that planning rules to encourage aspects such as industrial clustering and provide planning incentives would make planning easier / less risky for companies, resulting in carbon reductions compared to separate location. A shared cross sector 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. This enabler is relevant now and will become increasingly important in the future.

#	Category	Enablers	Literature review	Interviews	Workshops	Analysis and Interpretation
				how well placed it is for this technology. A decarbonised grid would have a big impact, but then it reduces effectiveness of CHP – a joined up approach is needed. Although contradictory to other interviews, one senior level interviewee stated that on a European level the UK is seen as 'fairly dependable' in terms of legislation stability that decisions can be based around.		
5	Energy	Small incremental investments do not need approval from headquarters. These include: 1. maintenance, operations, and component / equipment replacements; 2. process control and optimisation; 3. lighting and ventilation, process integration; 4. corporate framework		4 interviews One company stated that investments under £20k do not need approval from headquarters. Another said that for their company, this amount is approximately £0.5m, so limits vary considerably. Both said that because smaller investments do not need approval, improvements under this value would be easier to implement. CPI confirmed the above.		This enabler applies to the implementation of incremental energy efficiency investments which can be applied at the mill level. The level of budget for such energy efficiency improvements depends on the budget available from the Head Office of the organisation. In general, the budget available is related to the overall profitability of the organisation. The competition with other projects it has to compete with globally will only apply above a certain level of capital spend. There is a greater chance of implementation if the business case for the spend 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.

#	Category	Enablers	Literature review	Interviews	Workshops	Analysis and Interpretation
6	People and management	Senior management buy in and formal business commitment	1 literature source **O9:** Centre for Sustainable Energy (CSE) and the Environmental Change Institute, University of Oxford (ECI) for DECC. The closer that an energy manager is to the CEO in the corporate hierarchy the more likely that energy management activity will take place.	3 interviews One company stated that energy has long been a focus, this dates back to each site having an energy efficiency factor, based on the technology installed, and being measured against improvements achieved. This has naturally rolled on into carbon too. The means we can see the sites already ‘in tune’ with the idea of the metrics and have a good feel for how they can reduce energy/carbon intensity.	2 groups in the workshop identified this enabler.	Senior management buy-in and commitment is an enabler for the level of support and prioritisation that a companies’ carbon strategy has compared to other aspects of the business strategy. This can create a cascade effect through the mill, if supported by senior management. Safety is an issue often cited as a success story, with senior buy in the sector in the 1990’s the European pulp and paper sector has 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 associated sustainability reporting. Where the contribution of each mill is linked to the corporate target achievement and data collection as part of the overall sustainability reporting process may contribute towards this enabler. This focus is helpful as it aligns those within the company to the importance of carbon reductions and provides the underlying business case for energy reductions. None of the current company strategies look further than 2025 in terms of carbon reduction targets. 3/5 of the companies have sustainability reports, and one has a sustainability section on website. Smurfit Kappa: Yes http://www.smurfitkappa.com/Resources/Documents/Smurfit%20Kappa_Sustainable_Development_Report_2012.pdf

#	Category	Enablers	Literature review	Interviews	Workshops	Analysis and Interpretation
						Kimberly-Clark: Yes http://www.sustainabilityreport2012.kimberly-clark.com/files/K-C_2012_Sustainability_Report.pdf UPM: Global Reporting initiative (GRI) report within annual report: http://www.upm.com/EN/INVESTORS/Documents/UPM_Annual_Report_2013.pdf DS Smith: No report but has much info online here: http://www.dssmith.com/company/sustainability/ Arjo Wiggins: No report This enabler is applicable now.

Table 10: Raw data - enablers for the UK pulp and paper sector

Barriers

Number	Category	Barriers	Literature review	Interviews	Workshops	Analysis
1	Market and economy	Competitive marketplace with lowering profit margins overall in the UK pulp and paper sector, hamper any investments that are not critical	2 literature sources **O1**: Heather Haydock (Ricardo-AEA) and Tamaryn Napp (Imperial College), Decarbonisation of heat in industry - A review of the research evidence, Ricardo-AEA/R/ED58571, issue 1, 119 pages. "Cost Effectiveness - Increasing competition driven by imports and overcapacity has reduced the margins available to the manufacturers and has limited capital availability. This has led to reluctance to undertake investment with a payback of more than 12 months." (p. 28). "Operational Costs - the sector is under severe pressure on margins, so even if energy efficiency or fuel switching measures would reduce fuel costs they	2 interviews One interviewee highlighted that there is a danger for the UK to become uncompetitive in today's global climate. There is competition for finance with other mills internationally, also within the group. Another stated that global competition, as all business units have and the weak UK global position, where growth prospects are less favourable than other parts of the world.	3 groups in the workshop identified this barrier.	Caused by both the difficult economic climate and the decline of the sector, financial capital for large capital expenditures to finance decarbonisation is difficult to obtain. This was reflected in both the literature review, and confirmed in the interviews and workshops. Funding for large capital expenditures should for most organisations be obtained from the group headquarters, and the pulp and paper Industry is particularly global. There is a perception expressed that the UK mills may be in a weak position compared to their peers abroad because the UK is less competitive due to high energy costs other business environment factors. 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 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 paper mill related technology were identified in the literature to be a significant disincentive to invest. To make these large investments, interviews emphasised that UK mills are often competing for investment budget from group with their counterparts overseas. Several factors were mentioned that influence decisions of group level to invest in UK based mills rather than others. It was expressed that

Number	Category	Barriers	Literature review	Interviews	Workshops	Analysis
			may still not be taken up if they are accompanied by increases in maintenance costs for the equipment installed." (p. 28) **O12:** Patrik Thollander and Mikael Ottosson, 2008, An energy efficient Swedish pulp and paper Industry – exploring barriers to and driving forces for cost-effective energy efficiency investments "Another barrier which may prohibit investments in energy efficiency technologies, even if the investment is cost-effective, is lack of access to capital." (p. 5)			the growth projection for the UK business is lower than for businesses elsewhere, which disincentivises the group to invest in the UK. This is a barrier now and in the future.
2	legislation	Regulatory uncertainty with regards to decarbonisation and over-regulation of the industry, as well as increasing regulation of associated industries on which pulp and paper Industry is dependent; make it uncertain for companies to take		2 Interviews One company provided a specific example of a project that used locally sourced waste/wood from the forestry to produce energy. It stated that it had done an analysis of feasibility, for example engaging environmental groups	3 groups in the workshop identified this barrier.	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 feed in tariffs 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 a large buy in from stakeholders, including

Number	Category	Barriers	Literature review	Interviews	Workshops	Analysis
		large investment decisions.		and local communities. However the project was stalled due to the government's policy with regards to renewables and feed in tariffs which were changed at a very last stage. This hampered trust in the government and made any investment much more prone to risk. As a result the company was unable to get funding. "The major hurdle has to be uncertainty (and changing) government position and policies" The CPI acknowledged that there were sector perceptions and concerns raised regarding the changing government policies.		environmental groups and local residents and local authorities. However the government's position kept on changing, which led external financers and, eventually, the company themselves pull out the plug of the project. One company mentioned that they have been trying to lobby with the government to support on particular projects. For example, major investments that led to incremental decarbonisation in their mills were largely funded through national, EU, or Welsh Assembly funding. However, they also expressed the desire for federations to pursue a joint approach, rather than each mill doing their own lobbying to support the business case. The CPI cited three specific examples of where recent actions have reduced industrial confidence in policy, CHP policy changes in 2013; unilateral Carbon Price Floor Policy and cancellation of the Carbon Trust sector efficiency programme after potential projects had been collaboratively identified. This issue has made it difficult to get the level of engagement from the mills. This is a barrier now and in the future.
3	Market and economy	The pulp and paper Industry is conservative: it prefers to use technologies that have been proven before. There is a general resistance to changes and lack of cross sector knowledge in the latest	2 literature sources **O1**: Heather Haydock (Ricardo-AEA) and Tamaryn Napp (Imperial College), Decarbonisation of heat in industry - A review of the research evidence,	1 interviewee One interviewee stated that commercial sensitivity and an increasingly competitive marketplace creates a culture where sharing knowledge is limited, therefore information	2 groups in the workshop identified this barrier.	Literature indicated that conservatism is prevalent in the industry, leading to companies to be only willing to invest in technologies that have already been proven to be successful. In one study, companies indicated that they would rather not be the first to implement a new technology, but rather look at proven technologies in other industries, or to copy competitors.

Number	Category	Barriers	Literature review	Interviews	Workshops	Analysis
		technology	Ricardo-AEA/R/ED58571, issue 1, 119 pages **P.36-40**: "Conservatism - There is a degree of risk aversion in the sector, which is understandable, as technological failures would have a significant impact on business performance. This implies that new technologies need to be evolutionary rather than radical, or need to have been established in other sectors." **O3:** The Future of Heating: Meeting the challenge Short term thinking and risk: Conversely many businesses focus decisions on the short to medium term rather than the longer term. Heat intensive industries are also risk-averse, and particularly wary of risks to their product quality or output, and of being locked-in to inflexible infrastructure	about new technologies is simply not available.		Life cycles for paper machines range from 30 to 60 years and a replacement of the machine will require a large investment. Therefore if quick decarbonisation is desired, investments often need to happen outside of the normal investment cycles, whereas machines may have not yet reached their end-of-life as of yet. This is a mainly a future as no major machine replacement is the UK is currently planned.

Number	Category	Barriers	Literature review	Interviews	Workshops	Analysis
			and technologies. Delivery barriers			
4	Market and economy	There is uncertainty about return on capital on most energy efficient technology investments.	1 literature source **O1**: Heather Haydock (Ricardo-AEA) and Tamaryn Napp (Imperial College), Decarbonisation of heat in industry - A review of the research evidence, Ricardo-AEA/R/ED58571, issue 1, 119 pages. Operational Costs - 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.	5 interviews CPI	All 5 Workshop Groups	When taking investment decisions, interviewees, workshop groups and literature agreed that one of the most important decision factors is the payback time. The maximum length before it causes a significant hurdle differed from 12 months identified in literature, to four years for other organisations. A one or two year return on investment (ROI) period being deemed acceptable to the industry was a common theme of the interviews, the CPI reiterated this and that the planning horizon for mill developments is three years at best. This supports the information discussed in ‘Barrier 1’, and the reasons behind this relatively short-term approach to ROI is the competitive marketplace with lowering profit margins overall in the UK pulp and paper sector, hamper any investments that are not critical. The DNVGL interviewer explored different ways of asking this question to better determine how this approach to ROI could potentially be overcome, but the low profitability of the sector was always cited as the main barrier that should not be ignored. This is a barrier now.
5	Operations	There is uncertainty regarding the impact on machine operability	1 literature source **O1**: Heather Haydock (Ricardo-AEA) and Tamaryn Napp (Imperial College),		1 group in the workshop identified this barrier.	The potential impact of any changes in operations on machine operability and any impact on production and quality is also a barrier to decarbonisation that requires changes to machinery.

Number	Category	Barriers	Literature review	Interviews	Workshops	Analysis
			Decarbonisation of heat in industry - A review of the research evidence, Ricardo-AEA/R/ED58571, issue 1, 119 pages. Operability – if any technology contains uncertainty regarding the impact on machine operability this would be a major barrier to its adoption.			This can be linked to 'barrier 3' that the pulp and paper Industry is conservative: it prefers to use technologies that have been proven before. There is 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.
6	People and management	Lack of awareness and information imperfections lead to less initiative being undertaken to invest in low-carbon technologies	3 literature sources **O3:** The Future of Heating: Meeting the challenge Information: Information on the technical solutions to decarbonise and the costs and technology readiness (for example on industrial CCS) is imperfect among industry players.	2 interviews One company mentioned that the first priority should be to create a common vision (see on the right) and also highlighted that there is currently no platform to share lessons. The CPI confirmed that RD&D collaboration is currently not encouraged but could lead to technology advancement. This is what is meant by information imperfections in this context.	1 group in the workshop	One company stated that 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. 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. The need for greater knowledge sharing and RD&D collaboration among countries to accelerate technology advancement along the curve from demonstration to commercialisation was also a theme from the interviewees and CPI.

Number	Category	Barriers	Literature review	Interviews	Workshops	Analysis
			O11: Fleiter, 2012, The adoption of energy-efficient technologies by firms An integrated analysis of the technology, behaviour and policy dimensions (233p) p 149-BARRIERS TO ENERGY EFFICIENCY IN INDUSTRIAL BOTTOM-UP ENERGY DEMAND MODELS—A REVIEW - imperfect information (p.153)			This is linked to comments on the closure of the Paper Science department and the University of Manchester is reduced RD&D and the collaboration in the sector discussed in 'enabler 3' and elsewhere. There is a need for greater knowledge sharing and RD&D collaboration across countries to accelerate technology advancement along the curve from demonstration to commercialisation
			O12: Patrik Thollander and Mikael Ottosson, 2008, An energy efficient Swedish pulp and paper Industry – exploring barriers to and driving forces for cost-effective energy efficiency investments		Barriers described on the RHS were described in workshop discussions.	The literature gave further information on market-related barriers (p.5 and p7) and behavioural and organizational-related barriers (p.5). These included: Conflicts of interest within the mill/company; Uncertainty regarding the company's future; Cost of staff replacement, retirement, retraining; Difficulties in obtaining information about the energy use of purchased equipment; Energy objectives not integrated into operating, maintenance or purchasing procedures; Poor information quality regarding energy efficiency opportunities; Low priority given to energy management (by the company board); Lack of sub-metering; Energy manager lacks influence; Lack of technical skills; Cost of identifying opportunities, analysing cost effectiveness and tendering; Long decision chains; Lack of staff awareness; Other priorities for capital

Number	Category	Barriers	Literature review	Interviews	Workshops	Analysis
						investments; Lack of budget funding; Possible poor performance of equipment; Slim organization; Lack of access to capital; Lack of time or other priorities; Technology is inappropriate at the mill; Cost of production disruption/hassle/inconvenience; Technical risks such as risk of production disruptions; Dep./workers not accountable for energy costs. This is a barrier now and in the future as information is required in new technologies.
7	People and management	Shortage of technically competent staff and time and lack of funding for training prevents advancement	2 literature sources **O3:** The Future of Heating: Meeting the challenge Skills: 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. **O10:** IEA,2010, Energy Technology perspectives 2010 - SCENARIOS and STRATEGIES 2050, Developing a skilled low-carbon energy workforce; This includes the	1 interviewee CPI mentioned the general lack of industry specific academic RD&D in the UK following the closure of undergraduate courses in pulp and paper technology at the University of Manchester.	2 groups in the workshop identified this barrier.	The general lack of industry specific academic RD&D in the UK following the closure of undergraduate courses in pulp and paper technology at the University of Manchester. For longer term opportunities it was perceived as extremely difficult to bring a share of the Research and Development to the UK. This is linked to discussions under ‘enabler 3’ where the closure of the Paper Science department will have other impacts such as new recruits and ability to attract talent for the sector and competent staff such as engineers that understand the technical aspects of the industry that supports energy efficiency implementation. This is a barrier now as the profile of the workforce of the sector is ageing without sufficient succession planning in place.

Number	Category	Barriers	Literature review	Interviews	Workshops	Analysis
			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.			
8	Energy	Uncompetitive energy prices in the UK are causing high costs	1 literature source The UK 2014 Budget reads: "While UK electricity prices are currently close to the International Energy Agency (IEA) average, a typical EII 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 2020.51 This Budget announces a package of reforms to	4 interviews CPI highlighted that in in the past higher UK energy prices have coincided with several mills shutting down simultaneously. One interviewee said "European energy costs are growing; raising taxes on energy is affecting our competiveness. We have energy costs 2-4 times higher than the US, so this effect the baseline cost of our operations". One interviewee: I do		This specific barrier on energy prices links to the wider points on competiveness of the sector discussed under barrier 1. The perception is that this further promotes a difficult economic climate and the decline of the sector, resulting in the outcome that financial capital for large capital expenditures to finance decarbonisation is difficult to obtain. This was reflected in both the literature review, and confirmed in the interviews and workshops. Funding for large capital expenditures should for most organisations be obtained from the group headquarters, and the pulp and paper Industry is particularly global. There is a perception expressed that the UK mills may be in a weak position compared to their peers abroad because the UK is less competitive due to high energy process and other factors. Investor confidence was stated as a pre-requisite to give industry the background and

Number	Category	Barriers	Literature review	Interviews	Workshops	Analysis
			radically reduce the costs of energy policy for business – particularly in manufacturing"	also provide input to the group for the options with regards to regulations, such as EU ETS, especially from a perspective of what is economically the best option. So again, another example of how we co-ordinate on energy within the group, but with a primarily economic driver.		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 paper manufacturers (and other Energy Intensive Industries) are not driven out of the UK by policy decisions or pricing around energy and carbon. This is a barrier now and in the future.
9	Technology	Biomass: feedstock availability (competition with industry and biofuels for feedstock, and with food and fibre production for arable land); risks associated with intensive farming (fertilizers, chemicals, biodiversity);	1 literature source **O1**: Heather Haydock (Ricardo-AEA) and Tamaryn Napp (Imperial College), Decarbonisation of heat in industry - A review of the research evidence, Ricardo-AEA/R/ED58571, issue 1, 119 pages. Feedstock availability (competition with industry and biofuels for feedstock, and with food and fibre production for arable land); risks associated with intensive farming (fertilizers, chemicals, biodiversity).	2 interviewees One company stated that some companies had moved to biomass electricity. At the same time it wondered if this trend would continue as the materials for biomass are scarce and this may steer prices upward.		There is much discussion around the potential impact of biomass and whether this is a future barrier or enabler. Biomass is potentially an alternative fuel for the pulp and paper Industry. Feedstock availability 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. Although dependent very much on local market factors, the advantage of the pulp and paper sector is that the majority of sites are well linked geographically and through their supply chain to biomass sources, particularly wood based sources such as saw mill waste. For the pulp and paper companies that have timber products in their portfolio there is an opportunity for a 'closed loop' system to be established, where waste material is sent back to the mill for use as fuel. The sustainability of biomass, particularly

Number	Category	Barriers	Literature review	Interviews	Workshops	Analysis
						wood, faces challenge as combustion releases carbon dioxide while depleting carbon stored as standing timber. A truly sustainable timber combustion cycle would be in equilibrium with forest regrowth, but the current 'dash for biomass' is unlikely to be. The conclusions here should consider Government research and position in this area. This is a barrier in the future.

Table 11: Raw data - barriers for the UK pulp and paper sector

INDUSTRIAL DECARBONISATION AND ENERGY EFFICIENCY ROADMAP TO 2050 – PULP AND PAPER

APPENDIX C – FULL TECHNOLOGY OPTIONS REGISTER INCLUDING DESCRIPTIONS

APPENDIX C FULL TECHNOLOGY OPTIONS REGISTER, INCLUDING DESCRIPTIONS

Technology options identified in the below tables come from sources listed in the references in section 6 of the main pulp and paper sector report.

1. Options Register

Across Mill							
Option	**Technology Readiness Level**[6]	**Adoption rate**	**Practical Applicability**	**Capex (per site)**[7]	**Capex Data Source**	**CO_2 (C) or Electricity (E) Reduction**	**Reduction Data Source**
(Waste) heat recovery and heat integration	9	64%	100%	£500,000-1,000,000	Adapted for this project based on the following references and review by stakeholders at workshops (Fleiter, 2012)	9% (C)	Adapted for this project based on the following references and review by stakeholders at workshops (Thollander and Ottosson, 2007; Ostle, 2012)
Energy management including installing meters for steam, electricity, air and gas to allow for online energy balances	9	76%	100%	£200,000-5,000,000	Expert judgement (PB/DNV GL consortium) with review from trade association and their members	15% (C)	Adapted for this project based on the following references and review by stakeholders at workshops (Thollander and Ottosson, 2007; Ostle, 2012)

[6] Please note that for cases where no source is provided, expert opinion has been used to evaluate the TRL (technology readiness level).

[7] This is the average capex per site. When calculating the cost for the entire sector, the lower number has been used for small sites and the higher number for large sites. Smalls sites considered <50k tonnes/year, large sites >50k tonnes per year.

Across Mill							
Option	**Technology Readiness Level[6]**	**Adoption rate**	**Practical Applicability**	**Capex (per site)[7]**	**Capex Data Source**	**CO_2 (C) or Electricity (E) Reduction**	**Reduction Data Source**
Focus on maintenance	9	75%	100%	£0-200,000	Directly from literature and review by sector team (Chen et al., 2012)	10% (C)	Adapted for this project based on the following references and review by stakeholders at workshops (Berkeley National Lab, 2000)
Improved process control across the entire mill (process and utilities)	9	42%	100%	£200,000-5,000,000	Directly from literature and review by sector team (Austin, 2010)	5% (C)	Adapted for this project based on the following references and review by stakeholders at workshops (Energietransitie Papierketen, 2013)
Industrial clustering and heat networking	9	0%	19%	£2,000,000-7,000,000	Expert judgement (PB/DNV GL consortium) with review from trade association and their members	-	-
Organic rankine cycles, heat pumps and similar heat recovery technology	7-9	8%	80%	£500,000-1,000,000	Expert judgement (PB/DNV GL consortium) with review from trade association and their members	3% (C)	Expert judgement (PB/DNV GL consortium) with review from trade association and their members

Across Mill							
Option	**Technology Readiness Level**[6]	**Adoption rate**	**Practical Applicability**	**Capex (per site)**[7]	**Capex Data Source**	**CO_2 (C) or Electricity (E) Reduction**	**Reduction Data Source**
Replace lighting with high efficiency lighting	9	23%	100%	£0-200,000	Adapted for this project based on the following references and review by stakeholders at workshops (Chen et al., 2012; Berkeley National Lab, 2000)	3% (E)	Adapted for this project based on the following references and review by stakeholders at workshops (Chen et al., 2012; Berkeley National Lab, 2000)

Table 12: Across mill full technology options register

Fibre Supply							
Option	Technology Readiness Level[8]	Adoption rate	Practical Applicability	Capex (per site)[9]	Capex Data Source	CO_2 (C) or Electricity (E) Reduction	Reduction Data Source
Efficient dispersers (see pumps and motors)		0%	100%			0% (C)	
Efficient screening	9	83%	100%	£500,000-1,000,000	Directly from literature and review by sector team (Fleiter et al., 2012)	15% (E)	Adapted for this project based on the following references and review by stakeholders at workshops ((Fleiter et al., 2012; EC, 2013)
High consistency pulping	9	76%	100%	£2,000,000-7,000,000	Adapted for this project based on the following references and review by stakeholders at workshops ((Fleiter et al., 2012)	8% (E)	Adapted for this project based on the following references and review by stakeholders at workshops ((Fleiter et al., 2012; EC, 2013)
Improved quality of recycled paper		0%	100%			0% (C)	
Sludge dryer	8-9	12%	25%	£500,000-1,000,000	Provided by trade association and their members with review by sector team and PB/DNV GL	5% (C)	Adapted for this project based on the following references and review by stakeholders at workshops (Ruohonen et al., 2009)

Table 13: Fibre supply full technology options register

8 Please note that for cases where no source is provided, expert opinion has been used to evaluate the TRL (technology readiness level).

