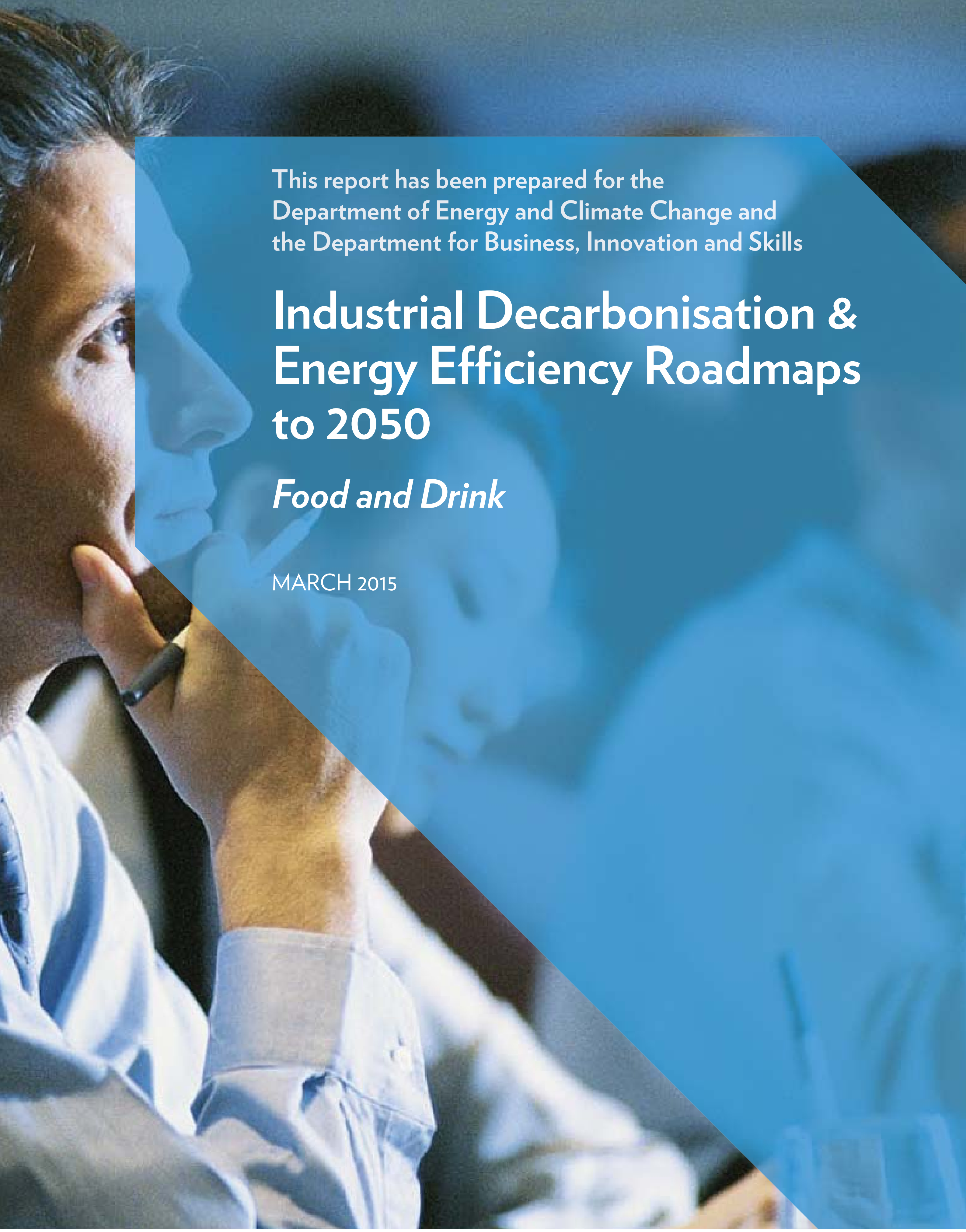

This report has been prepared for the Department of Energy and Climate Change and the Department for Business, Innovation and Skills

Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050

Food and Drink

MARCH 2015

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ACRONYMS

AD	Anaerobic Digester
AIC	Agricultural Industries Confederation
BAT	Best Available Technologies
BAU	Business as Usual
BBPA	British Beer and Pub Association
BFP	Bulk Fermentation Process
BIS	Department for Business, Innovation and Skills
CA	Compressed Air
capex	capital expenditure
CBP	Chorleywood Bread Process
CC	Carbon Capture
CCA	Climate Change Agreement
CCL	Climate Change Levy
CCS	Carbon Capture and Storage
CCU	Carbon Capture and Utilisation
CHP	Combined Heat and Power
CIP	Clean(ing)-in-Place
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CRC	Carbon Reduction Commitment
CSD	Carbonated Soft Drinks
DECC	Department of Energy and Climate Change
EBLEX	Organisation for the English Beef and Sheep Industry
EII	Energy Intensive Industries
ESOS	Energy Savings Opportunity Scheme
EU ETS	European Union Emissions Trading System
FDF	Food and Drink Federation
FiT	Feed-in Tariffs
GVA	Gross Value Added
HFC	HydroFluoroCarbons
HVAC	Heating, Ventilation and Air Conditioning
IEEA	Industrial Energy Efficiency Accelerator
INDEMAND	Industrial Energy and Material Demand
IQF	Individual Quick Frozen
KPI	Key Performance Indicator
LCA	Life Cycle Assessment
LPG	Liquid Petroleum Gas
MAP	Modified Atmosphere Packaging
Max Tech	Maximum Technical
MVR	Mechanical Vapour Recompression
NAEI	National Atmospheric Emissions Inventory
OEM	Original Equipment Manufacturer
PRV	Pressure Relief Valve
R&D	Research and Development
RD&D	Research, Development and Demonstration
REA	Rapid Evidence Assessment
RO	Reverse Osmosis
ROI	Return on Investment
SAT	State-of-the-Art Technologies
SAV	Sequential Air Ventilation
SEC	Specific Energy Consumption
SME	Small and Medium Enterprises