9 This is the average capex per site. When calculating the cost for the entire sector, the lower number has been used for small sites and the higher number for large sites. Smalls sites considered <50k tonnes/year, large sites >50k tonnes per year.

Paper Machine							
Option	Technology Readiness Level[10]	Adoption rate	Practical Applicability	Capex (per paper machine)[11]	Capex Data Source	CO_2 (C) or Electricity (E) Reduction	Reduction Data Source
Closed hood (electricity)	9	86%	98%	£1,000,000-2,000,000	Adapted for this project based on the following references and review by stakeholders at workshops (Kong et al., 2013)	45% (E)	Adapted for this project based on the following references and review by stakeholders at workshops (Kong et al., 2013)
Closed hood (fuel)	9	86%	98%	£1,000,000-2,000,000	Adapted for this project based on the following references and review by stakeholders at workshops (Kong et al., 2013)	13% (C)	Adapted for this project based on the following references and review by stakeholders at workshops (Kong et al., 2013)
Dry sheet forming	7	0%	0%	£2,000,000-7,000,000	Adapted for this project based on the following references and review by stakeholders at workshops (Berkeley National Lab, 2000)	42% (C)	Adapted for this project based on the following references and review by stakeholders at workshops (Berkeley National Lab, 2000; De Beer et al., 1997)

[10] Please note that for cases where no source is provided, expert opinion has been used to evaluate the TRL (technology readiness level).

[11] This is the average capex per paper machine. When calculating the cost for the entire sector, the lower number has been used for small sites and the higher number for large sites. Smalls sites considered <50k tonnes/year, large sites >50k tonnes per year.

Paper Machine							
Option	**Technology Readiness Level10**	**Adoption rate**	**Practical Applicability**	**Capex (per paper machine)11**	**Capex Data Source**	**CO_2 (C) or Electricity (E) Reduction**	**Reduction Data Source**
Extended nip press: tissue	9	0%	60%	£2,000,000-7,000,000	Adapted for this project based on the following references and review by stakeholders at workshops (Fleiter, 2012; Carbon Trust, 2011; Kong et al., 2013; EC, 2013)	13% (C)	Adapted for this project based on the following references and review by stakeholders at workshops (Fleiter, 2012; Carbon Trust, 2011; Kong et al., 2013)
Extended nip press: non-tissue	9	39%	100%	£2,000,000-7,000,000	Adapted for this project based on the following references and review by stakeholders at workshops (Fleiter, 2012; Carbon Trust, 2011; Kong et al., 2013 ; EC, 2013)	8% (C)	Adapted for this project based on the following references and review by stakeholders at workshops (Fleiter, 2012; Carbon Trust, 2011, Kong et al., 2013)
Heat recovery on hoods (future)	1-4	0%	98%	£500,000-1,000,000	Expert judgement (PB/DNV GL consortium) with review from trade association and their members	40% (C)	Expert judgement (PB/DNV GL consortium) with review from trade association and their members

Paper Machine							
Option	Technology Readiness Level10	Adoption rate	Practical Applicability	Capex (per paper machine)11	Capex Data Source	CO_2 (C) or Electricity (E) Reduction	Reduction Data Source
Heat recovery on hoods (present)	9	88%	98%	£500,000-1,000,000	Adapted for this project based on the following references and review by stakeholders at workshops (Carbon Trust, 2011; Kong et al., 2013)	8% (C)	Adapted for this project based on the following references and review by stakeholders at workshops (Carbon Trust, 2011; Energietransitie Papierketen, 2013; Kong et al., 2013)
High consistency forming	7	15%	50%	£2,000,000-7,000,000	Adapted for this project based on the following references and review by stakeholders at workshops (Berkeley National Lab, 2000)	3% (C)	Adapted for this project based on the following references and review by stakeholders at workshops (Berkeley National Lab, 2000)
Hot pressing	7-8	1%	50%	£500,000-1,000,000	Adapted for this project based on the following references and review by stakeholders at workshops (Carbon Trust, 2011; Haydock and Napp, 2005)	8% (C)	Adapted for this project based on the following references and review by stakeholders at workshops (Carbon Trust, 2011; Haydock and Napp, 2005)
Improved dewatering in press section beyond shoe press	1-4	5%	60%	£2,000,000-7,000,000	Adapted for this project based on the following references and review by stakeholders at workshops (Haydock and Napp, 2005)	8% (C)	Adapted for this project based on the following references and review by stakeholders at workshops (Haydock and Napp, 2005; Ostle, 2012)

Paper Machine							
Option	Technology Readiness Level10	Adoption rate	Practical Applicability	Capex (per paper machine)11	Capex Data Source	CO_2 (C) or Electricity (E) Reduction	Reduction Data Source
Impulse drying	8-9	0%	50%	£2,000,000-7,000,000	Adapted for this project based on the following references and review by stakeholders at workshops (Fleiter, 2012)	20% (C)	Adapted for this project based on the following references and review by stakeholders at workshops (Fleiter, 2012; De Beer et al., 1997)
Increase dew point in hood from 55°C to 70°C	9	63%	98%	£200,000-5,000,000	Expert judgement (PB/DNV GL consortium) with review from trade association and their members	5% (C)	Adapted for this project based on the following references and review by stakeholders at workshops (Laurrijssen et al., 2010)
Infrared profiling	9	9%	50%	£200,000-5,000,000	Adapted for this project based on the following references and review by stakeholders at workshops (Berkeley National Lab, 2000)	5% (C)	Adapted for this project based on the following references and review by stakeholders at workshops (Berkeley National Lab, 2000)
Only use necessary agitation (turn off agitators, slow down agitators, zone agitation where appropriate)	9	71%	100%	£0-200,000	Expert judgement (PB/DNV GL consortium) with review from trade association and their members	0% (E)	Expert judgement (PB/DNV GL consortium) with review from trade association and their members

Paper Machine							
Option	**Technology Readiness Level10**	**Adoption rate**	**Practical Applicability**	**Capex (per paper machine)11**	**Capex Data Source**	**CO_2 (C) or Electricity (E) Reduction**	**Reduction Data Source**
State-of-the-art steam system: includes condensate system with stationary syphones and spoiler bars, with optimized differential pressures for condensate evacuation	9	76%	99%	£200,000-5,000,000	Adapted for this project based on the following references and review by stakeholders at workshops (Ostle, 2012; US DOE, 2008; Fleiter, 2012)	10% (C)	Adapted for this project based on the following references and review by stakeholders at workshops (Ostle, 2012; US DOE, 2008)
Steam box to increase sheet temperature and dryness	9	58%	80%	£500,000-1,000,000	Adapted for this project based on the following references and review by stakeholders at workshops (Fleiter, 2012; Carbon Trust, 2011; EC, 2013)	5% (C)	Adapted for this project based on the following references and review by stakeholders at workshops (Fleiter, 2012; Carbon Trust, 2011; EC, 2013)
Use flash steam from condensate	9	35%	70%	£200,000-5,000,000	Adapted for this project based on the following references and review by stakeholders at workshops (Carbon Trust, 2011)	2% (C)	Adapted for this project based on the following references and review by stakeholders at workshops (Carbon Trust, 2011)

Table 14: Paper machine full technology options register

Utilities							
Option	**Technology Readiness Level**[12]	**Adoption rate**	**Practical Applicability**	**Capex (per site)**[13]	**Capex Data Source**	**CO_2 (C) or Electricity (E) Reduction**	**Reduction Data Source**
Biomass based CHP or boiler	9	19%	100%	£2,000,000-7,000,000	Adapted for this project based on the following references and review by stakeholders at workshops (Möllersten, 2003)	100% (C)	Adapted for this project based on the following references and review by stakeholders at workshops (Möllersten, 2003)
Economisers on steam boilers	9	78%	80%	£500,000-1,000,000	Expert judgement (PB/DNV GL consortium) with review from trade association and their members	8% (C)	Expert judgement (PB/DNV GL consortium) with review from trade association and their members
Gasification of biomass for use in gas turbine	8-9	0%	10%	£2,000,000-7,000,000	Expert judgement (PB/DNV GL consortium) with review from trade association and their members	100% (C)	Adapted for this project based on the following references and review by stakeholders at workshops (Isaksson et al., 2012)
Install anaerobic waste water treatment plant	9	7%	33%	£2,000,000-7,000,000	Adapted for this project based on the following references and review by stakeholders at workshops (Kong et al., 2013 ; EC, 2013)	2% (C)	Adapted for this project based on the following references and review by stakeholders at workshops (Kong et al., 2013 ; EC, 2013)

[12] Please note that for cases where no source is provided, expert opinion has been used to evaluate the TRL (technology readiness level).

[13] This is the average capex per site. When calculating the cost for the entire sector, the lower number has been used for small sites and the higher number for large sites. Smalls sites considered <50k tonnes/year, large sites >50k tonnes per year.

Utilities							
Option	Technology Readiness Level[12]	Adoption rate	Practical Applicability	Capex (per site)[13]	Capex Data Source	CO_2 (C) or Electricity (E) Reduction	Reduction Data Source
Match pumping capacity to duty, avoid oversizing pumps and motors, avoid throttling, use variable speed drive (VSD) and efficient motors where possible	9	83%	85%	£200,000-5,000,000	Adapted for this project based on the following references and review by stakeholders at workshops (EC, 2013; Möllersten et al., 2003; Carbon Trust, 2011)	15% (E)	Adapted for this project based on the following references and review by stakeholders at workshops (EC, 2013; Möllersten et al., 2003; Carbon Trust, 2011)
Optimise steam turbine control	9	66%	80%	£200,000-5,000,000	Adapted for this project based on the following references and review by stakeholders at workshops (Möllersten et al., 2003; Carbon Trust, 2011)	2% (C)	Adapted for this project based on the following references and review by stakeholders at workshops (Möllersten et al., 2003; Carbon Trust, 2011)
Oxygen trim control to adjust burner inlet air	9	70%	80%	£0-200,000	Adapted for this project based on the following references and review by stakeholders at workshops (Carbon Trust, 2011; Swagelok, 2005)	3% (C)	Adapted for this project based on the following references and review by stakeholders at workshops (USA EPA, 2010)
Generators replacing PRVs	8-9	0%	30%	£500,000-1,000,000	Adapted for this project based on the following references and review by stakeholders at workshops (US DOE, 2012)		Adapted for this project based on the following references and review by stakeholders at workshops (US DOE, 2012)

Utilities							
Option	**Technology Readiness Level**[12]	**Adoption rate**	**Practical Applicability**	**Capex (per site)**[13]	**Capex Data Source**	**CO_2 (C) or Electricity (E) Reduction**	**Reduction Data Source**
Use fans or blowers for low vacuum applications	9	17%	50%	£200,000-5,000,000	Adapted for this project based on the following references and review by stakeholders at workshops (Carbon Trust, 2011)	2% (E)	Adapted for this project based on the following references and review by stakeholders at workshops (Carbon Trust, 2011)
Review of system pressure, leak detection etc.	9	92%	100%	£0-200,000	Adapted for this project based on the following references and review by stakeholders at workshops (Carbon Trust, 2011)	1% (E)	Adapted for this project based on the following references and review by stakeholders at workshops (Carbon Trust, 2011)
Switch from compressed air to electric drives for activators	9	1%	50%	£500,000-1,000,000	Expert judgement (PB/DNV GL consortium) with review from trade association and their members	1% (E)	Expert judgement (PB/DNV GL consortium) with review from trade association and their members
Eliminate compressed air system	9	1%	100%	£2,000,000-7,000,000	Expert judgement (PB/DNV GL consortium) with review from trade association and their members		Expert judgement (PB/DNV GL consortium) with review from trade association and their members

Table 15: Utilities full technology options register

Two Team Project							
Option	Technology Readiness Level[14]	Adoption rate	Practical Applicability	Capex (per site)[15]	Capex Data Source	CO_2 (C) or Electricity (E) Reduction	Reduction Data Source
100% electricity (heat saving)	7-9	0%	100%	£2,000,000-7,000,000	Directly from literature (CEPI, 2013)	100% (C)	Directly from literature (CEPI, 2013)
100% electricity (electricity increase)	7-9	0%	100%	£2,000,000-7,000,000	Directly from literature (CEPI, 2013)	-304% (E)	Directly from literature (CEPI, 2013)
Deep eutectic solvents	3	0%	100%		Directly from literature (CEPI, 2013)	20% (C)	Directly from literature (CEPI, 2013)
Dry pulp for cure-formed paper	3	0%	100%		Directly from literature (CEPI, 2013)	55% (C)	Directly from literature (CEPI, 2013)
Flash condensing with steam	3-5	0%	100%		Directly from literature (CEPI, 2013)	50% (C)	Directly from literature (CEPI, 2013)
Functional surface	9	0%	100%		Directly from literature (CEPI, 2013)	0% (C)	Directly from literature (CEPI, 2013)
Supercritical CO_2	3	0%	100%		Directly from literature (CEPI, 2013)	15% (C)	Directly from literature (CEPI, 2013)
Superheated steam drying	3-5	0%	100%		Directly from literature (CEPI, 2013)	50% (C)	Directly from literature (CEPI, 2013)
Toolbox	5	0%	100%		Directly from literature (CEPI, 2013)	40% (C)	Directly from literature (CEPI, 2013)

Table 16: Two Team Project full technology options register.

[14] Please note that for cases where no source is provided, expert opinion has been used to evaluate the TRL (technology readiness level).
[15] This is the average capex per site. When calculating the cost for the entire sector, the lower number has been used for small sites and the higher number for large sites. Smalls sites considered <50k tonnes/year, large sites >50k tonnes per year.

2. Options Classification

As mentioned in appendix A, the options identified were further divided into the following classification: across mill, fibre supply, paper machine, utilities and Two Team Project. Descriptions of technologies in each of these subdivisions are provided in the tables below.

Across Mill

The opportunities for decarbonisation and energy efficiency for across mill are listed in Table 17.

Option	Description
Energy monitoring and energy management	Hands-on monitoring of the processes, with reliable data from meters placed on crucial energy flows, can improve energy efficiency, when actions are executed immediately after data analysis. Implement a structured energy management (e.g. ISO 50001) to control and improve all aspects of energy use in the process.
Improved process control (moisture, oxygen and temperature control, air flow control - knowledge based fuzzy logic)	Optimised control of the process, taking into account all possible parameters that can influence the process. For continuous processes fuzzy logic may be an improvement over a classic deterministic control. Improved control of utilities: steam system, air compressor, vacuum pumps, lighting, water systems and pumps, agitators (turn off agitators; slow down agitators, zone agitation where appropriate).
(Waste) heat recovery and heat integration (including organic ranking cycles, heat pumps and similar heat recovery technology)	Have a systematic approach to heat recovery using techniques such as pinch technology and novel heat recovery technology. Examples of heat recovery applications: - Optimize heat exchangers - Heat recovery on hoods - Waste heat recovery from bleaching waste water - Use waste heat for sludge drying - Pre-heating of shower water using waste heat - Blowdown steam recovery
Focus on maintenance	Have a regular maintenance program including predictive maintenance. Examples are: - Maintenance on utilities (vacuum, pumps, motors and fans) - Maintain clean wires, felts and drying surfaces - Monitor press performance
Industrial clustering and heat networking	Consider using residual heat from industrial complexes to heat municipalities or industry with low temperature heat demand. Planning location of new plants close to heat demand.
Replace existent (old) lighting with high efficiency lighting	High efficiency lighting can be obtained by: - Installing the most efficient lighting (e.g. LED) - Provide the needed lux levels, not more - Install controls (presence, dusk, timers, …) to limit on-time - Transparent roof panels lower the need for lighting

Table 17: Across mill options

Fibre Supply

The fibre supply options are listed in Table 18.

Option	Description
High consistency pulping	In pulping, most of the energy is used to circulate and move the slurry. Consequently, by increasing the consistency of the slurry, the electricity demand of the pulper could be decreased, due to reduced mass flow. Electricity savings of 2-10 kWh per ton of de-inked pulp are expected if the solids content is increased from a typical 5-7% to 20%.
Efficient screening	Improvements were made in the field of screening and filtering. Further optimisation of the screening process shows energy savings, depending on the plant characteristics.
Efficient dispersers	Use energy-efficient dispersers to separate remaining particles from the fibres.
Sludge dryer	Use waste heat to pre-dry sludge before burning to increase the calorific value of the sludge, thus replacing more fossil fuel.
Improved quality of recycled paper	Improved sorting and removal of impurities reduces energy and efforts to have good quality pulp.

Table 18: Fibre supply options

Paper Machine

The energy saving opportunities are given in Table 19. For the paper machine (PM), a division is made into: PM general savings, PM wet-end and PM dryer.

Option	Description
PM General Savings	
State-of-the-art steam and condensate system (with stationary siphons and spoiler bars)	Keeping set points of the stationary siphons at their initial value to reduce blow through steam losses.
Optimise differential pressures for condensate evacuation	Lower steam consumption, machine speed increase.
PM Wet-End	
Steam box to increase sheet temperature and dryness	Steam box can improve profile: use low pressure steam or vented steam for boxes and showers.
Install shoe press	High dewatering efficiency + saving on opex + energy reduction in the drying part.
Improved dewatering in press section beyond shoe press	
Hot pressing	Increase the solids content before entering the dryer.
High consistency forming	The process pulp entering the forming stage has more than double the normal (3%) consistency. This measure increases forming speed and reduces dewatering and vacuum power requirements.
Dry sheet forming	Fibres can be dispersed through carding (mechanical) or air laying techniques.
Impulse drying	Applying heat and pressure for dewatering before drying.
PM Dryer	
Infrared profiling	Short-wave IR drying provides better heat transfer capabilities and compactness. Along with improved energy efficiency, it increases the drying power output.

Option	Description
Increase dew point set point in hood (e.g. from 38% to 50% or from 55°C to 70°C)	Increasing the relative humidity reduces the air flow rates by 30% → fan savings = 50%.
Heat recovery on hoods: closed hoods	15-20% steam reduction when replacing semi-open by a closed hood, leading to 40-50% less electricity use by the fans.

Table 19: Paper machine options

Utilities

The general energy saving opportunities for utilities are given in Table 20. A division is made into: vacuum, compressed air (CA), pumps and motors, water, and steam system.

option	Description
Vacuum	
Use fans or blowers for low vacuum applications	Don't use deep vacuum for applications such as foils.
Compressed Air	
Review of system pressure	Keep as low as possible as 1 bar increase of pressure requires 7-8% more compressor energy.
Switch from CA to electric drives for activators	Avoid using CA for operations that can also be done with electric motors.
Eliminate use of CA system	Try to avoid using CA where possible (prefer blower air, shut down parts of grid that are no longer in use)
Pumps and Motors	
Optimum design	Match pumping capacity to duty, avoid over-sizing pumps and motors, avoid throttling and use high-efficiency motors.
Water	
Install anaerobic waste water treatment plant	Production of CH_4 to be burnt in a CHP to produce electricity.
Steam	
Optimise steam turbine control	Prevent choking of turbine, which leads to reduced power output.
Biomass based CHP	Shift from fossil fuel to CO_2-neutral fuel.
State-of-the-art steam system	New, complete, well-dimensioned and controlled steam system.
Gasification of biomass for use in gas turbine	Shift from fossil fuel to a CO_2-neutral fuel.
Oxygen trim control to adjust burner inlet air (and detect air infiltration)	By combining an oxygen monitor with an intake air monitor, it is possible to detect even small leaks. Using a combination of CO ($_2$) and O_2 readings, it is possible to optimise the fuel/air mixture for high flame temperature (and best energy efficiency).
Economisers on steam boilers	Installing economisers on steam boilers can improve efficiency with 3-4%.
Generators replacing PRVs	Install local steam generators instead of using high pressure steam through Pressure Reduction Valves (PRV).

Table 20: Utilities options

Two Team Project

The general energy saving opportunities proposed by the CEPI Two Team Project are given in Table 21.

Option	Description
Flash Condensing with Steam	Process: largely dry fibres are blasted into a forming zone with agitated steam and condensed into a web using one-thousandth the volume of water used today.
Superheated steam drying	Use superheated steam for drying and use it afterwards as fibre carrier and for forming paper.
Dry pulp for cure-formed paper	Waterless paper production by means of two techniques: dry pulp and cure-forming.
Supercritical CO_2	To dry pulp and paper without the need for heat or steam and even dye paper or remove contaminants.
100% electricity	Evolution towards green electricity will reduce fossil fuels consumption; reduction of energy cost in the total cost by 12%.
Functional surface	Shift to producing more lightweight products; selling surface instead of weight (up to 30% material reduction per surface unit).
Toolbox	Combination of innovations, e.g. enzymatic pulp treatment, shear compression, energy efficient thermo-mechanical pulping, sophisticated biomass fractionation into lignin, cellulose and hemi-cellulose, biomass separation into molecules.
Deep eutectic solvents (DES)	DES opens the way to produce pulp at low temperatures and at atmospheric pressure. Any type of biomass could be dissolved into lignin, cellulose and hemicellulose with minimal energy and emissions

Table 21: Options from the Two Team Project

INDUSTRIAL DECARBONISATION AND ENERGY EFFICIENCY ROADMAP TO 2050 – PULP AND PAPER

APPENDIX D – ADDITIONAL PATHWAYS ANALYSIS

APPENDIX D ADDITIONAL PATHWAYS ANALYSIS

1. Option Deployment for Pathways under Different Scenarios

Challenging World

Pathway: Business as Usual Scenario: Challenging World (CW)

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%	0%	25%	25%	50%	75%	100%	100%	100%
02 Improved process control across the entire mill (process & utilities)	42%	100%	0%	0%	25%	25%	50%	75%	100%	100%	100%
03 (waste) heat recovery and heat integration	64%	100%	0%	0%	25%	25%	50%	75%	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%	0%	25%	25%	50%	75%	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%	0%	25%	25%	50%	75%	100%	100%	100%
09 Use flash steam from condensate	35%	70%	0%	0%	20%	25%	50%	75%	100%	100%	100%
Paper Machine - Wet End											
10 steam box to increase sheet temperature and dryness	58%	80%	0%	0%	25%	25%	50%	75%	100%	100%	100%
11 Extended Nip Press: Tissue	0%	60%	0%	0%	25%	25%	50%	75%	100%	100%	100%
12 Extended Nip Press: Non-Tissue	39%	100%	0%	0%	25%	25%	50%	75%	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%	0%	25%	25%	50%	75%	100%	100%	100%
20 Heat recovery on hoods present	88%	98%	0%	0%	25%	25%	50%	75%	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%	0%	25%	25%	50%	75%	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%	0%	25%	25%	50%	75%	100%	100%	100%
29 Economisers on steam boilers	78%	100%	0%	0%	25%	25%	50%	75%	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%	0%	25%	25%	50%	75%	100%	100%	100%
40 Efficient screening	83%	100%	0%	0%	25%	25%	50%	75%	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%	0%	25%	25%	50%	75%	100%	100%	100%
43 Use fans or blowers for low vacuum applications	17%	50%	0%	0%	25%	25%	50%	50%	75%	75%	100%
Utilities - Steam System											
44 Optimize steam turbine control	66%	100%	0%	0%	25%	25%	50%	75%	100%	100%	100%
Utilities -Compressed Air											
46 Review of system pressure, leak detection etc.	92%	100%	0%	0%	25%	25%	50%	75%	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%	0%	25%	25%	50%	75%	100%	100%	100%
Paper Machine - Dryer											
49 Closed hood (elec)	86%	98%	0%	0%	25%	25%	50%	75%	100%	100%	100%
Two Teams											
50 100% electricity (elec increase)	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Figure 5: BAU pathway, challenging world scenario

Pathway: Max Technical 1   Scenario: Challenging World (CW)

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%	0%	25%	25%	50%	75%	100%	100%	100%
02 Improved process control across the entire mill (process & utilities)	42%	100%	0%	0%	25%	25%	50%	75%	100%	100%	100%
03 (waste) heat recovery and heat integration	64%	100%	0%	0%	25%	25%	50%	75%	100%	100%	100%
04 organic Rankine cycles, heat pumps and similar heat recovery technology	8%	80%	0%	0%	25%	25%	50%	50%	75%	100%	100%
05 Focus on maintenance	75%	100%	0%	0%	25%	25%	50%	75%	100%	100%	100%
06 Industrial clustering and heat networking	0%	100%	0%	0%	0%	0%	0%	0%	0%	25%	25%
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%	0%	25%	25%	50%	50%	75%	75%	100%
09 Use flash steam from condensate	35%	70%	0%	0%	20%	25%	50%	50%	75%	75%	100%
Paper Machine - Wet End											
10 steam box to increase sheet temperature and dryness	58%	80%	0%	0%	25%	25%	50%	50%	75%	75%	100%
11 Extended Nip Press: Tissue	0%	60%	1%	0%	25%	25%	50%	50%	25%	25%	25%
12 Extended Nip Press: Non-Tissue	39%	100%	1%	0%	25%	25%	50%	50%	25%	25%	25%
13 Improved dewatering in press section beyond extended Nip Press	0%	60%	0%	0%	25%	25%	50%	50%	75%	75%	75%
14 Hot pressing	1%	50%	0%	0%	25%	25%	50%	50%	75%	75%	100%
15 High consistency forming	15%	50%	0%	0%	25%	25%	50%	50%	75%	75%	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%	0%	25%	25%	50%	75%	100%	100%	100%
20 Heat recovery on hoods present	88%	98%	0%	0%	25%	25%	50%	50%	75%	50%	50%
21 Heat recovery on hoods future	0%	98%	0%	0%	0%	0%	0%	25%	25%	50%	50%
22 Closed hood (fuel)	86%	98%	0%	0%	25%	25%	50%	75%	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%	0%	25%	25%	50%	75%	100%	100%	100%
29 Economisers on steam boilers	78%	100%	0%	0%	25%	25%	50%	50%	75%	75%	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%	0%	25%	25%	50%	50%	75%	75%	100%
40 Efficient screening	83%	100%	0%	0%	25%	25%	50%	75%	100%	100%	100%
41 Sludge dryer	12%	25%	0%	0%	0%	0%	0%	25%	25%	50%	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%	0%	25%	25%	50%	75%	100%	100%	100%
43 Use fans or blowers for low vacuum applications	17%	50%	0%	0%	25%	25%	50%	50%	75%	75%	100%
Utilities - Steam System											
44 Optimize steam turbine control	66%	100%	0%	0%	25%	25%	50%	75%	100%	100%	100%
Utilities -Compressed Air											
46 Review of system pressure, leak detection etc.	92%	100%	0%	0%	25%	25%	50%	75%	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%	0%	25%	25%	50%	50%	75%	75%	100%
Paper Machine - Dryer											
49 Closed hood (elec)	86%	98%	0%	0%	25%	25%	50%	75%	100%	100%	100%
Two Teams											
50 100% electricity (elec increase)	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Figure 6: Max Tech pathway 1, challenging world scenario

Pathway: Max Technical 2 Scenario: Challenging World (CW)

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%	0%	25%	25%	50%	75%	100%	100%	100%
02 Improved process control across the entire mill (process & utilities)	42%	100%	0%	0%	25%	25%	50%	75%	100%	100%	100%
03 (waste) heat recovery and heat integration	64%	100%	0%	0%	25%	25%	50%	75%	100%	100%	100%
04 organic Rankine cycles, heat pumps and similar heat recovery technology	8%	80%	0%	0%	25%	25%	50%	50%	75%	100%	100%
05 Focus on maintenance	75%	100%	0%	0%	25%	25%	50%	75%	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%	0%	25%	25%	50%	50%	75%	75%	100%
09 Use flash steam from condensate	35%	70%	0%	0%	20%	25%	50%	50%	75%	75%	100%
Paper Machine - Wet End											
10 steam box to increase sheet temperature and dryness	58%	80%	0%	0%	25%	25%	50%	50%	75%	75%	100%
11 Extended Nip Press: Tissue	0%	60%	1%	0%	25%	25%	50%	50%	25%	25%	25%
12 Extended Nip Press: Non-Tissue	39%	100%	1%	0%	25%	25%	50%	50%	25%	25%	25%
13 Improved dewatering in press section beyond extended Nip Press	0%	60%	0%	0%	25%	25%	50%	50%	75%	75%	75%
14 Hot pressing	1%	50%	0%	0%	25%	25%	50%	50%	75%	75%	100%
15 High consistency forming	15%	50%	0%	0%	25%	25%	50%	50%	75%	75%	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%	0%	25%	25%	50%	75%	100%	100%	100%
20 Heat recovery on hoods present	88%	98%	0%	0%	25%	25%	50%	50%	75%	50%	50%
21 Heat recovery on hoods future	0%	98%	0%	0%	0%	0%	0%	25%	25%	50%	50%
22 Closed hood (fuel)	86%	98%	0%	0%	25%	25%	50%	75%	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%	25%	25%	25%	50%	50%
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%	0%	25%	25%	50%	75%	100%	100%	100%
29 Economisers on steam boilers	78%	100%	0%	0%	25%	25%	50%	50%	75%	75%	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%	0%	25%	25%	50%	50%	75%	75%	100%
40 Efficient screening	83%	100%	0%	0%	25%	25%	50%	75%	100%	100%	100%
41 Sludge dryer	12%	25%	0%	0%	0%	0%	0%	25%	25%	50%	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%	0%	25%	25%	50%	75%	100%	100%	100%
43 Use fans or blowers for low vacuum applications	17%	50%	0%	0%	25%	25%	50%	50%	75%	75%	100%
Utilities - Steam System											
44 Optimize steam turbine control	66%	100%	0%	0%	25%	25%	50%	75%	100%	100%	100%
Utilities -Compressed Air											
46 Review of system pressure, leak detection etc.	92%	100%	0%	0%	25%	25%	50%	75%	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%	0%	25%	25%	50%	50%	75%	75%	100%
Paper Machine - Dryer											
49 Closed hood (elec)	86%	98%	0%	0%	25%	25%	50%	75%	100%	100%	100%
Two Teams											
50 100% electricity (elec increase)	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Figure 7: Max Tech pathway 2, challenging world scenario

Collaborative Growth

Pathway: Business as Usual   Scenario: Collaborative Growth (CG)

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 8: BAU pathway, collaborative growth scenario

Pathway: 20% - 40% Scenario: Collaborative Growth (CG)

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%	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%	75%	50%	25%	25%	0%	0%
12 Extended Nip Press: Non-Tissue	39%	100%	0%	0%	100%	75%	50%	25%	25%	0%	0%
13 Improved dewatering in press section beyond extended Nip Press	0%	60%	0%	0%	0%	25%	50%	75%	75%	100%	100%
14 Hot pressing	1%	50%	0%	0%	25%	50%	75%	75%	100%	100%	100%
15 High consistency forming	15%	50%	0%	0%	25%	50%	75%	75%	100%	100%	100%
17 Impulse drying	0%	50%	0%	0%	0%	25%	50%	75%	100%	100%	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%	75%	50%	50%	25%	0%	0%
21 Heat recovery on hoods future	0%	98%	0%	0%	0%	25%	50%	50%	75%	100%	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%	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 9: 20-40% CO_2 reduction pathway, collaborative growth scenario

Pathway: 40% - 60%   Scenario: Collaborative Growth (CG)

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%	75%	50%	25%	25%	0%	0%
12 Extended Nip Press: Non-Tissue	39%	100%	0%	0%	100%	75%	50%	25%	25%	0%	0%
13 Improved dewatering in press section beyond extended Nip Press	0%	60%	0%	0%	0%	25%	50%	75%	75%	100%	100%
14 Hot pressing	1%	50%	0%	0%	25%	50%	75%	75%	100%	100%	100%
15 High consistency forming	15%	50%	0%	0%	25%	50%	75%	75%	100%	100%	100%
17 Impulse drying	0%	50%	0%	0%	0%	25%	50%	75%	100%	100%	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%	75%	50%	50%	25%	0%	0%
21 Heat recovery on hoods future	0%	98%	0%	0%	0%	25%	50%	50%	75%	100%	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%	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 10: 40-60% CO_2 reduction pathway, collaborative growth scenario

Pathway: Max Technical 1 Scenario: Collaborative Growth (CG)

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%	25%	60%	60%	75%	75%	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%	25%	25%	0%	0%
12 Extended Nip Press: Non-Tissue	39%	100%	0%	0%	100%	75%	50%	25%	25%	0%	0%
13 Improved dewatering in press section beyond extended Nip Press	0%	60%	0%	0%	0%	25%	50%	75%	75%	100%	100%
14 Hot pressing	1%	50%	0%	0%	25%	50%	75%	75%	100%	100%	100%
15 High consistency forming	15%	50%	0%	0%	25%	50%	75%	75%	100%	100%	100%
17 Impulse drying	0%	50%	0%	0%	0%	25%	50%	75%	100%	100%	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%	75%	50%	50%	25%	0%	0%
21 Heat recovery on hoods future	0%	98%	0%	0%	0%	25%	50%	50%	75%	100%	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%	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%	25%	25%

Figure 11: Max Tech pathway 2, collaborative growth scenario

Pathway: Max Technical 2 Scenario: Collaborative Growth (CG)

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%	75%	50%	25%	25%	0%	0%
12 Extended Nip Press: Non-Tissue	39%	100%	0%	0%	100%	75%	50%	25%	25%	0%	0%
13 Improved dewatering in press section beyond extended Nip Press	0%	60%	0%	0%	0%	25%	50%	75%	75%	100%	100%
14 Hot pressing	1%	50%	0%	0%	25%	50%	75%	75%	100%	100%	100%
15 High consistency forming	15%	50%	0%	0%	25%	50%	75%	75%	100%	100%	100%
17 Impulse drying	0%	50%	0%	0%	0%	25%	50%	75%	100%	100%	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%	75%	50%	50%	25%	0%	0%
21 Heat recovery on hoods future	0%	98%	0%	0%	0%	25%	50%	50%	75%	100%	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%	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 12: Max Tech pathway 2, collaborative growth scenario

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CONTENTS

INDUSTRIAL DECARBONISATION AND ENERGY EFFICIENCY ROADMAP TO 2050 – PULP AND PAPER

APPENDIX A - METHODOLOGY

APPENDIX A METHODOLOGY

The overall methodology used in this project to develop a decarbonisation roadmap for the pulp and paper sector consists of four stages:

(1) Evidence gathering and processing based on literature, interviews and workshops
(2) Modelling of draft pathways, including scenario testing and sensitivity analysis
(3) Testing and developing final pathways
(4) Creating a sector vision for 2050 with main conclusions and recommendation of next steps

This methodology is illustrated in Figure 1 and summarised in the report. A detailed description is given in this appendix.

An important aspect of the methodology has been stakeholder engagement to ensure that all implicated parties have been invited to participate and contribute. We have worked closely with both CPI and PITA to identify and invite the right people from the sector. In addition we have worked with the Department of Energy and Climate Change (DECC) and the Department for Business Innovation and Skills (BIS) to identify appropriate academic and other stakeholders, such as financial industry personnel, to participate and contribute.

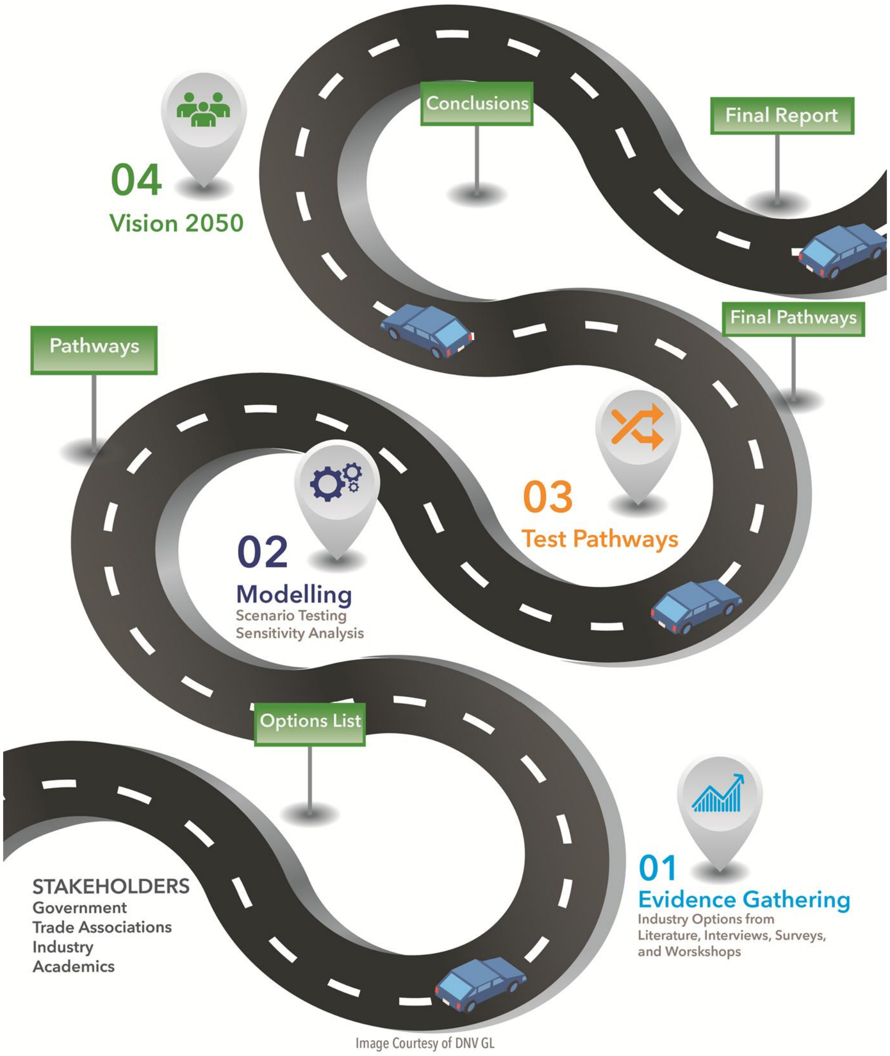

Figure 1: Roadmap methodology

1. Evidence Gathering

Evidence gathering focused on technical and social and business evidence, and aimed to acquire information about:

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

This evidence was required either to answer the principal questions directly, or to inform the development of pathways and the sector vision for 2050. The evidence was developed from the literature review, interviews and evidence gathering workshops. By using three different sources of information, the evidence gathered could be triangulated to improve the overall research. Themes that were identified during the literature review could subsequently be used as a focus or a starting point during the interviews and workshops. The data from the literature could be subjected to sensitivity testing by comparing it with information from the interviews and the workshops. In a similar way, information gaps during the interviews and workshops could be populated using literature data.

The three sources of evidence were used to develop a consolidated list of barriers and enablers for decarbonisation, and a register of technical options for the pulp and paper sector. This information was subsequently used to inform the development of a set of pathways to illustrate the decarbonisation potential of the pulp and paper industry in the UK.

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 members of DECC and BIS.

The evidence gathering exercise 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 literature review was not intended to be exhaustive and aimed to capture key documentation that applied to the UK. The companies interviewed represented over 80% of carbon emissions produced in the UK pulp and paper sector and captured 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. However, because many of the companies in the UK are globally owned, it was difficult to involve senior staff at a global corporate level. This also applied to workshop attendees.

The identification of relevant information and data was approached from a global and UK viewpoint. The global outlook examined dominating technologies and process types, global production and CO_2 emissions (in the EU-28) and the global outlook to 2050, including the implications for pulp and paper producers and consumers, and production and demand uncertainties. The UK outlook examined 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. The major UK pulp and paper producers and their key sites, dominant technologies and processes were also reviewed.

Options examined were relevant to fibre supply, the paper machine and the provision of utilities, as well as options that were applicable across the whole mill. Transformative options from the Confederation of European Paper Industry's (CEPI) Two Team Project were also included.

2. Literature Review

A literature review was undertaken on the pulp and paper sector. Its aim was to help to identify options, barriers and enablers for implementing decarbonisation throughout the sector. It seeks to answer the principal questions, determine the barriers and enablers for implementing decarbonisation and identify what are the necessary conditions for companies to invest and consider carbon management as a strategic issue to determine appropriate technical options for the sector.

The literature review covered over 150 documents. This was not a thorough literature review or rapid evidence assessment (REA) but a desktop research exercise deemed sufficient by the project team[1] in its breadth and depth to capture the evidence required for the purpose of this project. Based on the table of contents and a quick assessment (10 to 30 minutes per document), criteria were defined to identify which documents were to be used for the detailed analysis and evidence gathering (see 3 of APPENDIX A). Where

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

literature was deemed significant and of good quality, it was read and results were gathered on the principal questions.

The review has drawn on a range of literature (published after 2000), that examines energy efficiency and decarbonisation of the sector and also wider reviews, studies and reports deemed relevant to energy-intensive industries overall. Sector based and academic literature was also added. The documents are listed in section 6 of the main report.

The literature review was conducted in the following phases:

- Broad literature review and information or data collection
- Detailed literature analysis on technical points of note
- Identification of decarbonisation options and associated drivers or barriers
- Information on adoption rate, applicability, improvement potential, ease of implementation, capex, Return on Investment (ROI) and the saving potential for all options where available
- Construction of decarbonisation options list for short- (2015-2020), medium- (2020-2030) and long-term (2030-2050)
- Provision of information on strengths, weaknesses, opportunities, threats, enablers and barriers. This information was used in the evidence gathering workshop as a starting point for discussion. It provided evidence to support the development of a consolidated list of enablers and barriers for decarbonisation and, subsequently, to inform the list of the possible technological options and pathways that would lead to decarbonisation.

	Details
Main focus (all in the pulp and paper sector)	Energy efficiency improvements CO_2 and carbon reduction Fuel switching
Secondary focus	Drivers, barriers, policy Carbon capture and storage (CCS)
Excluded	Alternative trends in paper-making (e.g. paper based on plastics) District heating Technologies not applicable in UK pulp and paper sector (e.g. black liquor, gasification, chemical pulping, kraft)

Table 1: Scope of review

3. Criteria for Including Literature

As described earlier, the literature review followed a quick assessment process. General criteria used for including or excluding literature are shown in Table 2.

	Considerations	Final criteria
Literature value	Preference was given to official publications, such as academic papers or governmental publications. Information from paper machine constructors or pulp and paper suppliers (grey literature) was interesting as sector-related info. However, as there is no objective standard with which to compare this information, no extensive search in this domain was executed. The grey literature	Preference was given to published papers: the main source was ScienceDirect and published official reports.

	was used as input to the workshops.	
Time period to be covered	Given the fact that the European Energy Directive (end 2012) is a recent factor in the energy-related political landscape, preference was given to information which was (very) recently published. Some valuable, but older, information was included, as technology penetration is conducted at different speeds throughout the pulp and paper sector	No constraint was set on the date of the publication, but older information was given a lower quality rating, due to its lower relevance.
Geographical area	Preference was given to the UK industry, with a broader look to Europe (Scandinavia and Germany), as the technology competition in this area is the most prominent.	No geographical exclusion criteria were used, but information on the UK pulp and paper was given a higher quality rating, due to its higher relevance.
sector specifics	Given the specific nature of the UK pulp and paper sector, some technologies could be discarded, as there are no plants using them.	All information on black liquor was discarded, as of no importance to the UK. Similarly, not much focus was given to virgin pulping including chemical (kraft) and mechanical pulping.
Language	As the majority of information is in English, no special attention was given to publications in other languages.	The search was limited to papers in English, but where easily obtainable qualitative information was found in other languages, this was included[2].

Table 2: High-level selection criteria

For academic literature, the primary source was ScienceDirect. Of the documents that came on top in the search result (typically the first 25 papers), a skim-read of the abstract decided on the relevance of the paper.

A total of more than 150 papers, official publications and grey literature experts on pulp and paper were collected using this search methodology. The quality, source and objectivity of each document was analysed by reading the abstract (where present), followed by a skim-read of the document.

Each document was given a score on different aspects of relevance:

- Category: is the content of the document focusing on technology, drivers or barriers or policy-related aspects
- Affiliation: what is the source of the document: academia, governance or is it sector-based
- Financial-technical evaluation criteria present (YES/NO)
- Overall quality of the document (+/++/+++)
- Relevance for the UK pulp and paper sector (0/+/++/+++)
- Information on technological aspects (0/+/++/+++)
- Information on drivers and barriers (0/+/++/+++)
- Information on policy/legislation (0/+/++/+++)
- Document relevant for developing scenarios (0/+/++/+++)

Based on all these aspects, the document was given a relevance classification: ‘high’, ‘medium-high’, ‘medium-low’ or ‘low’.

2 Some valuable references are in Dutch or German.

The approach to selecting and categorising literature is depicted in Figure 2.

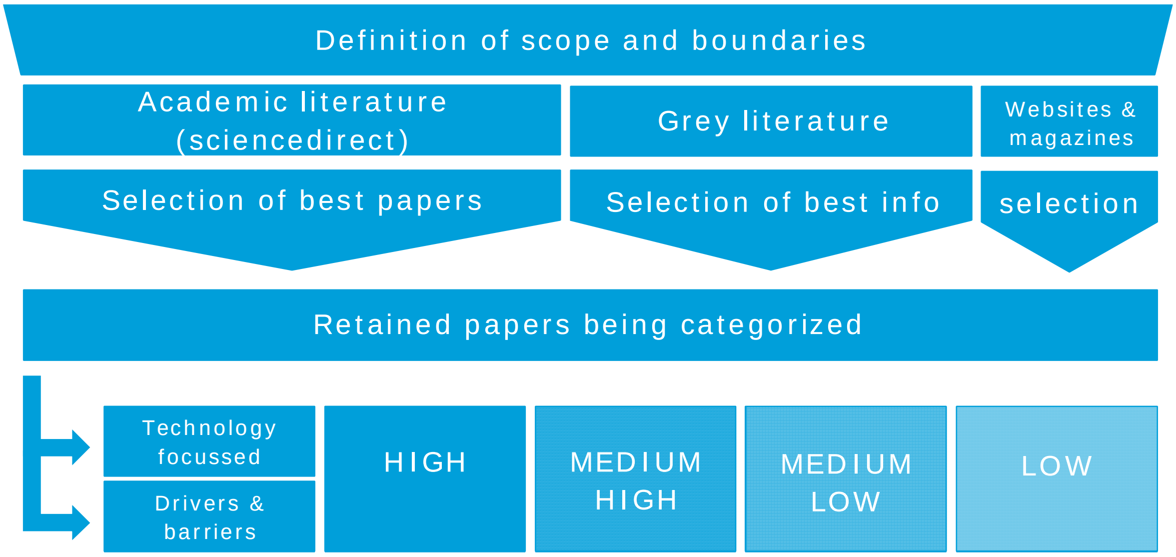

Figure 2: Diagram of the selecting and categorising process

All documents categorised as ‘high’ and ‘medium-high’ were read in detail, assessed and then included in the literature review process. The documents categorised as ‘medium-low’ and’ ‘low’ were read and assessed in part and only included if a significant reason for inclusion was found.

Energy saving measures (if present) were listed from each document included in the review process and this list was used to construct a decarbonisation options list for short- (2015-2020), medium- (2020-2030) and long-term (2030-2050) timelines.

NOTE: Additional and specific information or data was added to the overall review process from e.g. stakeholder input datasheets and as a result of following citation trails, expert knowledge and further targeted searches and recommendations.

Method of Analysing Literature

The following method was used to go through the selected literature:

1. Reading and noting of the abstract (or summary) followed by review of the document in detail to extract any relevant information on sector description or outlook and information or data on energy and carbon reduction measures
2. Relevant information (if appropriate) was extracted from other sources (or referred to) and document citation trails (if appropriate) were checked for further relevant information or data
3. Incorporation of the documents into the literature review and collating of the most relevant information or data on energy and carbon reduction measures
4. Energy reduction, where possible, were preferably extracted as a percentage, or as a specific energy saving per relevant unit (e.g. kWh/tonne pulp or GJ/tonne paper)
5. For financial savings, the amounts were kept in their original currency

4. Technical Literature Review

Identifying Literature

The primary aim of the literature review has been to gather evidence on technical potential and options (under different timelines) in order to inform the opportunities and challenges associated with the decarbonisation of energy use and improved energy efficiency for the pulp and paper sector in the UK.

In parallel to the above review process, a number of key academics were identified to participate and provide perspectives on current research and to provide additional input and feedback. This was to ensure that the appropriate literature and research had been identified, screened and included.

Research Questions

The evidence review addressed the following research questions:

TECHNICAL POTENTIAL: What existing research is there on the technical potential for improving the energy efficiency and lowering the carbon footprint of the pulp and paper industry to 2050? What generic and specific technical measures exist and what is their potential?

TECHNOLOGY COSTS: What research is available on the costs of these technical measures, and what does it tell us?

DRIVERS or ENABLERS: What does research tell us about the drivers or enablers for organisations in the pulp and paper sector to decarbonise their energy use? What are the perceived benefits for industrial organisations to decarbonise their heat use?

BARRIERS: What does research tell us about the barriers for organisations limiting effective decarbonisation of their energy use?

PRINCIPAL QUESTIONS: Check for other links to issues raised by principal questions.

SWOT ANALYSIS: Check for any information using terms strengths, weaknesses, threats and opportunities.

Information Found by the Consortium during Technical Literature Review

A number of additional documents were identified during the course of the literature review. These documents were identified through Google or ScienceDirect[3] and through the pulp and paper sector team. The search terms used in ScienceDirect and Google were:

- “Pulp”
- “Pulp and paper”
- “Pulp” AND “UK”
- “Pulp and paper” AND “energy case study”
- “Pulp and paper” AND “energy (reduction)”
- “Pulp and paper” AND “recycle/recycling”
- “Pulp and paper” AND “UK”
- “Pulp and paper” AND “newsprint / tissue”
- “Pulp and paper” AND “carbon capture / CCS”
- “Pulp and paper” AND “refining”
- “Pulp and paper” AND “energy/energy consumption”
- “Pulp and paper” AND “CHP / cogen (eration)”
- “Pulp and paper” AND “driver(s)/barrier(s)”

[3] http://www.sciencedirect.com/

- “Pulp and paper” AND “policy/politics”

Other documents in ScienceDirect were found by checking the references of the papers found by the above searches.

The results of the technical literature review are summarised in Figure 3.

Summary of strength of evidence on energy efficiency in pulp and paper									
Division	Number of information sources reviewed					Strength of the evidence			
	Academic searches	Direct website searches	expert reviewer	grey literature	Total	HIGH	MEDIUM HIGH	MEDIUM LOW	LOW
General	28	29	29	0	86	15	31	30	10
Pulping	1	2	3	0	6		2	4	
Paper Machine	6	4	13	0	23	5	5	11	2
CO2 & CCS	12	8	4	0	24	1	9	13	1
Drivers/barriers	0	6	2	0	8	4	4		
Social and Business	16	6	3	12	37	3	10	11	13
Pathways	1	2	0	0	3	1	2		

Figure 3: Overview of literature review

A complete reference list is available in section 6 of the main report.

5. Social and Business Literature Review

In addition to the work and processes described in the technical literature review, the social and business literature review key points and additions are:

- We reviewed over 37 documents (some of them the same as the technical literature review) to create a broad overview of the sector SWOT and identification of drivers and barriers to energy efficiency improvement and decarbonisation, and identification of main uncertainties in generic and business environment.

- The literature review included documents listed in the ITT (invitation to tender) as well as grey literature from trade associations, companies, DECC and BIS. Specific search terms were used which were agreed with DECC to identify the key enablers and barriers.

- We used a systematic and structured approach to the literature review. The criteria for assessing the relevance of the literature were defined to determine whether they address the key principal questions. The literature identified was analysed using a quick assessment process to identify the most relevant information on SWOT, enablers and barriers to decarbonisation.

- Based on table of contents and a quick assessment, we presented the results in a table as below. The analysis resulted in the identification of documents to be used for detailed analysis and evidence gathering. Where literature was deemed significant and of good quality (three stars or above), the literature was read and reviewed and results were gathered on the principal question areas.

	Year	Relevance	Quality	Characteristics	SWOT, Drivers and Barriers	Uncertainties future trends	options	pathways
Title 1		+++	++	0	++++	++	0	++++
…		++	+++	++	0	+++	+	+
…		+	++	+	0	++++	++	0
Title 10		++	++++	+++	++	+++	+++	++

Table 3: Literature review assessment process

0= very low, ++++ very high

The outcome of the literature review was a comprehensive list of strengths, weaknesses, opportunities, threats, enablers and barriers which were used in the evidence gathering workshop as a starting point for discussion and voted on to check which ones were most important.

6. Interviews

The evidence gathering stage of the project also involved a series of interviews. These aimed to obtain further details on the different subsectors within the pulp and paper industry and to gain a deeper understanding of the principal questions, including how companies make investment decisions, how advanced technologies are financed, the companies' strategic priorities are and where climate change sits within this.

Of the 17 biggest pulp and paper companies that represent 80% of the sector emissions, there are four subsectors: printing and writing (two), packaging (six), newsprint (three) and tissue (six). Although the sector is very heterogeneous, the different subsectors have similar manufacturing equipment and are facing the same type of challenges. It was agreed to undertake five interviews for the pulp and paper sector. We identified the proposed interviewees in liaison with CPI, DECC and BIS, and in accordance with the pre-defined criteria.

Five face-to-face interviews were completed and the following companies were interviewed:

- DS Smith - Procurement, EU Energy Manager (packaging)
- Arjo Wiggins - Mill Manager (printing and writing)
- KCC - Energy and Environment Manager (packaging and tissue)
- UPM - Head of Environment, UK and Ireland (newsprint, printing and writing, packaging)
- Smurfit Kappa - Energy Manager (packaging)

Comments collated via CPI, the workshop and subsequent email correspondence was also used as part of the evidence gathering process.

Interviewees were interviewed using the 'interview protocol' template, developed in liaison with DECC and BIS. The interview protocol was used to ensure consistency across interviews, to ensure that the interviews could be used to fill gaps in the literature review, identify key success stories of decarbonisation, and extract the key social and business barriers of moving to low-carbon technologies. The interview protocol can be found further in this section.

Evidence Gap

At the end of the evidence gathering process, it was recognised that a number of the UK mills are owned overseas and a key challenge with organising the interviews in this sector was that it was difficult to gain buy-in for the key investment decision makers outside the UK to participate in this project. It was also decided that further information was required on biomass. Therefore, two additional interviews were agreed with senior level decision makers:

- Smurfit Kappa – CEO
- Iggesund Paper and Board - Managing Director

These interviews helped to reaffirm the decision-making hierarchy and supported the enablers and barriers identified in this report. One interview focused heavily on the installation of a 100% biofuel based CHP plant and the decisions leading up to this investment, providing highly valuable insight for this report. It was also agreed to have an additional interview with CPI to help fill in any gaps in the evidence.

Assumptions

Going into each interview, a number of assumptions were made to refine the approach being taken:

1. Results from the literature review are available and partially well covered. Well covered areas are not addressed during the interview. Results may include:
    a. Options register of technical options
    b. Sector and subsector characteristic
    c. Sector SWOT analysis
    d. Main trends and drivers
    e. Some hurdles to and barriers for change, or energy or carbon reduction

2. Preparation of interviews includes rapid review of website and annual reports information related to business and energy and emissions reduction strategies.
3. The technical review covered any gaps in data or information (e.g. specifically related to that company's data) which may be appropriate to obtain during the interview process.
4. Interviewee role is reviewed prior to conducting the interview.
5. All interviews are conducted by interviewers in their own proficient way of dealing with issues around openness, consent, and follow-up.
6. Interviews are conducted by PB or DNV GL consultants (representatives from both technical and social and business disciplines), with their own proficient way of dealing with issues around openness, issues of consent, encouraging openness, and follow-up.
7. There might be follow-up with interviewees to obtain additional information discussed during the interview.

Interview Protocol

Preparation

1. Interviewee identification

Interviewees are identified in liaison with DECC and BIS in order to achieve good coverage of each sector. The steps taken to identify relevant candidates are:

- Identify the number of subsectors using SIC (standard industrial classification) codes listed in the ITT or another appropriate subsector division
- Where possible, subsectors were grouped based on similarities in products or production techniques to reduce the number of subsectors
- Identify which subsectors and/or organisations were most significant using the following criteria:
    - Size (e.g. by revenue or emissions)
    - Innovation level of companies
    - Whether headquartered in UK
    - Level of supply chain integration
- Select candidates best positioned to represent the views of the breadth of subsectors

***2.* Interview preparation**

The focus of each interview is to be informed by research of the key issues and challenges, successes and opportunities faced by each sector and an understanding of the specific knowledge held by the interviewee. The research incorporates:

- Social business literature review
- The findings of the technical review and decarbonisation options identified
- Review of company websites, annual reports and other materials relating business and emissions reduction strategies
- Assessment of the role of the interviewee and extensiveness of their knowledge
- Review of website, ONS data, IBIS data and annual reports information related to business and energy and emissions reduction strategies.
- Development of the options register

3. Interview format

Introductions

Interviewer sets out the project context and interview agenda.

Goals

Interviewer introduces the goals of the project as follows:

1. To determine the current state, ambitions or plans, successes and problems or challenges of each of the interviewee's organisation or sector with regard to energy use, energy reduction and carbon reduction:
   a. Identify and analyse examples of the implementation of energy and carbon reduction projects to deliver insight in the problems and barriers at a company level
   b. Develop an understanding of the decision-making processes
   c. Develop an understanding of the relationship between energy/carbon strategy and business strategy
2. To develop insight into the energy and carbon reduction options available to the organisations or sector and their potential:
   a. As currently deployed by organisations
   b. As an option to be deployed in the future
3. Understanding of the main drivers and barriers for change in general and with regard to energy and carbon reduction in the sector
4. To develop insight into the specific characteristics (strengths, weaknesses, opportunities and threats) of subsectors (where required)

Existing and future strategy for energy and carbon reduction

Interviewer to engage the interviewee on the focus of their organisations energy and carbon strategy using the following questions:

1. What is your organisations strategy for energy and carbon reduction? (If the strategy is clear, summarise and ask for confirmation). Cover the following sub-questions:
   a What are the main elements of the strategy?
   b How far in advance are you planning the company's energy efficiency strategy?
   c In your opinion, what are the enablers and/or challenges for the strategy?
      i) Please specify why:
         1. Constrained finance for funding for investments internally or externally
         2. Etc.
2. Do you consider your organisation as a leader (innovator or early adopter) or as a follower (early, late majority) on energy and carbon reduction? Cover the following sub-questions:
   a. Can you give one or more example(s) of actions undertaken by members of your organisation that fit with the stated market position?
   b. Do you expect the organisation's position with regard to energy and carbon reduction to change?

  c. Please state why your organisation is or is not a leader.
3. What energy and carbon projects have you implemented the last five years and why? What energy and carbon projects have you not implemented the last five years and why?

   Guidance for interviewer: use the prepared options register (prepared by technical lead and sector team) to identify energy and carbon reduction options. For parts of the list that are not covered, challenge the interviewee to identify options that could be valuable. With front runners place emphasise on more innovative options.

4. How important is energy and carbon reduction for your organisation? Please address how the carbon and energy strategy fits into wider business strategy and the extent to which it is embedded.

Stories (interviewees not self-identified as leaders)

Interviewer to lead discussion of a story or example related to an energy or carbon reduction project that went well and another that did not

Stories: Questions for leaders (only for self-identified leaders)

Interviewer to lead discussion of a story or example related to an energy or carbon reduction project using the questions below:

1. What energy and carbon reduction options have been implemented, why, when and where?
2. Can you tell the story of a project from the initial idea generation until now? Ensure this covers how ideas were generated (i.e. the step before any appraisal of options takes place):
    a. What was the timeline, sequence of events?
    b. Cover: idea generation, feasibility study (technological, financial, and organisation), decision-making, board presentation, and implementation
    c. What was your process for making a case for an investment and who was involved? Consider: key factors during decision-making, required payback, main perceived or actual risks, influence of alternative options for investment, financial and non-financial factors
    d. What were the critical moments (breakthroughs, barriers)?
3. What was the original position of the main stakeholders to the energy carbon project? Did their attitudes towards the subject change? How?
4. Why do you consider this story as a success or an area for improvement?
5. What are the main conclusions you can draw from this story - positive and negative?
    a. Lessons for future action?
    b. Main drivers and barriers for energy and carbon reduction in your company?
    c. Lessons for the way of organising energy and carbon reduction options within you company?
    d. Conclusions regarding potential reduction targets on short-, medium- and long-term?
    e. How well did the carbon reduction option work in practice, in relation to the anticipated performance?
6. Can any reports or presentations on this innovation be supplied?

Business Environment: value chain and capacity for innovation

Interviewer to ask the following questions:

1. What do you consider to be the main drivers for energy and carbon reduction in the sector?
    a. What are main characteristics of the main parts of the production process? Following the structure of the options register:
        i. Ask specific questions on any elements not covered in the desk research
        ii. Ask specific questions on the characteristics of the subsector (input, process, output, energy use, value chain, competitive forces)
    b. What do you perceive as the strengths and weaknesses of your value chain?
    c. What have been the main changes in the value chain over the last ten years?
    d. What innovations do you expect to see in the value chain in the coming 10/20/30 years?
    e. What are possible game changers for the value chain/ or sector?
2. Main innovators or early adopters in the sector:
    a. Who influences action (whom or what are they listening to? Why?
        i. Organisations and people within organisations (role or function)?
        ii. Within or outside the sector (other sectors, academics, non-government organisations, politicians, etc.)?
3. Questions on the dimensions of innovations[4] . These questions will be on a multiple choice list (answer categories strongly disagree, disagree, neither agree or not agree, agree, strongly agree[5]). After filling the list, ask for clarifications and examples that underpin answers in the following areas:
    a. Technical: networks with other companies, academics, knowledge of competitive and emerging technologies, participation in R&D, pilots, experiments
    b. Human capital: improvement projects, multi-disciplinary teams, training on innovation/change/improvement
    c. Organisation: horizontal communication lines, clear goals or responsibilities, customer focus
    d. Management: clear performance criteria for projects, structural follow up of main improvement projects in management meeting, clear status information on projects
4. (Optional) Please set out a characteristic story of a (successful) sector and subsector that implemented a change/innovation related to energy or carbon reduction. This question should be asked if consortia or sector teams feel a need to get a better overview of success stories. The question is relevant because in most business environments managers are influenced most by their peers.

Enablers and barriers for sector change

Interviewer to lead a summary discussion of the main drivers and barriers for sector change (general and or specific for energy and carbon reduction) using the following questions:

1. What do you consider the main drivers for change in the sector?
    a. Please state specific drivers in the following fields: social, policy, technical regulatory factors
    b. Interviewer to review the pre-prepared list of main driver and check seek further detail from the interviewee
2. What do you consider the main barriers for change in the sector?
    a. Please state specific barriers in the following fields: social, policy, technical regulatory factors
    b. Interviewer to review the pre-prepared list of main barriers and seek further detail from the interviewee

[4] Questions are asked to get a better (and broad overview of space or possibilities for change (not only including investments but also the change that potential of option will materialise.
[5] This way of working is chosen to be able to just cover the field quickly and get a quick first idea what they consider the important aspects so we can spend as much time as possible on this. We normally don't use the survey results to collect quantitative answers to these.

Function of Interview Protocol

The interview protocol was designed to collect, build upon and collaborate specific answers to principal questions which are not covered by results of desk research. The general timeline of one interview is illustrated below:

Intro	5-10 minutes
Current state and plans energy and carbon reduction	20-30 minutes
Stories of energy or carbon reduction	30-45 minutes
Business environment and innovation power	15-20 minutes
Drivers and hurdles for sector change (to test survey or workshop questionnaire)	If time left

Table 4: General interview timeline

7. Evidence Gathering Workshop

The evidence gathering stage of the project also involved workshop 1, the 'evidence gathering workshop'.

We worked with CPI, PITA, DECC and BIS to identify the most relevant attendees for the workshop. The research work already undertaken as part of the literature review and interviews were used to inform the content of the workshop.

The workshop was divided into two key activities. The first activity focused on reviewing all potential technological options for decarbonisation and identifying adoption rate, applicability, improvement potential, ease of implementation, capex, ROI, saving potential and timeline for the different options. This was done through two breakout sessions, one focused on collecting more data and the other focused on the timeline under different scenarios. The second activity involved splitting participants into five groups to discuss and vote on the enablers and barriers. Participants were also asked if they had any other enablers and barriers to be included. The aim of this section of the workshop was to prioritise the enablers and barriers and begin to consider how to overcome them (so that this could feed into later work on the options register, pathways and next steps).

We recognise that the voting process was based on initial reactions and that everyone voting may not have the expertise required on specific technical solutions to decarbonisation. In order to counter this limitation, CPI provided a validation of the options data after the first workshop.

The outcome of the evidence gathering workshop (and all evidence gathering stages of the project) was a consolidated list of enablers and barriers, and a more complete list of possible technological options with a suitable timeline for their implementation.

8. Pathways

A pathway is a combination of different decarbonisation options, deployed under the assumed constraints of each scenario that would achieve a decarbonisation level that falls into one of the following decarbonisation bands:

- 20-40% CO_2 reduction pathway
- 40-60% CO_2 reduction pathway
- 60-80% CO_2 reduction pathway

In addition, two purely technology-driven pathways were developed: a business as usual (BAU) pathway and a maximum technical (Max Tech) pathway. The BAU pathway consisted of the continued deployment of technologies that are presently being deployed across the sector. The Max Tech pathways - Max Tech 1 and Max Tech 2 - included a technology or technology combination that would achieve the maximum CO_2 reduction possible within the sector, given constraints of deployment rates and interaction. Two Max Tech pathways were developed because two potential avenues for reaching the maximum decarbonisation of the sector exist and it is presently not possible to determine which would be more likely. The pathways have not been optimised to achieve a certain decarbonisation level.

9. Pathways Development and Analysis

Overview

Pathways were developed in an iterative manual process in order to facilitate the exploration of uncertain relationships that would be difficult to express analytically. This process started with the data collected in the evidence gathering phase. This data was then challenged and enriched through discussions with the sector team and in the first workshop.

Logical reasoning (largely driven by option interaction and scenario constraints), sector knowledge and technical expertise were applied when selecting options for the different pathways under each scenario. For example, incremental options with lower costs and higher levels of technical readiness were selected for the lower decarbonisation bands, whereas more 'disruptive' options were selected for the higher decarbonisation bands in order to reach the desired levels of decarbonisation. These pathways were challenged by the sector team, modelled and assessed under the three scenarios and finally challenged 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 were detailed in the options register and relevant worksheets of the model.

It is important to keep in mind that the pathways results are the outcome of a model. As with all models the accuracy of the results is based on the quality of the input data. There are uncertainties associated with the input data and the output should therefore be seen as indicative and used to support the vision and next steps, not necessarily to drive it. Also the model was a simplification of reality, and there are likely to be other conditions which are not modelled.

The analysis only produced results (pathways) which were iterative inputs of the model operator, without any optimisation.

Process

1. The gathered evidence (from literature review, sector team discussions, stakeholder feedback and judgement) was consolidated into a condensed list of options.
2. Timing and readiness of options was developed by the sector team and during the first workshop, based on evidence from literature, sector knowledge and technical expertise.
3. Options were classified as SAT (incremental), major investment or Two Team.
4. BAU and Max Tech options were chosen and rolled out to the maximum level and rate allowable under the current trends scenario.
5. Options were added to the BAU pathway or reduced or taken out of the Max Tech pathway until each intermediary pathway band was reached.
6. Technical constraints and interactions across the list of options were taken into account when selecting options and deployment.

7. The deployment was adjusted to account for the output of the social and business research as well as current investment cycles.
8. pathways were modelled under the current trends scenario, accounting for changes in production and the carbon emissions of the electricity grid.
9. The results were reviewed and modifications made to the deployment, applicability and reduction potential for any options that appeared to be giving an unexpected or unusual result.
10. Further changes to option choices were made as required through iterations of points 5-9.
11. Revised pathways under current trends were produced for presentation at the second workshop.
12. Feedback on pathways was used to make any further necessary adjustments to the pathways under current trends.
13. The final pathways developed under current trends were used as a basis for the development of pathways under challenging world and collaborative growth scenarios.
14. Deployment of each option under challenging world and collaborative growth was adjusted according to the constraints of each scenario, including the removal of options that would not be likely under challenging world and the deployment of additional options that would become feasible under collaborative growth.
15. Deployment of each option was adjusted within the technical and scenario constraints in order to reach each pathway band where possible. Note that not all pathway bands are possible under some scenarios.

The options are listed in appendix C.

Deployment of Options

For each pathway, options were selected and deployed over time according to their readiness level, timing constraints, and those most likely to allow the pathway band to be achieved. This process occurred iteratively, involving the sector team, trade association and other Stakeholders (who contributed via the second workshop). The sector lead provided an expert view on whether the options identified in each pathway produced a feasible pathway.

As described within the pathways section of the report, the technologies included within each banded pathway under each scenario may differ in order to meet the pathway band under each scenario.

The selection and deployment of options accounted for evidence from the social and business research, for example which options could be deployed without any changes to policy and where the deployment of options may be slowed or curtailed by identified barriers or accelerated by enablers.

Option Interaction

There were a number of possible ways in which options could interact with each other. These interaction types, and how they were dealt with in the development of pathways, are described below:

- **One option excludes another:** This is taken into account by the user in the deployment inputs in the option selector by ensuring that no exclusive options are rolled out to a conflicting level in the same time period. For example, extended nip press and improved dewatering in press section beyond extended nip press are two options that are mutually exclusive in a paper machine. In the 40-60% pathway it can be seen that extended nip press and improved dewatering in press section beyond extended nip press are never deployed at more than 100% combined.
- **One option depends upon another being adopted:** This is taken into account by the user in the deployment section of the option selector by ensuring that if any option requires a precursor that this

precursor is rolled out to the appropriate level. In the BAU pathway it can be seen that closed hoods is a prerequisite to heat recovery on hoods.

- **Options are independent and act in parallel:** The ‘minimum interaction’ pathway curve assumes that all options are independent and their effect on energy or emissions are therefore incremental.
- **Options improve a common energy or emissions stream and act in series:** The ‘maximum interaction’ pathway curve assumes that the saving from each option reduces the remaining energy or emissions for downstream options to act upon.

The pathway curves included a ‘maximum interaction’ and a ‘minimum interaction’ curve. The actual pathway curve would lie between these two extremes.

Evidence Not Used in Pathways Modelling

Specific energy use of processes was considered constant in the modelling, whereas they are actually dependent on the load factor (production level) of the equipment. Increasing the production level of existing equipment would increase efficiency (in terms of kWh/tonne paper or Mt CO_2 per tonne paper), which should be taken into account when calculating emissions. However, a full bottom-up model would be needed, which was beyond the scope of this work.

The options were modelled with a fixed CO_2 and fuel saving as input values. As technologies mature, it is likely that these values would increase. This was not taken into account in the model, as the uncertainty of that development is high.

The adoption rates and applicability rates were used to inform deployment, but without a full bottom-up model implemented on a site-by-site basis, it was difficult to link these parameters directly to investment cycles.

10. Pathways Modelling

Scenarios

Modelling pathways starts with the development of scenarios. A scenario is a specific set of conditions external to the sector that would directly or indirectly affect the ability of the sector to decarbonise. An example of a condition in a scenario was the emissions factor of the electricity grid. Where appropriate, conditions were described qualitatively through annual trends. The scenarios analysis also included qualitative descriptions of exogenous drivers which were difficult to quantify, or for which analytical relationships to quantitative factors were indefinable.

For each pathway, the following three scenarios were tested: current trends, challenging world and collaborative growth. Scenario parameters are shown in Table 5 below.

Current Trends

The current trends scenario projected moderate UK and global growth. Alongside this, international policies on climate change were assumed to develop, gradually but effectively driving down emissions.

New low-carbon generation technologies were assumed to progressively decarbonise the electricity grid to 100 g/kWh by 2030.

Pulp and paper production was assumed to increase by 1% annually. It was assumed that the Pulp and paper business environment, the economic recession and the weak demand for paper may continue to limit revenues and thereby hamper the cash flow. An uneven playing field and carbon leakage was assumed to continue to be an issue, adding to the UK pulp and paper sector's lack of competitiveness on the global marketplace. Other governments were assumed to start taxing carbon.

Challenging World

The challenging world scenario was characterised by lower global growth rates. Climate change was assumed to have a lower profile than at present, so that there would be less effective action to reduce emissions.

New low-carbon generation technologies were assumed to progressively decarbonise the electricity grid to 200 g/kWh by 2030.

The pulp and paper industry was subject to more intense competition, both for raw materials and sales, leading to a decline of 0.5% per year in UK production over the period. An uneven playing field and carbon leakage were an issue adding to the UK pulp and paper sector's lack of competitiveness on the global marketplace.

Collaborative Growth

The collaborative growth scenario was represented by higher levels of global growth and concerted action to reduce carbon emissions.

New low-carbon generation technologies were assumed to progressively decarbonise the electricity grid to 50 g/kWh by 2030.

The UK pulp and paper industry sees growth at 2% per year, with a shift towards more advanced processes, increased reuse and recycling in general, growth in higher added value and lower carbon footprint products. The business environment was assumed to be positive with increased demand for UK pulp and paper and plants are working at the optimum capacity. A favourable global carbon price was assumed to be in place.

	Challenging world	Current trends	collaborative growth
International consensus	National self-interest	Modest	Consistent, coordinated efforts
International economic context	More limited growth, some unstable markets, weakening of international trade in commodities	Slow growth in EU, stronger in world, relatively stable markets	Stronger growth in EU, stable markets, strong international trade.
Resource availability and prices	Strong competition, High Volatility High price trends.	Competitive pressure on resources. Some volatile prices Central price trends.	Competitive pressure on resources. Some Volatile prices Central price trends.
International agreements on climate change	No new agreements. Compliance with some agreements delayed	Slow progress on new agreements on emissions reductions, all existing agreements adhered to.	Stronger worldwide agreements on emissions reductions, consistent targets for all countries
General Technical Innovation	Slow innovation and limited application	Modest innovation, incidental breakthroughs	Concerted efforts lead to broad range of early breakthroughs on Nano, bio, green and ICT technologies.
Attitude of end consumers to sustainability and energy efficiency	Consumer interest in green products only if price competitive. Limited interest in energy efficiency.	Limited consumer demand for green products, efficiency efforts limited to economically viable improvements	Consumer willing to pay extra for sustainable, low carbon products. Strong efforts to energy efficiency even where not cost effective.
Collaboration between sectors and organisations	Minimal joint effort, opportunistic, defensive	Only incidental, opportunistic, short term cooperation	Well supported shared and symbiotic relationships
Demographics (world outlook)	Declining slowly in the west Higher growth elsewhere	Declining slowly in the west Modest growth elsewhere	Stable in the west Slowing growth elsewhere

	Challenging world	Current trends	collaborative growth
World energy demand and supply outlook	Significant growth in demand with strong competition for resources. High dependence on imported fossil fuels	Balanced but demand growth dependent on supplies of fossil fuels from new fields.	Growing demands balanced by strong growth in supply of renewable energy, slowly declining importance of fossil fuels.
UK Economic outlook	Weaker OBR growth assumption.	Current OBR growth assumption	High OBR growth assumptions
Carbon intensity of electricity	Weakest trend of electricity carbon intensity reduction 200g/kWh at 2030	Stronger trend of electricity carbon intensity reduction 100g/kWh at 2030	Rapid decline in electricity carbon intensity 50g/kWh at 2030
CCS availability	Technology develops slowly, only becoming established by 2040	Technology does not become established until 2030	Technology becomes proven and economic by 2020
Low carbon process technology	New technology viability delayed by ten years	New technology economically viable as expected	New technology viability achieved early

Table 5: Summary of scenario context and specific assumptions applicable to the scenarios

11. Options

Classification and Readiness of Options

The options were divided into three groups reflecting the likely timing of their deployment:

- Existing state-of-the-art technologies (SAT) with wide deployment
- Major investment technologies
- Two Team Project technologies

SAT were assumed to begin to be deployed immediately as the technologies exist and are proven. They were assumed to be easy to implement. Adoption of these technologies aligned with equipment replacement to current SAT.

Major investment technologies were defined as technologies that have limited adoption today. The technology is proven but not widely accepted in industry. Few demonstration projects exist in the UK. These technologies would benefit from demonstration installations in the UK combined with training and other activities to spread the knowledge and reduce costs. Some novel technologies yet to be fully developed were included, such as improved dewatering in press section beyond the extended nip press. The deployment of these technologies was assumed to start in 2020 and be completely rolled-out by 2050. Some of these technologies would replace SAT. Therefore certain SAT were assumed to be decommissioned in line with the deployment of some major investment technologies.

The **Two Team Project technologies** originated from CEPI's Two Team Project. In the pathways, only one option from the Two Team project was considered: 100% electricity. This option was combined with carbon neutral steam supplied from an adjacent carbon neutral steam producer, such as a waste incineration plant (industrial clustering and heat networking). Assuming that the electricity grid would decarbonise, this option could achieve considerable decarbonisation of the sector. The deployment of this option was assumed to begin in 2040.

Options Processing

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 evidence gathering workshop which options they would consider to be viable, and through receiving detailed information packs from members of CPI. The technical team drafted the first list of options. However, each option had strengths, weaknesses, enablers, and barriers which needed to be taken into account to develop and refine the options register to feed into the model.

A comprehensive list of enablers and barriers identified from the literature review was refined and triangulated with the evidence gathering workshop and interviews. To find the most relevant enablers and barriers for incorporating into the options register and pathways, enablers and barriers that were not supported by the evidence gathering workshop and interviews were removed from the list.

The impact of social and business research was captured in the options register, under the individual technologies (where possible) and in the subsequent pathways selected.

We have used the decision tree below to determine whether the social and business findings should impact upon the options and pathways. The pathways represent a selection of options, and this determines when and to what extent the options become active.

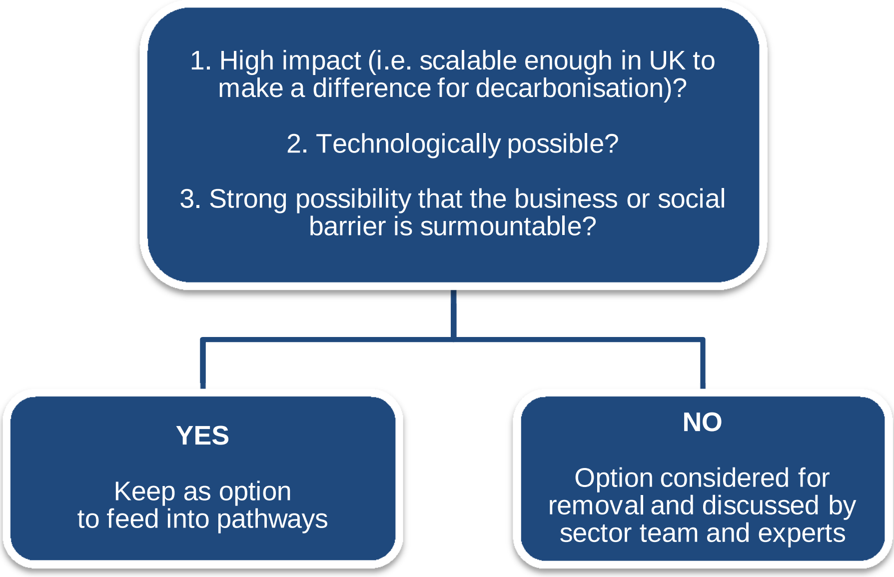

Figure 4: Social and business pathways impact tree

The options identified were further divided into the following subdivision (referred to as process factor): across mill, fibre supply, paper machine, utilities and Two Team Project.

12. Pathway and Action Plan Workshop

The second workshop, the 'pathway and action plan' workshop, focused on reviewing the draft decarbonisation and energy efficiency pathways and identifying potential actions for delivering them. This included presenting and discussing draft pathways in groups and then asking the question, "Taking into account the identified barriers and enablers, what next steps would assist in delivering the pathways?"

The outputs of the second workshop were used to validate the pathways and to inform the conclusions of the roadmap, which include example next steps and actions.

13. Next Steps

The output of the pathway development and social and business research included identification of barriers to and enablers for:

- Implementation of the pathways
- Decarbonisation and energy efficiency in the pulp and paper sector more generally

To draw conclusions, the analysis of barriers and enablers is taken further by describing a list of possible next steps to be implemented by a combination of industry, government and other organisations. These actions can take the form of strategic conclusions which are high-level or longer term, or more specific, discrete activities which can lead to tangible benefits.

The development of conclusions and next steps has considered the following:

- Actions from other pulp and paper decarbonisation projects

- Necessary changes in future markets, product features, business environment to enable the different pathways
- The outputs of workshops held as part of this project covering decarbonisation and energy efficiency pathways and next steps

- Actions that help maximise the success of a pathway under a range of scenarios
- options within the pathways that are necessary for success, e.g. if a particular technology option is necessary for the success of a number of pathways, or an option has a very high decarbonisation potential, actions to implement this option are included
- Policy and regulations that could contribute to the removal of barriers or enhancement of enablers

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APPENDIX B – FULL SOCIAL AND BUSINESS FINDINGS

APPENDIX B FULL SOCIAL AND BUSINESS FINDINGS

1. SWOT Outcomes

The table below highlights the top strengths, weaknesses, opportunities and threats in relation to decarbonising the pulp and paper sector in the UK.

STRENGTHS	WEAKNESSES	OPPORTUNITIES	THREATS
Inherently sustainable product life cycle	Declining phase of the sector, impacts investor confidence	Commercial driver behind lowering energy costs impacting cost of sale	Regulatory uncertainty
Energy investment and RD&D are a well-established discipline	Challenging payback criteria for investments	Increasingly attractive positioning for the industry around recycled, bio-based, and paper based hygiene products	Underinvestment in training and resources
Positioned well as bio-renewable product industry grows	Energy intensive process largely influenced by grid carbon intensity	CHP, biomass	Competitive market with low margins
Mill groups setting global decarbonisation targets	Imperfect information and visibility of Best Available Technology	Heat recovery and integration	Short-term thinking and risk aversion
Established recycled fibre supply chain			Reliance on ‘breakthrough technology’
Senior management buy-in			

Table 6: SWOT analysis for pulp and paper sector

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. In order to understand the inter-linkages between the SWOT analysis for the sector and the key enablers and barriers we identified from the literature review, interviews, and workshop, we analysed the root causes of the enablers and barriers and linked it back to the market environment and internal decision-making. The top SWOT outcomes were identified from the literature review, reinforced in the interviews and voted on by workshop participants as the most important.

Other social and business research methods used include elements of system analysis, root cause analysis, causal mapping, Porter's Five Forces analysis, and storytelling. **System analysis** can be used to help decision makers identify a better course of actions and make better decisions. It is a process of studying a procedure or business in order to identify goals and purposes, and to create systems and procedures that will achieve those goals most efficiently. It uses an experimental approach to understand the behaviour of an economy, market or other complex phenomenon. **Root cause analysis** is a method of problem solving that tries to identify the root causes of a problem. A root cause is a cause that - once removed from the problem - prevents the final undesirable event from recurring. **Causal mapping** is a visual representation, showing causalities or influences as links between different nodes. These maps can be used to aid strategic planning and thinking. **Porter's Five Forces** is a framework to analyse the level of competition within an industry and business strategy development. **Storytelling** is a technique that uses a clear and compelling narrative to convey a message or provide context to a conversation with the aim to engage the interviewee and encourage openness.

2. Market Structure

Subsector	Industry Definition	Market share major companies	Key external drivers
Paper and paperboard manufacturing	Firms in this industry manufacture paper and paperboard products from pulp and recycled materials. The bulk of the industry's output is intended for further processing by downstream manufacturers (e.g. cardboard packaging and tissues) although the industry also supplies finished products such as newsprint, writing paper and paperboard liner.	1. UPM-Kymmene (UK) Ltd 20.6% 2. DS Smith plc 18.1% 3. Aylesford Newsprint Holding Ltd 5.3%	• IT and telecommunications adoption • Demand from cardboard packaging and paper bag manufacturing • Demand from printing • Demand from newspaper printing • World price of wood pulp
Printing	Companies in this industry print books, magazines, brochures, labels and tags, posters, diaries, calendars, maps, stamps, security papers, cheques, banknotes and other products. This industry excludes the printing of newspapers and periodicals that appear at least four times a week.	1. De La Rue plc - 3.4% 2. St Ives plc - 2.7%	• Retail sales index • Percentage of households with internet access • Producer price index for paper and paperboard • Demand from book publishing
Cardboard packaging and paper bag manufacturing	Operators in this industry manufacture cardboard packaging and paper bags and sacks. Cardboard packaging includes corrugated and solid cardboard boxes, folding cartons and customised cardboard containers.	1. DS Smith Packaging Ltd - 17.2% 2. Smurfit Kappa UK Ltd 13.5%	• Demand from plastic packing goods manufacturing • Real effective exchange rate • Real private consumption expenditure • Producer price index for paper and paperboard
Sanitary products manufacturing	Industry operators convert sanitary paper stock or wadding, as well as pulp and paper, into sanitary paper products such as facial tissues, handkerchiefs, table napkins, kitchen towels, toilet paper, disposable nappies, sanitary towels and tampons. The final products are sold to wholesalers for distribution, straight to retailers or directly to large commercial customers.	1. Kimberly-Clark Ltd - 24.5% 2. SCA Hygiene Products UK Ltd - 23.7%	• Real private consumption expenditure • World price of wood pulp • International tourist numbers • Demand from takeaway and fast-food restaurants
Paper stationary manufacturing	Firms in this industry are principally involved in the manufacture of paper stationery products used in commercial, educational and household applications. This includes ready-to-use office paper, envelopes, folders, binders, diaries and manifold business forms.	1. Adare Group Ltd - 7.7% 2. Paragon Group UK Ltd - 7.0% 3. Hamelin Brands Ltd - 6.9% 4. Encore Envelopes Ltd - 5.6%	• IT and telecommunications adoption • Demand from newsagents and stationery stores • Percentage of households with internet access • Producer price index for paper and paperboard • Demand from printing

Table 7: Market structure – subsector definition, market share and external drivers within the pulp and paper sector

Subsector	Revenue (£M)	Profit (£M)	Wages (£M)	Annual Growth	Imports/ Demand (%)	Exports/ Revenue (%)	Revenue/ Employee (£"000)	Wages/ Revenue (%)	Employees/ establishment (nr.)	Average wage (£"000)	Share of economy (%)	Number of establishments
Paper and paper board	3,000	119.9	405	-4.10%	63.52%	30%	324	13.51%	34.77	43.78	0.05%	266
Printing	8,900	471.9	2374	-6.9%	5.79%	5.99%	115.07	26.66%	7.24	30.68	0.21%	10,690
Card board and paper bag	4,000	326.5	811	1.2%	15.51%	5.09%	151.54	20.12%	32.84	30.49	0.09%	810
Sanitary products	2,500	94	227.6	-1.8%	24.85%	13.23%	34.42	9.20%	61.15	34.46	0.03%	108
Paper stationary	564	24.3	105	-0.9%	16.54%	3.81%	184.92	18.62%	8.97	34.43	0.01%	340

Table 8: Market structure – subsector data within the pulp and paper sector

3. Assessing Enablers and Barriers

The first stage in our 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 evidence and whether the findings were validated via more than one information source. If the strength of the evidence was deemed high or medium high, then for the social and business research the enabler and/or barrier was included and information was used to support the answer to the principal question '*What are the main business enablers and barriers to decarbonisation?'*. If the strength of the evidence was deemed high or medium high for the technical options, the uncertainties in the modelling were reduced. The evidence was given a relevance classification of: 'high', 'medium-high', 'medium-low' or 'low'. The classifications are defined in Table 9 below.

It should be noted that the nature of the interview and workshop discussion process means that these represent the opinions and perceptions of the interviewees and workshop participants which could not always be backed up with evidence from other information sources.

The evidence was analysed and interpreted using a variety of evidence analytical techniques such as SWOT analysis, system analysis and root cause analysis or causal mapping where possible.

Classification	Definition
High	High relevance for the UK pulp and paper sector Good financial-economic decarbonisation data Recent information (after 2000) Provides a good example or story of decarbonisation Validated across all evidence gathering methods
Medium-high	Relevance for the UK pulp and paper sector Financial-economic data not always complete or clear-cut and only generic decarbonisation data Provides a good example or story of decarbonisation Validated by more than one evidence gathering method
Medium-low	Information that is or too general or too specific Relevant grey literature Old information but still relevant If only mentioned via one evidence gathering method
Low	Background information No or low applicability for the UK pulp and paper sector Grey literature of limited value Old information Lack of relevance or only mentioned once

Table 9: Evidence classification definition

The following tables provide a summary of raw data collected relating to enablers and barriers.

4. Detailed Analysis of Enablers and Barriers

Enablers

#	Category	Enablers	Literature review	Interviews	Workshops	Analysis and Interpretation
1	Market and economy	Diversification into recycled products and services, and bio-products with higher value added than paper, as well as paper-based hygiene products due to growing consumer demand.	**1 literature source** **O22** *CEPI, 2013, The Two Team Project, 42* According to CEPI, new products could make a goal of creating 50% more value from the sectors products achievable by 2050, but success would rely on significant breakthrough technologies being realised by 2030.	**2 Interviews** One company's strategy sees it moving away from commoditised paper grades towards value added bio-based products. The paper mill processes over 600,000 tonnes of recovered paper every year with the introduction of its new materials recovery facility, it is able to process plastics, cans and household waste For each tonne of recyclable material that are sorted at the facility, over 100,000 tonnes are newspapers and magazines that are used at the mill as raw material. It has partnered with external waste management experts, for a new product. This is a pellet that constitutes mainly paper fibre retrieved from wet waste, which is then shipped back to the mill to be burned for clean energy.	3 groups in the workshop identified this enabler.	A number of global manufacturers are beginning to shift their long term strategy to alternative products. We identified bio-products, biomass, and hygiene products as particular enablers for the industry. One example is the strategy, which sees the company moving away from commoditised paper grades towards value added bio-based products. The sector has existing expertise in the processing of biomass – one possible vector for the industry could be diversification into bio products with higher value added than paper products. '*It is not just a newsprint mill, it's waste management, renewable power operation too, the mill innovates and this approach to waste is unique as far as I know'* The most successful projects joined up different kinds of low-carbon behaviours (energy, waste, transport etc.); In the long term paper-based hygiene products serving basic human needs will become more and more available and used also in developing markets, while in mature markets they will remain essential for everyday life. Women will be important drivers of consumption, both in emerging and mature markets and the ageing

#	Category	Enablers	Literature review	Interviews	Workshops	Analysis and Interpretation
				Another interviewee stated that responding the customer needs is something that drives the business case for investment, in particular where it offers the opportunity for differentiation.		population will also increase the need for hygiene products. Such developments support the move towards high tech or high value added products and stimulate further enablers as the sector becomes more competitive which releases more capital for other aspects such as energy efficiency. This enabler is relevant now and will become increasingly important in the future.
2	Market and economy	Cost savings through lower energy consumption will lead to lower consumer prices and thus a higher demand	1 literature source CSE, ECI, 2012, What are the factors influencing energy behaviours and decision-making in the non-domestic sector? This reveals that the common and well established driver in sectors such as pulp and paper sector for driving lower energy use is cost.	2 interviews At one of the Mills, the driver for approving capital investments was reducing energy bill of the site (which used to equal consumption of a large city centre). This reduced the energy requirements of the core process which was stated that it also helped secure the mills future, the decision. This reduced energy consumption by 60-70%. Another interviewee confirmed that energy is a significant cost in the mills and there is a commercial drive to reduce energy consumption.	2 groups in the workshop identified this enabler.	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 that specific mill to remain in business but for growth and increased competitiveness of the sector as a whole. This could impact on lower consumer prices which could lead to higher demand and again improved competitiveness of the sector. One interviewee stated “*Energy is a significant cost to our mills, so there is a commercial drive too. This runs through all decisions, from small to large*” This is mostly a future enabler.
3	Market and economy	Collaboration in the value chain, including:	1 literature source	2 interviews	-	The pulp and paper supply chain is complex, with many interrelated specialist

#	Category	Enablers	Literature review	Interviews	Workshops	Analysis and Interpretation
		closed loop recycling, collaborating with machine suppliers, collaboratively refining existing technologies and developing new technologies, will be able to catalyse decarbonisation	**O10:** IEA, 2010, Energy Technology perspectives 2010 - SCENARIOS and STRATEGIES 2050. This reveals that the common driver in sectors such as pulp and paper sector for driving lower energy use is cost.	Segregated waste, as found elsewhere in Europe could remove cost and energy through efficiencies in sorting and pulping process. The closure of the Paper Science department and the University of Manchester has reduced the potential for RD&D in the sector		functions that do not fall into the boundaries of one single organisation, yet have the opportunity to influence performance. For example, the quality of recycled waste streams. Segregated waste, as found elsewhere in Europe could help improve efficiencies in sorting and pulping process. pulp and paper waste streams also offer the opportunity for further development. Waste sludge is viewed as waste, but can provide raw material for other industry sectors, e.g. lightweight 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. . Consideration should also be given on how to strengthen international collaboration. The closure of the Paper Science department and the University of Manchester has reduced RD&D and collaboration in the sector and resulted in other impacts such recruitment of new talent. There is a need for greater knowledge sharing and RD&D collaboration across countries to accelerate technology advancement along the curve from demonstration to commercialisation. This enabler is relevant now and will become increasingly important in the future.

#	Category	Enablers	Literature review	Interviews	Workshops	Analysis and Interpretation
4	Legislation	Government policy can encourage companies to decarbonise, for example removing barriers to entry, exit and growth of new firms that are important for the low-carbon energy technology development; developing a common vision together with the industry to secure public support for spending and subsidies.	1 literature source **O10:** IEA,2010, Energy Technology perspectives 2010 - SCENARIOS and STRATEGIES 2050, - Government steps to remove barriers to the entry, exit and growth of new firms may have an important part to play in low-carbon energy technology development in general	4 interviews One organisation stated that the Renewable Observation Certificates (ROCs) were a key factor in the decision to invest in a biomass powered CHP plant on site. Without these the 100% biomass fuelled CHP plant would have not gone ahead. All of the major investments in the mill has had assisted funding through national, EU or Welsh Assembly funding. As part of a global mill group, investment decisions consider a range of options, including investment outside of the UK, With clear and significant financial support major investments can be encouraged in the UK market. Other interviewees stated that the principle of subsidising energy savings will help to drive investments in the UK paper industry. CHP incentives would make a lot of sense, given the nature of our industry and	2 groups in the workshop identified this enabler.	The government can play a major role in encouraging the industry to decarbonise. Interviewees felt that successful energy efficient projects had been supported by funding from the European Union or the UK government. In one case, government backed incentives, such as the Renewable Observations Certificates (ROCs) were the single most important factor in going ahead with the investment. This can also be supported by keeping energy prices competitive with the rest of Europe, while at the same time incentivising low-carbon technologies. It was also mentioned that planning rules to encourage aspects such as industrial clustering and provide planning incentives would make planning easier / less risky for companies, resulting in carbon reductions compared to separate location. A shared cross sector 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. This enabler is relevant now and will become increasingly important in the future.

#	Category	Enablers	Literature review	Interviews	Workshops	Analysis and Interpretation
				how well placed it is for this technology. A decarbonised grid would have a big impact, but then it reduces effectiveness of CHP – a joined up approach is needed. Although contradictory to other interviews, one senior level interviewee stated that on a European level the UK is seen as 'fairly dependable' in terms of legislation stability that decisions can be based around.		
5	Energy	Small incremental investments do not need approval from headquarters. These include: 1. maintenance, operations, and component / equipment replacements; 2. process control and optimisation; 3. lighting and ventilation, process integration; 4. corporate framework		4 interviews One company stated that investments under £20k do not need approval from headquarters. Another said that for their company, this amount is approximately £0.5m, so limits vary considerably. Both said that because smaller investments do not need approval, improvements under this value would be easier to implement. CPI confirmed the above.		This enabler applies to the implementation of incremental energy efficiency investments which can be applied at the mill level. The level of budget for such energy efficiency improvements depends on the budget available from the Head Office of the organisation. In general, the budget available is related to the overall profitability of the organisation. The competition with other projects it has to compete with globally will only apply above a certain level of capital spend. There is a greater chance of implementation if the business case for the spend 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.

#	Category	Enablers	Literature review	Interviews	Workshops	Analysis and Interpretation
6	People and management	Senior management buy in and formal business commitment	1 literature source **O9:** Centre for Sustainable Energy (CSE) and the Environmental Change Institute, University of Oxford (ECI) for DECC. The closer that an energy manager is to the CEO in the corporate hierarchy the more likely that energy management activity will take place.	3 interviews One company stated that energy has long been a focus, this dates back to each site having an energy efficiency factor, based on the technology installed, and being measured against improvements achieved. This has naturally rolled on into carbon too. The means we can see the sites already 'in tune' with the idea of the metrics and have a good feel for how they can reduce energy/carbon intensity.	2 groups in the workshop identified this enabler.	Senior management buy-in and commitment is an enabler for the level of support and prioritisation that a companies' carbon strategy has compared to other aspects of the business strategy. This can create a cascade effect through the mill, if supported by senior management. Safety is an issue often cited as a success story, with senior buy in the sector in the 1990's the European pulp and paper sector has 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 associated sustainability reporting. Where the contribution of each mill is linked to the corporate target achievement and data collection as part of the overall sustainability reporting process may contribute towards this enabler. This focus is helpful as it aligns those within the company to the importance of carbon reductions and provides the underlying business case for energy reductions. None of the current company strategies look further than 2025 in terms of carbon reduction targets. 3/5 of the companies have sustainability reports, and one has a sustainability section on website. Smurfit Kappa: Yes http://www.smurfitkappa.com/Resources/Documents/Smurfit%20Kappa_Sustainable_Development_Report_2012.pdf

#	Category	Enablers	Literature review	Interviews	Workshops	Analysis and Interpretation
						Kimberly-Clark: Yes http://www.sustainabilityreport2012.kimberly-clark.com/files/K-C_2012_Sustainability_Report.pdf UPM: Global Reporting initiative (GRI) report within annual report: http://www.upm.com/EN/INVESTORS/Documents/UPM_Annual_Report_2013.pdf DS Smith: No report but has much info online here: http://www.dssmith.com/company/sustainability/ Arjo Wiggins: No report This enabler is applicable now.

Table 10: Raw data - enablers for the UK pulp and paper sector

Barriers

Number	Category	Barriers	Literature review	Interviews	Workshops	Analysis
1	Market and economy	Competitive marketplace with lowering profit margins overall in the UK pulp and paper sector, hamper any investments that are not critical	2 literature sources **O1**: Heather Haydock (Ricardo-AEA) and Tamaryn Napp (Imperial College), Decarbonisation of heat in industry - A review of the research evidence, Ricardo-AEA/R/ED58571, issue 1, 119 pages. "Cost Effectiveness - Increasing competition driven by imports and overcapacity has reduced the margins available to the manufacturers and has limited capital availability. This has led to reluctance to undertake investment with a payback of more than 12 months." (p. 28). "Operational Costs - the sector is under severe pressure on margins, so even if energy efficiency or fuel switching measures would reduce fuel costs they	2 interviews One interviewee highlighted that there is a danger for the UK to become uncompetitive in today's global climate. There is competition for finance with other mills internationally, also within the group. Another stated that global competition, as all business units have and the weak UK global position, where growth prospects are less favourable than other parts of the world.	3 groups in the workshop identified this barrier.	Caused by both the difficult economic climate and the decline of the sector, financial capital for large capital expenditures to finance decarbonisation is difficult to obtain. This was reflected in both the literature review, and confirmed in the interviews and workshops. Funding for large capital expenditures should for most organisations be obtained from the group headquarters, and the pulp and paper Industry is particularly global. There is a perception expressed that the UK mills may be in a weak position compared to their peers abroad because the UK is less competitive due to high energy costs other business environment factors. 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 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 paper mill related technology were identified in the literature to be a significant disincentive to invest. To make these large investments, interviews emphasised that UK mills are often competing for investment budget from group with their counterparts overseas. Several factors were mentioned that influence decisions of group level to invest in UK based mills rather than others. It was expressed that

Number	Category	Barriers	Literature review	Interviews	Workshops	Analysis
			may still not be taken up if they are accompanied by increases in maintenance costs for the equipment installed." (p. 28) **O12:** Patrik Thollander and Mikael Ottosson, 2008, An energy efficient Swedish pulp and paper Industry – exploring barriers to and driving forces for cost-effective energy efficiency investments "Another barrier which may prohibit investments in energy efficiency technologies, even if the investment is cost-effective, is lack of access to capital." (p. 5)			the growth projection for the UK business is lower than for businesses elsewhere, which disincentivises the group to invest in the UK. This is a barrier now and in the future.
2	legislation	Regulatory uncertainty with regards to decarbonisation and over-regulation of the industry, as well as increasing regulation of associated industries on which pulp and paper Industry is dependent; make it uncertain for companies to take		2 Interviews One company provided a specific example of a project that used locally sourced waste/wood from the forestry to produce energy. It stated that it had done an analysis of feasibility, for example engaging environmental groups	3 groups in the workshop identified this barrier.	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 feed in tariffs 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 a large buy in from stakeholders, including

Number	Category	Barriers	Literature review	Interviews	Workshops	Analysis
		large investment decisions.		and local communities. However the project was stalled due to the government's policy with regards to renewables and feed in tariffs which were changed at a very last stage. This hampered trust in the government and made any investment much more prone to risk. As a result the company was unable to get funding. "The major hurdle has to be uncertainty (and changing) government position and policies" The CPI acknowledged that there were sector perceptions and concerns raised regarding the changing government policies.		environmental groups and local residents and local authorities. However the government's position kept on changing, which led external financers and, eventually, the company themselves pull out the plug of the project. One company mentioned that they have been trying to lobby with the government to support on particular projects. For example, major investments that led to incremental decarbonisation in their mills were largely funded through national, EU, or Welsh Assembly funding. However, they also expressed the desire for federations to pursue a joint approach, rather than each mill doing their own lobbying to support the business case. The CPI cited three specific examples of where recent actions have reduced industrial confidence in policy, CHP policy changes in 2013; unilateral Carbon Price Floor Policy and cancellation of the Carbon Trust sector efficiency programme after potential projects had been collaboratively identified. This issue has made it difficult to get the level of engagement from the mills. This is a barrier now and in the future.
3	Market and economy	The pulp and paper Industry is conservative: it prefers to use technologies that have been proven before. There is a general resistance to changes and lack of cross sector knowledge in the latest	2 literature sources **O1**: Heather Haydock (Ricardo-AEA) and Tamaryn Napp (Imperial College), Decarbonisation of heat in industry - A review of the research evidence,	1 interviewee One interviewee stated that commercial sensitivity and an increasingly competitive marketplace creates a culture where sharing knowledge is limited, therefore information	2 groups in the workshop identified this barrier.	Literature indicated that conservatism is prevalent in the industry, leading to companies to be only willing to invest in technologies that have already been proven to be successful. In one study, companies indicated that they would rather not be the first to implement a new technology, but rather look at proven technologies in other industries, or to copy competitors.

Number	Category	Barriers	Literature review	Interviews	Workshops	Analysis
		technology	Ricardo-AEA/R/ED58571, issue 1, 119 pages **P.36-40**: "Conservatism - There is a degree of risk aversion in the sector, which is understandable, as technological failures would have a significant impact on business performance. This implies that new technologies need to be evolutionary rather than radical, or need to have been established in other sectors." **O3:** The Future of Heating: Meeting the challenge Short term thinking and risk: Conversely many businesses focus decisions on the short to medium term rather than the longer term. Heat intensive industries are also risk-averse, and particularly wary of risks to their product quality or output, and of being locked-in to inflexible infrastructure	about new technologies is simply not available.		Life cycles for paper machines range from 30 to 60 years and a replacement of the machine will require a large investment. Therefore if quick decarbonisation is desired, investments often need to happen outside of the normal investment cycles, whereas machines may have not yet reached their end-of-life as of yet. This is a mainly a future as no major machine replacement is the UK is currently planned.

Number	Category	Barriers	Literature review	Interviews	Workshops	Analysis
			and technologies. Delivery barriers			
4	Market and economy	There is uncertainty about return on capital on most energy efficient technology investments.	1 literature source **O1**: Heather Haydock (Ricardo-AEA) and Tamaryn Napp (Imperial College), Decarbonisation of heat in industry - A review of the research evidence, Ricardo-AEA/R/ED58571, issue 1, 119 pages. Operational Costs - 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.	5 interviews CPI	All 5 Workshop Groups	When taking investment decisions, interviewees, workshop groups and literature agreed that one of the most important decision factors is the payback time. The maximum length before it causes a significant hurdle differed from 12 months identified in literature, to four years for other organisations. A one or two year return on investment (ROI) period being deemed acceptable to the industry was a common theme of the interviews, the CPI reiterated this and that the planning horizon for mill developments is three years at best. This supports the information discussed in 'Barrier 1', and the reasons behind this relatively short-term approach to ROI is the competitive marketplace with lowering profit margins overall in the UK pulp and paper sector, hamper any investments that are not critical. The DNVGL interviewer explored different ways of asking this question to better determine how this approach to ROI could potentially be overcome, but the low profitability of the sector was always cited as the main barrier that should not be ignored. This is a barrier now.
5	Operations	There is uncertainty regarding the impact on machine operability	1 literature source **O1**: Heather Haydock (Ricardo-AEA) and Tamaryn Napp (Imperial College),		1 group in the workshop identified this barrier.	The potential impact of any changes in operations on machine operability and any impact on production and quality is also a barrier to decarbonisation that requires changes to machinery.

Number	Category	Barriers	Literature review	Interviews	Workshops	Analysis
			Decarbonisation of heat in industry - A review of the research evidence, Ricardo-AEA/R/ED58571, issue 1, 119 pages. Operability – if any technology contains uncertainty regarding the impact on machine operability this would be a major barrier to its adoption.			This can be linked to 'barrier 3' that the pulp and paper Industry is conservative: it prefers to use technologies that have been proven before. There is 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.
6	People and management	Lack of awareness and information imperfections lead to less initiative being undertaken to invest in low-carbon technologies	3 literature sources **O3:** The Future of Heating: Meeting the challenge Information: Information on the technical solutions to decarbonise and the costs and technology readiness (for example on industrial CCS) is imperfect among industry players.	2 interviews One company mentioned that the first priority should be to create a common vision (see on the right) and also highlighted that there is currently no platform to share lessons. The CPI confirmed that RD&D collaboration is currently not encouraged but could lead to technology advancement. This is what is meant by information imperfections in this context.	1 group in the workshop	One company stated that 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. 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. The need for greater knowledge sharing and RD&D collaboration among countries to accelerate technology advancement along the curve from demonstration to commercialisation was also a theme from the interviewees and CPI.

Number	Category	Barriers	Literature review	Interviews	Workshops	Analysis
			O11: Fleiter, 2012, The adoption of energy-efficient technologies by firms An integrated analysis of the technology, behaviour and policy dimensions (233p) p 149-BARRIERS TO ENERGY EFFICIENCY IN INDUSTRIAL BOTTOM-UP ENERGY DEMAND MODELS—A REVIEW - imperfect information (p.153)			This is linked to comments on the closure of the Paper Science department and the University of Manchester is reduced RD&D and the collaboration in the sector discussed in ‘enabler 3’ and elsewhere. There is a need for greater knowledge sharing and RD&D collaboration across countries to accelerate technology advancement along the curve from demonstration to commercialisation
			O12: Patrik Thollander and Mikael Ottosson, 2008, An energy efficient Swedish pulp and paper Industry – exploring barriers to and driving forces for cost-effective energy efficiency investments		Barriers described on the RHS were described in workshop discussions.	The literature gave further information on market-related barriers (p.5 and p7) and behavioural and organizational-related barriers (p.5). These included: Conflicts of interest within the mill/company; Uncertainty regarding the company's future; Cost of staff replacement, retirement, retraining; Difficulties in obtaining information about the energy use of purchased equipment; Energy objectives not integrated into operating, maintenance or purchasing procedures; Poor information quality regarding energy efficiency opportunities; Low priority given to energy management (by the company board); Lack of sub-metering; Energy manager lacks influence; Lack of technical skills; Cost of identifying opportunities, analysing cost effectiveness and tendering; Long decision chains; Lack of staff awareness; Other priorities for capital

Number	Category	Barriers	Literature review	Interviews	Workshops	Analysis
						investments; Lack of budget funding; Possible poor performance of equipment; Slim organization; Lack of access to capital; Lack of time or other priorities; Technology is inappropriate at the mill; Cost of production disruption/hassle/inconvenience; Technical risks such as risk of production disruptions; Dep./workers not accountable for energy costs. This is a barrier now and in the future as information is required in new technologies.
7	People and management	Shortage of technically competent staff and time and lack of funding for training prevents advancement	2 literature sources **O3:** The Future of Heating: Meeting the challenge Skills: 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. **O10:** IEA,2010, Energy Technology perspectives 2010 - SCENARIOS and STRATEGIES 2050, Developing a skilled low-carbon energy workforce; This includes the	1 interviewee CPI mentioned the general lack of industry specific academic RD&D in the UK following the closure of undergraduate courses in pulp and paper technology at the University of Manchester.	2 groups in the workshop identified this barrier.	The general lack of industry specific academic RD&D in the UK following the closure of undergraduate courses in pulp and paper technology at the University of Manchester. For longer term opportunities it was perceived as extremely difficult to bring a share of the Research and Development to the UK. This is linked to discussions under 'enabler 3' where the closure of the Paper Science department will have other impacts such as new recruits and ability to attract talent for the sector and competent staff such as engineers that understand the technical aspects of the industry that supports energy efficiency implementation. This is a barrier now as the profile of the workforce of the sector is ageing without sufficient succession planning in place.

Number	Category	Barriers	Literature review	Interviews	Workshops	Analysis
			development of academic curricula and training of experts, including geologists to facilitate CO2 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.			
8	Energy	Uncompetitive energy prices in the UK are causing high costs	1 literature source The UK 2014 Budget reads: "While UK electricity prices are currently close to the International Energy Agency (IEA) average, a typical EII 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 2020.51 This Budget announces a package of reforms to	4 interviews CPI highlighted that in in the past higher UK energy prices have coincided with several mills shutting down simultaneously. One interviewee said "European energy costs are growing; raising taxes on energy is affecting our competiveness. We have energy costs 2-4 times higher than the US, so this effect the baseline cost of our operations". One interviewee: I do		This specific barrier on energy prices links to the wider points on competiveness of the sector discussed under barrier 1. The perception is that this further promotes a difficult economic climate and the decline of the sector, resulting in the outcome that financial capital for large capital expenditures to finance decarbonisation is difficult to obtain. This was reflected in both the literature review, and confirmed in the interviews and workshops. Funding for large capital expenditures should for most organisations be obtained from the group headquarters, and the pulp and paper Industry is particularly global. There is a perception expressed that the UK mills may be in a weak position compared to their peers abroad because the UK is less competitive due to high energy process and other factors. Investor confidence was stated as a pre-requisite to give industry the background and

Number	Category	Barriers	Literature review	Interviews	Workshops	Analysis
			radically reduce the costs of energy policy for business – particularly in manufacturing”	also provide input to the group for the options with regards to regulations, such as EU ETS, especially from a perspective of what is economically the best option. So again, another example of how we co-ordinate on energy within the group, but with a primarily economic driver.		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 paper manufacturers (and other Energy Intensive Industries) are not driven out of the UK by policy decisions or pricing around energy and carbon. This is a barrier now and in the future.
9	Technology	Biomass: feedstock availability (competition with industry and biofuels for feedstock, and with food and fibre production for arable land); risks associated with intensive farming (fertilizers, chemicals, biodiversity);	1 literature source **O1**: Heather Haydock (Ricardo-AEA) and Tamaryn Napp (Imperial College), Decarbonisation of heat in industry - A review of the research evidence, Ricardo-AEA/R/ED58571, issue 1, 119 pages. Feedstock availability (competition with industry and biofuels for feedstock, and with food and fibre production for arable land); risks associated with intensive farming (fertilizers, chemicals, biodiversity).	2 interviewees One company stated that some companies had moved to biomass electricity. At the same time it wondered if this trend would continue as the materials for biomass are scarce and this may steer prices upward.		There is much discussion around the potential impact of biomass and whether this is a future barrier or enabler. Biomass is potentially an alternative fuel for the pulp and paper Industry. Feedstock availability 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. Although dependent very much on local market factors, the advantage of the pulp and paper sector is that the majority of sites are well linked geographically and through their supply chain to biomass sources, particularly wood based sources such as saw mill waste. For the pulp and paper companies that have timber products in their portfolio there is an opportunity for a ‘closed loop’ system to be established, where waste material is sent back to the mill for use as fuel. The sustainability of biomass, particularly

Number	Category	Barriers	Literature review	Interviews	Workshops	Analysis
						wood, faces challenge as combustion releases carbon dioxide while depleting carbon stored as standing timber. A truly sustainable timber combustion cycle would be in equilibrium with forest regrowth, but the current ‘dash for biomass’ is unlikely to be. The conclusions here should consider Government research and position in this area. This is a barrier in the future.

Table 11: Raw data - barriers for the UK pulp and paper sector

INDUSTRIAL DECARBONISATION AND ENERGY EFFICIENCY ROADMAP TO 2050 – PULP AND PAPER

APPENDIX C – FULL TECHNOLOGY OPTIONS REGISTER INCLUDING DESCRIPTIONS

APPENDIX C FULL TECHNOLOGY OPTIONS REGISTER, INCLUDING DESCRIPTIONS

Technology options identified in the below tables come from sources listed in the references in section 6 of the main pulp and paper sector report.

1. Options Register

Across Mill							
Option	**Technology Readiness Level**[6]	**Adoption rate**	**Practical Applicability**	**Capex (per site)**[7]	**Capex Data Source**	**CO_2 (C) or Electricity (E) Reduction**	**Reduction Data Source**
(Waste) heat recovery and heat integration	9	64%	100%	£500,000-1,000,000	Adapted for this project based on the following references and review by stakeholders at workshops (Fleiter, 2012)	9% (C)	Adapted for this project based on the following references and review by stakeholders at workshops (Thollander and Ottosson, 2007; Ostle, 2012)
Energy management including installing meters for steam, electricity, air and gas to allow for online energy balances	9	76%	100%	£200,000-5,000,000	Expert judgement (PB/DNV GL consortium) with review from trade association and their members	15% (C)	Adapted for this project based on the following references and review by stakeholders at workshops (Thollander and Ottosson, 2007; Ostle, 2012)

[6] Please note that for cases where no source is provided, expert opinion has been used to evaluate the TRL (technology readiness level).

[7] This is the average capex per site. When calculating the cost for the entire sector, the lower number has been used for small sites and the higher number for large sites. Smalls sites considered <50k tonnes/year, large sites >50k tonnes per year.

Across Mill							
Option	**Technology Readiness Level[6]**	**Adoption rate**	**Practical Applicability**	**Capex (per site)[7]**	**Capex Data Source**	**CO_2 (C) or Electricity (E) Reduction**	**Reduction Data Source**
Focus on maintenance	9	75%	100%	£0-200,000	Directly from literature and review by sector team (Chen et al., 2012)	10% (C)	Adapted for this project based on the following references and review by stakeholders at workshops (Berkeley National Lab, 2000)
Improved process control across the entire mill (process and utilities)	9	42%	100%	£200,000-5,000,000	Directly from literature and review by sector team (Austin, 2010)	5% (C)	Adapted for this project based on the following references and review by stakeholders at workshops (Energietransitie Papierketen, 2013)
Industrial clustering and heat networking	9	0%	19%	£2,000,000-7,000,000	Expert judgement (PB/DNV GL consortium) with review from trade association and their members	-	-
Organic rankine cycles, heat pumps and similar heat recovery technology	7-9	8%	80%	£500,000-1,000,000	Expert judgement (PB/DNV GL consortium) with review from trade association and their members	3% (C)	Expert judgement (PB/DNV GL consortium) with review from trade association and their members

Across Mill							
Option	**Technology Readiness Level[6]**	**Adoption rate**	**Practical Applicability**	**Capex (per site)[7]**	**Capex Data Source**	**CO_2 (C) or Electricity (E) Reduction**	**Reduction Data Source**
Replace lighting with high efficiency lighting	9	23%	100%	£0-200,000	Adapted for this project based on the following references and review by stakeholders at workshops (Chen et al., 2012; Berkeley National Lab, 2000)	3% (E)	Adapted for this project based on the following references and review by stakeholders at workshops (Chen et al., 2012; Berkeley National Lab, 2000)

Table 12: Across mill full technology options register

Fibre Supply							
Option	Technology Readiness Level[8]	Adoption rate	Practical Applicability	Capex (per site)[9]	Capex Data Source	CO_2 (C) or Electricity (E) Reduction	Reduction Data Source
Efficient dispersers (see pumps and motors)		0%	100%			0% (C)	
Efficient screening	9	83%	100%	£500,000-1,000,000	Directly from literature and review by sector team (Fleiter et al., 2012)	15% (E)	Adapted for this project based on the following references and review by stakeholders at workshops ((Fleiter et al., 2012; EC, 2013)
High consistency pulping	9	76%	100%	£2,000,000-7,000,000	Adapted for this project based on the following references and review by stakeholders at workshops ((Fleiter et al., 2012)	8% (E)	Adapted for this project based on the following references and review by stakeholders at workshops ((Fleiter et al., 2012; EC, 2013)
Improved quality of recycled paper		0%	100%			0% (C)	
Sludge dryer	8-9	12%	25%	£500,000-1,000,000	Provided by trade association and their members with review by sector team and PB/DNV GL	5% (C)	Adapted for this project based on the following references and review by stakeholders at workshops (Ruohonen et al., 2009)

Table 13: Fibre supply full technology options register

8 Please note that for cases where no source is provided, expert opinion has been used to evaluate the TRL (technology readiness level).

9 This is the average capex per site. When calculating the cost for the entire sector, the lower number has been used for small sites and the higher number for large sites. Smalls sites considered <50k tonnes/year, large sites >50k tonnes per year.

Paper Machine							
Option	Technology Readiness Level10	Adoption rate	Practical Applicability	Capex (per paper machine)11	Capex Data Source	CO_2 (C) or Electricity (E) Reduction	Reduction Data Source
Closed hood (electricity)	9	86%	98%	£1,000,000-2,000,000	Adapted for this project based on the following references and review by stakeholders at workshops (Kong et al., 2013)	45% (E)	Adapted for this project based on the following references and review by stakeholders at workshops (Kong et al., 2013)
Closed hood (fuel)	9	86%	98%	£1,000,000-2,000,000	Adapted for this project based on the following references and review by stakeholders at workshops (Kong et al., 2013)	13% (C)	Adapted for this project based on the following references and review by stakeholders at workshops (Kong et al., 2013)
Dry sheet forming	7	0%	0%	£2,000,000-7,000,000	Adapted for this project based on the following references and review by stakeholders at workshops (Berkeley National Lab, 2000)	42% (C)	Adapted for this project based on the following references and review by stakeholders at workshops (Berkeley National Lab, 2000; De Beer et al., 1997)

[10] Please note that for cases where no source is provided, expert opinion has been used to evaluate the TRL (technology readiness level).

[11] This is the average capex per paper machine. When calculating the cost for the entire sector, the lower number has been used for small sites and the higher number for large sites. Smalls sites considered <50k tonnes/year, large sites >50k tonnes per year.

Paper Machine							
Option	Technology Readiness Level10	Adoption rate	Practical Applicability	Capex (per paper machine)11	Capex Data Source	CO_2 (C) or Electricity (E) Reduction	Reduction Data Source
Extended nip press: tissue	9	0%	60%	£2,000,000-7,000,000	Adapted for this project based on the following references and review by stakeholders at workshops (Fleiter, 2012; Carbon Trust, 2011; Kong et al., 2013; EC, 2013)	13% (C)	Adapted for this project based on the following references and review by stakeholders at workshops (Fleiter, 2012; Carbon Trust, 2011; Kong et al., 2013)
Extended nip press: non-tissue	9	39%	100%	£2,000,000-7,000,000	Adapted for this project based on the following references and review by stakeholders at workshops (Fleiter, 2012; Carbon Trust, 2011; Kong et al., 2013 ; EC, 2013)	8% (C)	Adapted for this project based on the following references and review by stakeholders at workshops (Fleiter, 2012; Carbon Trust, 2011, Kong et al., 2013)
Heat recovery on hoods (future)	1-4	0%	98%	£500,000-1,000,000	Expert judgement (PB/DNV GL consortium) with review from trade association and their members	40% (C)	Expert judgement (PB/DNV GL consortium) with review from trade association and their members

Paper Machine							
Option	Technology Readiness Level10	Adoption rate	Practical Applicability	Capex (per paper machine)11	Capex Data Source	CO_2 (C) or Electricity (E) Reduction	Reduction Data Source
Heat recovery on hoods (present)	9	88%	98%	£500,000-1,000,000	Adapted for this project based on the following references and review by stakeholders at workshops (Carbon Trust, 2011; Kong et al., 2013)	8% (C)	Adapted for this project based on the following references and review by stakeholders at workshops (Carbon Trust, 2011; Energietransitie Papierketen, 2013; Kong et al., 2013)
High consistency forming	7	15%	50%	£2,000,000-7,000,000	Adapted for this project based on the following references and review by stakeholders at workshops (Berkeley National Lab, 2000)	3% (C)	Adapted for this project based on the following references and review by stakeholders at workshops (Berkeley National Lab, 2000)
Hot pressing	7-8	1%	50%	£500,000-1,000,000	Adapted for this project based on the following references and review by stakeholders at workshops (Carbon Trust, 2011; Haydock and Napp, 2005)	8% (C)	Adapted for this project based on the following references and review by stakeholders at workshops (Carbon Trust, 2011; Haydock and Napp, 2005)
Improved dewatering in press section beyond shoe press	1-4	5%	60%	£2,000,000-7,000,000	Adapted for this project based on the following references and review by stakeholders at workshops (Haydock and Napp, 2005)	8% (C)	Adapted for this project based on the following references and review by stakeholders at workshops (Haydock and Napp, 2005; Ostle, 2012)

Paper Machine							
Option	Technology Readiness Level10	Adoption rate	Practical Applicability	Capex (per paper machine)11	Capex Data Source	CO_2 (C) or Electricity (E) Reduction	Reduction Data Source
Impulse drying	8-9	0%	50%	£2,000,000-7,000,000	Adapted for this project based on the following references and review by stakeholders at workshops (Fleiter, 2012)	20% (C)	Adapted for this project based on the following references and review by stakeholders at workshops (Fleiter, 2012; De Beer et al., 1997)
Increase dew point in hood from 55°C to 70°C	9	63%	98%	£200,000-5,000,000	Expert judgement (PB/DNV GL consortium) with review from trade association and their members	5% (C)	Adapted for this project based on the following references and review by stakeholders at workshops (Laurrijssen et al., 2010)
Infrared profiling	9	9%	50%	£200,000-5,000,000	Adapted for this project based on the following references and review by stakeholders at workshops (Berkeley National Lab, 2000)	5% (C)	Adapted for this project based on the following references and review by stakeholders at workshops (Berkeley National Lab, 2000)
Only use necessary agitation (turn off agitators, slow down agitators, zone agitation where appropriate)	9	71%	100%	£0-200,000	Expert judgement (PB/DNV GL consortium) with review from trade association and their members	0% (E)	Expert judgement (PB/DNV GL consortium) with review from trade association and their members

Paper Machine							
Option	**Technology Readiness Level10**	**Adoption rate**	**Practical Applicability**	**Capex (per paper machine)11**	**Capex Data Source**	**CO_2 (C) or Electricity (E) Reduction**	**Reduction Data Source**
State-of-the-art steam system: includes condensate system with stationary syphones and spoiler bars, with optimized differential pressures for condensate evacuation	9	76%	99%	£200,000-5,000,000	Adapted for this project based on the following references and review by stakeholders at workshops (Ostle, 2012; US DOE, 2008; Fleiter, 2012)	10% (C)	Adapted for this project based on the following references and review by stakeholders at workshops (Ostle, 2012; US DOE, 2008)
Steam box to increase sheet temperature and dryness	9	58%	80%	£500,000-1,000,000	Adapted for this project based on the following references and review by stakeholders at workshops (Fleiter, 2012; Carbon Trust, 2011; EC, 2013)	5% (C)	Adapted for this project based on the following references and review by stakeholders at workshops (Fleiter, 2012; Carbon Trust, 2011; EC, 2013)
Use flash steam from condensate	9	35%	70%	£200,000-5,000,000	Adapted for this project based on the following references and review by stakeholders at workshops (Carbon Trust, 2011)	2% (C)	Adapted for this project based on the following references and review by stakeholders at workshops (Carbon Trust, 2011)

Table 14: Paper machine full technology options register

Utilities							
Option	**Technology Readiness Level**[12]	**Adoption rate**	**Practical Applicability**	**Capex (per site)**[13]	**Capex Data Source**	**CO_2 (C) or Electricity (E) Reduction**	**Reduction Data Source**
Biomass based CHP or boiler	9	19%	100%	£2,000,000-7,000,000	Adapted for this project based on the following references and review by stakeholders at workshops (Möllersten, 2003)	100% (C)	Adapted for this project based on the following references and review by stakeholders at workshops (Möllersten, 2003)
Economisers on steam boilers	9	78%	80%	£500,000-1,000,000	Expert judgement (PB/DNV GL consortium) with review from trade association and their members	8% (C)	Expert judgement (PB/DNV GL consortium) with review from trade association and their members
Gasification of biomass for use in gas turbine	8-9	0%	10%	£2,000,000-7,000,000	Expert judgement (PB/DNV GL consortium) with review from trade association and their members	100% (C)	Adapted for this project based on the following references and review by stakeholders at workshops (Isaksson et al., 2012)
Install anaerobic waste water treatment plant	9	7%	33%	£2,000,000-7,000,000	Adapted for this project based on the following references and review by stakeholders at workshops (Kong et al., 2013 ; EC, 2013)	2% (C)	Adapted for this project based on the following references and review by stakeholders at workshops (Kong et al., 2013 ; EC, 2013)

[12] Please note that for cases where no source is provided, expert opinion has been used to evaluate the TRL (technology readiness level).

[13] This is the average capex per site. When calculating the cost for the entire sector, the lower number has been used for small sites and the higher number for large sites. Smalls sites considered <50k tonnes/year, large sites >50k tonnes per year.

Utilities							
Option	Technology Readiness Level[12]	Adoption rate	Practical Applicability	Capex (per site)[13]	Capex Data Source	CO_2 (C) or Electricity (E) Reduction	Reduction Data Source
Match pumping capacity to duty, avoid oversizing pumps and motors, avoid throttling, use variable speed drive (VSD) and efficient motors where possible	9	83%	85%	£200,000-5,000,000	Adapted for this project based on the following references and review by stakeholders at workshops (EC, 2013; Möllersten et al., 2003; Carbon Trust, 2011)	15% (E)	Adapted for this project based on the following references and review by stakeholders at workshops (EC, 2013; Möllersten et al., 2003; Carbon Trust, 2011)
Optimise steam turbine control	9	66%	80%	£200,000-5,000,000	Adapted for this project based on the following references and review by stakeholders at workshops (Möllersten et al., 2003; Carbon Trust, 2011)	2% (C)	Adapted for this project based on the following references and review by stakeholders at workshops (Möllersten et al., 2003; Carbon Trust, 2011)
Oxygen trim control to adjust burner inlet air	9	70%	80%	£0-200,000	Adapted for this project based on the following references and review by stakeholders at workshops (Carbon Trust, 2011; Swagelok, 2005)	3% (C)	Adapted for this project based on the following references and review by stakeholders at workshops (USA EPA, 2010)
Generators replacing PRVs	8-9	0%	30%	£500,000-1,000,000	Adapted for this project based on the following references and review by stakeholders at workshops (US DOE, 2012)		Adapted for this project based on the following references and review by stakeholders at workshops (US DOE, 2012)

Utilities							
Option	Technology Readiness Level[12]	Adoption rate	Practical Applicability	Capex (per site)[13]	Capex Data Source	CO_2 (C) or Electricity (E) Reduction	Reduction Data Source
Use fans or blowers for low vacuum applications	9	17%	50%	£200,000-5,000,000	Adapted for this project based on the following references and review by stakeholders at workshops (Carbon Trust, 2011)	2% (E)	Adapted for this project based on the following references and review by stakeholders at workshops (Carbon Trust, 2011)
Review of system pressure, leak detection etc.	9	92%	100%	£0-200,000	Adapted for this project based on the following references and review by stakeholders at workshops (Carbon Trust, 2011)	1% (E)	Adapted for this project based on the following references and review by stakeholders at workshops (Carbon Trust, 2011)
Switch from compressed air to electric drives for activators	9	1%	50%	£500,000-1,000,000	Expert judgement (PB/DNV GL consortium) with review from trade association and their members	1% (E)	Expert judgement (PB/DNV GL consortium) with review from trade association and their members
Eliminate compressed air system	9	1%	100%	£2,000,000-7,000,000	Expert judgement (PB/DNV GL consortium) with review from trade association and their members		Expert judgement (PB/DNV GL consortium) with review from trade association and their members

Table 15: Utilities full technology options register

Two Team Project							
Option	Technology Readiness Level[14]	Adoption rate	Practical Applicability	Capex (per site)[15]	Capex Data Source	CO_2 (C) or Electricity (E) Reduction	Reduction Data Source
100% electricity (heat saving)	7-9	0%	100%	£2,000,000-7,000,000	Directly from literature (CEPI, 2013)	100% (C)	Directly from literature (CEPI, 2013)
100% electricity (electricity increase)	7-9	0%	100%	£2,000,000-7,000,000	Directly from literature (CEPI, 2013)	-304% (E)	Directly from literature (CEPI, 2013)
Deep eutectic solvents	3	0%	100%		Directly from literature (CEPI, 2013)	20% (C)	Directly from literature (CEPI, 2013)
Dry pulp for cure-formed paper	3	0%	100%		Directly from literature (CEPI, 2013)	55% (C)	Directly from literature (CEPI, 2013)
Flash condensing with steam	3-5	0%	100%		Directly from literature (CEPI, 2013)	50% (C)	Directly from literature (CEPI, 2013)
Functional surface	9	0%	100%		Directly from literature (CEPI, 2013)	0% (C)	Directly from literature (CEPI, 2013)
Supercritical CO_2	3	0%	100%		Directly from literature (CEPI, 2013)	15% (C)	Directly from literature (CEPI, 2013)
Superheated steam drying	3-5	0%	100%		Directly from literature (CEPI, 2013)	50% (C)	Directly from literature (CEPI, 2013)
Toolbox	5	0%	100%		Directly from literature (CEPI, 2013)	40% (C)	Directly from literature (CEPI, 2013)

Table 16: Two Team Project full technology options register.

[14] Please note that for cases where no source is provided, expert opinion has been used to evaluate the TRL (technology readiness level).
[15] This is the average capex per site. When calculating the cost for the entire sector, the lower number has been used for small sites and the higher number for large sites. Smalls sites considered <50k tonnes/year, large sites >50k tonnes per year.

2. Options Classification

As mentioned in appendix A, the options identified were further divided into the following classification: across mill, fibre supply, paper machine, utilities and Two Team Project. Descriptions of technologies in each of these subdivisions are provided in the tables below.

Across Mill

The opportunities for decarbonisation and energy efficiency for across mill are listed in Table 17.

Option	Description
Energy monitoring and energy management	Hands-on monitoring of the processes, with reliable data from meters placed on crucial energy flows, can improve energy efficiency, when actions are executed immediately after data analysis. Implement a structured energy management (e.g. ISO 50001) to control and improve all aspects of energy use in the process.
Improved process control (moisture, oxygen and temperature control, air flow control - knowledge based fuzzy logic)	Optimised control of the process, taking into account all possible parameters that can influence the process. For continuous processes fuzzy logic may be an improvement over a classic deterministic control. Improved control of utilities: steam system, air compressor, vacuum pumps, lighting, water systems and pumps, agitators (turn off agitators; slow down agitators, zone agitation where appropriate).
(Waste) heat recovery and heat integration (including organic ranking cycles, heat pumps and similar heat recovery technology)	Have a systematic approach to heat recovery using techniques such as pinch technology and novel heat recovery technology. Examples of heat recovery applications: - Optimize heat exchangers - Heat recovery on hoods - Waste heat recovery from bleaching waste water - Use waste heat for sludge drying - Pre-heating of shower water using waste heat - Blowdown steam recovery
Focus on maintenance	Have a regular maintenance program including predictive maintenance. Examples are: - Maintenance on utilities (vacuum, pumps, motors and fans) - Maintain clean wires, felts and drying surfaces - Monitor press performance
Industrial clustering and heat networking	Consider using residual heat from industrial complexes to heat municipalities or industry with low temperature heat demand. Planning location of new plants close to heat demand.
Replace existent (old) lighting with high efficiency lighting	High efficiency lighting can be obtained by: - Installing the most efficient lighting (e.g. LED) - Provide the needed lux levels, not more - Install controls (presence, dusk, timers, …) to limit on-time - Transparent roof panels lower the need for lighting

Table 17: Across mill options

Fibre Supply

The fibre supply options are listed in Table 18.

Option	Description
High consistency pulping	In pulping, most of the energy is used to circulate and move the slurry. Consequently, by increasing the consistency of the slurry, the electricity demand of the pulper could be decreased, due to reduced mass flow. Electricity savings of 2-10 kWh per ton of de-inked pulp are expected if the solids content is increased from a typical 5-7% to 20%.
Efficient screening	Improvements were made in the field of screening and filtering. Further optimisation of the screening process shows energy savings, depending on the plant characteristics.
Efficient dispersers	Use energy-efficient dispersers to separate remaining particles from the fibres.
Sludge dryer	Use waste heat to pre-dry sludge before burning to increase the calorific value of the sludge, thus replacing more fossil fuel.
Improved quality of recycled paper	Improved sorting and removal of impurities reduces energy and efforts to have good quality pulp.

Table 18: Fibre supply options

Paper Machine

The energy saving opportunities are given in Table 19. For the paper machine (PM), a division is made into: PM general savings, PM wet-end and PM dryer.

Option	Description
PM General Savings	
State-of-the-art steam and condensate system (with stationary siphons and spoiler bars)	Keeping set points of the stationary siphons at their initial value to reduce blow through steam losses.
Optimise differential pressures for condensate evacuation	Lower steam consumption, machine speed increase.
PM Wet-End	
Steam box to increase sheet temperature and dryness	Steam box can improve profile: use low pressure steam or vented steam for boxes and showers.
Install shoe press	High dewatering efficiency + saving on opex + energy reduction in the drying part.
Improved dewatering in press section beyond shoe press	
Hot pressing	Increase the solids content before entering the dryer.
High consistency forming	The process pulp entering the forming stage has more than double the normal (3%) consistency. This measure increases forming speed and reduces dewatering and vacuum power requirements.
Dry sheet forming	Fibres can be dispersed through carding (mechanical) or air laying techniques.
Impulse drying	Applying heat and pressure for dewatering before drying.
PM Dryer	
Infrared profiling	Short-wave IR drying provides better heat transfer capabilities and compactness. Along with improved energy efficiency, it increases the drying power output.

Option	Description
Increase dew point set point in hood (e.g. from 38% to 50% or from 55°C to 70°C)	Increasing the relative humidity reduces the air flow rates by 30% → fan savings = 50%.
Heat recovery on hoods: closed hoods	15-20% steam reduction when replacing semi-open by a closed hood, leading to 40-50% less electricity use by the fans.

Table 19: Paper machine options

Utilities

The general energy saving opportunities for utilities are given in Table 20. A division is made into: vacuum, compressed air (CA), pumps and motors, water, and steam system.

option	Description
Vacuum	
Use fans or blowers for low vacuum applications	Don't use deep vacuum for applications such as foils.
Compressed Air	
Review of system pressure	Keep as low as possible as 1 bar increase of pressure requires 7-8% more compressor energy.
Switch from CA to electric drives for activators	Avoid using CA for operations that can also be done with electric motors.
Eliminate use of CA system	Try to avoid using CA where possible (prefer blower air, shut down parts of grid that are no longer in use)
Pumps and Motors	
Optimum design	Match pumping capacity to duty, avoid over-sizing pumps and motors, avoid throttling and use high-efficiency motors.
Water	
Install anaerobic waste water treatment plant	Production of CH_4 to be burnt in a CHP to produce electricity.
Steam	
Optimise steam turbine control	Prevent choking of turbine, which leads to reduced power output.
Biomass based CHP	Shift from fossil fuel to CO_2-neutral fuel.
State-of-the-art steam system	New, complete, well-dimensioned and controlled steam system.
Gasification of biomass for use in gas turbine	Shift from fossil fuel to a CO_2-neutral fuel.
Oxygen trim control to adjust burner inlet air (and detect air infiltration)	By combining an oxygen monitor with an intake air monitor, it is possible to detect even small leaks. Using a combination of CO ($_2$) and O_2 readings, it is possible to optimise the fuel/air mixture for high flame temperature (and best energy efficiency).
Economisers on steam boilers	Installing economisers on steam boilers can improve efficiency with 3-4%.
Generators replacing PRVs	Install local steam generators instead of using high pressure steam through Pressure Reduction Valves (PRV).

Table 20: Utilities options

Two Team Project

The general energy saving opportunities proposed by the CEPI Two Team Project are given in Table 21.

Option	Description
Flash Condensing with Steam	Process: largely dry fibres are blasted into a forming zone with agitated steam and condensed into a web using one-thousandth the volume of water used today.
Superheated steam drying	Use superheated steam for drying and use it afterwards as fibre carrier and for forming paper.
Dry pulp for cure-formed paper	Waterless paper production by means of two techniques: dry pulp and cure-forming.
Supercritical CO_2	To dry pulp and paper without the need for heat or steam and even dye paper or remove contaminants.
100% electricity	Evolution towards green electricity will reduce fossil fuels consumption; reduction of energy cost in the total cost by 12%.
Functional surface	Shift to producing more lightweight products; selling surface instead of weight (up to 30% material reduction per surface unit).
Toolbox	Combination of innovations, e.g. enzymatic pulp treatment, shear compression, energy efficient thermo-mechanical pulping, sophisticated biomass fractionation into lignin, cellulose and hemi-cellulose, biomass separation into molecules.
Deep eutectic solvents (DES)	DES opens the way to produce pulp at low temperatures and at atmospheric pressure. Any type of biomass could be dissolved into lignin, cellulose and hemicellulose with minimal energy and emissions

Table 21: Options from the Two Team Project

INDUSTRIAL DECARBONISATION AND ENERGY EFFICIENCY ROADMAP TO 2050 – PULP AND PAPER

APPENDIX D – ADDITIONAL PATHWAYS ANALYSIS

APPENDIX D ADDITIONAL PATHWAYS ANALYSIS

1. Option Deployment for Pathways under Different Scenarios

Challenging World

Pathway: Business as Usual Scenario: Challenging World (CW)

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%	0%	25%	25%	50%	75%	100%	100%	100%
02 Improved process control across the entire mill (process & utilities)	42%	100%	0%	0%	25%	25%	50%	75%	100%	100%	100%
03 (waste) heat recovery and heat integration	64%	100%	0%	0%	25%	25%	50%	75%	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%	0%	25%	25%	50%	75%	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%	0%	25%	25%	50%	75%	100%	100%	100%
09 Use flash steam from condensate	35%	70%	0%	0%	20%	25%	50%	75%	100%	100%	100%
Paper Machine - Wet End											
10 steam box to increase sheet temperature and dryness	58%	80%	0%	0%	25%	25%	50%	75%	100%	100%	100%
11 Extended Nip Press: Tissue	0%	60%	0%	0%	25%	25%	50%	75%	100%	100%	100%
12 Extended Nip Press: Non-Tissue	39%	100%	0%	0%	25%	25%	50%	75%	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%	0%	25%	25%	50%	75%	100%	100%	100%
20 Heat recovery on hoods present	88%	98%	0%	0%	25%	25%	50%	75%	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%	0%	25%	25%	50%	75%	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%	0%	25%	25%	50%	75%	100%	100%	100%
29 Economisers on steam boilers	78%	100%	0%	0%	25%	25%	50%	75%	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%	0%	25%	25%	50%	75%	100%	100%	100%
40 Efficient screening	83%	100%	0%	0%	25%	25%	50%	75%	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%	0%	25%	25%	50%	75%	100%	100%	100%
43 Use fans or blowers for low vacuum applications	17%	50%	0%	0%	25%	25%	50%	50%	75%	75%	100%
Utilities - Steam System											
44 Optimize steam turbine control	66%	100%	0%	0%	25%	25%	50%	75%	100%	100%	100%
Utilities -Compressed Air											
46 Review of system pressure, leak detection etc.	92%	100%	0%	0%	25%	25%	50%	75%	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%	0%	25%	25%	50%	75%	100%	100%	100%
Paper Machine - Dryer											
49 Closed hood (elec)	86%	98%	0%	0%	25%	25%	50%	75%	100%	100%	100%
Two Teams											
50 100% electricity (elec increase)	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Figure 5: BAU pathway, challenging world scenario

Pathway: Max Technical 1 Scenario: Challenging World (CW)

OPTION	ADOP.	APP.	DEPLOYMENT								
DIRECT			2014	2015	2020	2025	2030	2035	2040	2045	2050
Across Mill - General											
01 Energy management including installing meters for steam, electricity, air and gas to allow for online energy balances	76%	100%	0%	0%	25%	25%	50%	75%	100%	100%	100%
02 Improved process control across the entire mill (process & utilities)	42%	100%	0%	0%	25%	25%	50%	75%	100%	100%	100%
03 (waste) heat recovery and heat integration	64%	100%	0%	0%	25%	25%	50%	75%	100%	100%	100%
04 organic Rankine cycles, heat pumps and similar heat recovery technology	8%	80%	0%	0%	25%	25%	50%	50%	75%	100%	100%
05 Focus on maintenance	75%	100%	0%	0%	25%	25%	50%	75%	100%	100%	100%
06 Industrial clustering and heat networking	0%	100%	0%	0%	0%	0%	0%	0%	0%	25%	25%
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%	0%	25%	25%	50%	50%	75%	75%	100%
09 Use flash steam from condensate	35%	70%	0%	0%	20%	25%	50%	50%	75%	75%	100%
Paper Machine - Wet End											
10 steam box to increase sheet temperature and dryness	58%	80%	0%	0%	25%	25%	50%	50%	75%	75%	100%
11 Extended Nip Press: Tissue	0%	60%	1%	0%	25%	25%	50%	50%	25%	25%	25%
12 Extended Nip Press: Non-Tissue	39%	100%	1%	0%	25%	25%	50%	50%	25%	25%	25%
13 Improved dewatering in press section beyond extended Nip Press	0%	60%	0%	0%	25%	25%	50%	50%	75%	75%	75%
14 Hot pressing	1%	50%	0%	0%	25%	25%	50%	50%	75%	75%	100%
15 High consistency forming	15%	50%	0%	0%	25%	25%	50%	50%	75%	75%	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%	0%	25%	25%	50%	75%	100%	100%	100%
20 Heat recovery on hoods present	88%	98%	0%	0%	25%	25%	50%	50%	75%	50%	50%
21 Heat recovery on hoods future	0%	98%	0%	0%	0%	0%	0%	25%	25%	50%	50%
22 Closed hood (fuel)	86%	98%	0%	0%	25%	25%	50%	75%	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%	0%	25%	25%	50%	75%	100%	100%	100%
29 Economisers on steam boilers	78%	100%	0%	0%	25%	25%	50%	50%	75%	75%	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%	0%	25%	25%	50%	50%	75%	75%	100%
40 Efficient screening	83%	100%	0%	0%	25%	25%	50%	75%	100%	100%	100%
41 Sludge dryer	12%	25%	0%	0%	0%	0%	0%	25%	25%	50%	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%	0%	25%	25%	50%	75%	100%	100%	100%
43 Use fans or blowers for low vacuum applications	17%	50%	0%	0%	25%	25%	50%	50%	75%	75%	100%
Utilities - Steam System											
44 Optimize steam turbine control	66%	100%	0%	0%	25%	25%	50%	75%	100%	100%	100%
Utilities -Compressed Air											
46 Review of system pressure, leak detection etc.	92%	100%	0%	0%	25%	25%	50%	75%	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%	0%	25%	25%	50%	50%	75%	75%	100%
Paper Machine - Dryer											
49 Closed hood (elec)	86%	98%	0%	0%	25%	25%	50%	75%	100%	100%	100%
Two Teams											
50 100% electricity (elec increase)	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Figure 6: Max Tech pathway 1, challenging world scenario

Pathway: Max Technical 2 Scenario: Challenging World (CW)

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%	0%	25%	25%	50%	75%	100%	100%	100%
02 Improved process control across the entire mill (process & utilities)	42%	100%	0%	0%	25%	25%	50%	75%	100%	100%	100%
03 (waste) heat recovery and heat integration	64%	100%	0%	0%	25%	25%	50%	75%	100%	100%	100%
04 organic Rankine cycles, heat pumps and similar heat recovery technology	8%	80%	0%	0%	25%	25%	50%	50%	75%	100%	100%
05 Focus on maintenance	75%	100%	0%	0%	25%	25%	50%	75%	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%	0%	25%	25%	50%	50%	75%	75%	100%
09 Use flash steam from condensate	35%	70%	0%	0%	20%	25%	50%	50%	75%	75%	100%
Paper Machine - Wet End											
10 steam box to increase sheet temperature and dryness	58%	80%	0%	0%	25%	25%	50%	50%	75%	75%	100%
11 Extended Nip Press: Tissue	0%	60%	1%	0%	25%	25%	50%	50%	25%	25%	25%
12 Extended Nip Press: Non-Tissue	39%	100%	1%	0%	25%	25%	50%	50%	25%	25%	25%
13 Improved dewatering in press section beyond extended Nip Press	0%	60%	0%	0%	25%	25%	50%	50%	75%	75%	75%
14 Hot pressing	1%	50%	0%	0%	25%	25%	50%	50%	75%	75%	100%
15 High consistency forming	15%	50%	0%	0%	25%	25%	50%	50%	75%	75%	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%	0%	25%	25%	50%	75%	100%	100%	100%
20 Heat recovery on hoods present	88%	98%	0%	0%	25%	25%	50%	50%	75%	50%	50%
21 Heat recovery on hoods future	0%	98%	0%	0%	0%	0%	0%	25%	25%	50%	50%
22 Closed hood (fuel)	86%	98%	0%	0%	25%	25%	50%	75%	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%	25%	25%	25%	50%	50%
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%	0%	25%	25%	50%	75%	100%	100%	100%
29 Economisers on steam boilers	78%	100%	0%	0%	25%	25%	50%	50%	75%	75%	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%	0%	25%	25%	50%	50%	75%	75%	100%
40 Efficient screening	83%	100%	0%	0%	25%	25%	50%	75%	100%	100%	100%
41 Sludge dryer	12%	25%	0%	0%	0%	0%	0%	25%	25%	50%	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%	0%	25%	25%	50%	75%	100%	100%	100%
43 Use fans or blowers for low vacuum applications	17%	50%	0%	0%	25%	25%	50%	50%	75%	75%	100%
Utilities - Steam System											
44 Optimize steam turbine control	66%	100%	0%	0%	25%	25%	50%	75%	100%	100%	100%
Utilities -Compressed Air											
46 Review of system pressure, leak detection etc.	92%	100%	0%	0%	25%	25%	50%	75%	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%	0%	25%	25%	50%	50%	75%	75%	100%
Paper Machine - Dryer											
49 Closed hood (elec)	86%	98%	0%	0%	25%	25%	50%	75%	100%	100%	100%
Two Teams											
50 100% electricity (elec increase)	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Figure 7: Max Tech pathway 2, challenging world scenario

Collaborative Growth

Pathway: Business as Usual   Scenario: Collaborative Growth (CG)

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%	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 8: BAU pathway, collaborative growth scenario

Pathway: 20% - 40% Scenario: Collaborative Growth (CG)

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%	75%	50%	25%	25%	0%	0%
12 Extended Nip Press: Non-Tissue	39%	100%	0%	0%	100%	75%	50%	25%	25%	0%	0%
13 Improved dewatering in press section beyond extended Nip Press	0%	60%	0%	0%	0%	25%	50%	75%	75%	100%	100%
14 Hot pressing	1%	50%	0%	0%	25%	50%	75%	75%	100%	100%	100%
15 High consistency forming	15%	50%	0%	0%	25%	50%	75%	75%	100%	100%	100%
17 Impulse drying	0%	50%	0%	0%	0%	25%	50%	75%	100%	100%	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%	75%	50%	50%	25%	0%	0%
21 Heat recovery on hoods future	0%	98%	0%	0%	0%	25%	50%	50%	75%	100%	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%	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 9: 20-40% CO_2 reduction pathway, collaborative growth scenario

Pathway: 40% - 60% Scenario: Collaborative Growth (CG)

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%	75%	50%	25%	25%	0%	0%
12 Extended Nip Press: Non-Tissue	39%	100%	0%	0%	100%	75%	50%	25%	25%	0%	0%
13 Improved dewatering in press section beyond extended Nip Press	0%	60%	0%	0%	0%	25%	50%	75%	75%	100%	100%
14 Hot pressing	1%	50%	0%	0%	25%	50%	75%	75%	100%	100%	100%
15 High consistency forming	15%	50%	0%	0%	25%	50%	75%	75%	100%	100%	100%
17 Impulse drying	0%	50%	0%	0%	0%	25%	50%	75%	100%	100%	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%	75%	50%	50%	25%	0%	0%
21 Heat recovery on hoods future	0%	98%	0%	0%	0%	25%	50%	50%	75%	100%	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%	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 10: 40-60% CO_2 reduction pathway, collaborative growth scenario

Pathway: Max Technical 1   Scenario: Collaborative Growth (CG)

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%	25%	60%	60%	75%	75%	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%	25%	25%	0%	0%
12 Extended Nip Press: Non-Tissue	39%	100%	0%	0%	100%	75%	50%	25%	25%	0%	0%
13 Improved dewatering in press section beyond extended Nip Press	0%	60%	0%	0%	0%	25%	50%	75%	75%	100%	100%
14 Hot pressing	1%	50%	0%	0%	25%	50%	75%	75%	100%	100%	100%
15 High consistency forming	15%	50%	0%	0%	25%	50%	75%	75%	100%	100%	100%
17 Impulse drying	0%	50%	0%	0%	0%	25%	50%	75%	100%	100%	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%	75%	50%	50%	25%	0%	0%
21 Heat recovery on hoods future	0%	98%	0%	0%	0%	25%	50%	50%	75%	100%	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%	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%	25%	25%

Figure 11: Max Tech pathway 2, collaborative growth scenario

Pathway: Max Technical 2   Scenario: Collaborative Growth (CG)

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%	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%	75%	50%	25%	25%	0%	0%
12 Extended Nip Press: Non-Tissue	39%	100%	0%	0%	100%	75%	50%	25%	25%	0%	0%
13 Improved dewatering in press section beyond extended Nip Press	0%	60%	0%	0%	0%	25%	50%	75%	75%	100%	100%
14 Hot pressing	1%	50%	0%	0%	25%	50%	75%	75%	100%	100%	100%
15 High consistency forming	15%	50%	0%	0%	25%	50%	75%	75%	100%	100%	100%
17 Impulse drying	0%	50%	0%	0%	0%	25%	50%	75%	100%	100%	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%	75%	50%	50%	25%	0%	0%
21 Heat recovery on hoods future	0%	98%	0%	0%	0%	25%	50%	50%	75%	100%	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%	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 12: Max Tech pathway 2, collaborative growth scenario

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