SWA	Scotch Whisky Association
SWOT	Strengths, Weaknesses, Opportunities and Threats
TRL	Technology Readiness Level
TVR	Thermal Vapour Recompression
VSD	Variable Speed Drive

1. EXECUTIVE SUMMARY

1.1 What is the ‘Decarbonisation and Energy Efficiency Roadmap’ for the Food and Drink Sector?

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

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

The roadmap project therefore aims to:

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

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

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

1.2 Developing the Food and Drink Sector Roadmap

The development of the food and drink sector roadmap consisted of three main phases:

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

A sector team comprising representatives from the food and drink industry and its trade associations (the Food and Drink Federation, the Scotch Whisky Association, the British Beer and Pub Association, Dairy UK and the Agricultural Industries Confederation) and the government has acted as a steering group as well as contributing evidence and reviewing draft project outputs. In addition, the outputs have been independently peer reviewed. It should be noted that the findings from the interviews and workshops represent the opinions and perceptions of particular industrial stakeholders, and may not therefore be representative of the entire sector. Where possible we have tried to include alternative findings or viewpoints, but this has not always been possible; this needs to be taken into account when reading this report.

1.3 Sector Findings

The UK food and drink sector is very diverse with many subsectors such as dairy, brewery, distilling, sugar, confectionery, bakery, rendering, meat processing, fish and seafood, poultry, malting, soft drinks, animal feed, oil and fat, glucose, canned food, ice cream, and pet food. Each of these subsectors has very specific processing technologies. The main processing techniques and unit operations applied throughout the entire food and drink sector include materials reception and preparation; size reduction, mixing and forming; separation techniques; product processing techniques; heat processing; concentration by heat; processing by removal of heat; post-processing operation; and utility processes. The five biggest subsectors are other groceries, cereals and bakery, meat, dairy, and fish and seafood. The sector contributed to the UK economy with a gross value added of more than £25 billion in 2012. In that year, it was estimated to emit 9.5 million tonnes of carbon dioxide.

The most common technologies for the food and drink sector and their share in energy consumption are boilers (54%), direct heating (27%), motors (12%), refrigeration (5%) and compressed air (2%). The fuel use in the sector is dominated by natural gas (about two-thirds), followed by electricity, and a minor amount of oil and coal. The high heat demand of several processes (drying, evaporation, baking ovens, pasteurisation, kilning, steam production, etc.), together with indirect emissions from electricity consumption (used for refrigeration and cooling, mixing, conveying, compressed air, pumps and fans, stirring, rendering, grinding, etc.) mainly make up the food and drink sector carbon dioxide emissions shown in Table 1. The UK food and drink sector has already reduced its absolute emissions by 41% since 1990 (FDF, 2014).

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

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

The UK food and drink sector is dominated by SMEs (small and medium enterprises) with 86% of companies having fewer than 20 employees, which establishes a healthy dose of competition and a strong innovation drive (IBIS, 2014). Yet such significant sector heterogeneity makes it challenging to achieve economies of scale, which will allow the reduction of energy consumption overall and on a per-product basis.

UK population is expected to grow, presenting an opportunity for the food and drink sector to service the needs of a growing yet ageing consumer base. Export is another area of potential growth especially for products with longer shelf life, such as spirits. Growth will also depend on the ability of the UK food and drink manufacturers to predict and satisfy the changing preferences of the diverse and complex consumer base in the UK. Change of diet and lifestyle is perceived to increase the demand for healthier and readily available options and expected to alter product mix, portion size and production routines.

Retailers hold a strong position in the market and can exercise its bargaining power towards food and drink manufacturers. In most cases, this is focused on reducing retail prices, limiting contractual periods and extending payment periods. This continuous process has driven down margins and reduced the ability of manufacturers, especially small ones, to invest in new more energy-efficient technologies.

1.4 Enablers and Barriers for Decarbonisation in the Food and Drink Sector

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

- Strong, evidence-based business case
- Projects providing multiple benefits

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

- Leadership commitment to climate change
- Effective best practice sharing within the organisation
- Realistic commitments
- Collaboration in the value chain
- Compliance with regulation

The main barriers to decarbonisation have been identified as:

- High capital cost and long investment cycles
- Limited financing
- Risk of not meeting required product quality or changing character
- Risk of production disruption
- Shortage of skilled labour
- Shortage of demonstrated technologies
- Lack of reliable and complete information

1.5 Analysis of Decarbonisation Potential in the Food and Drink Sector

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

The pathways created in the current trends scenario, the central of three scenarios used in this study, are shown below in Figure 1.[3]

[3] Two versions of Max Tech are presented to illustrate alternative pathways

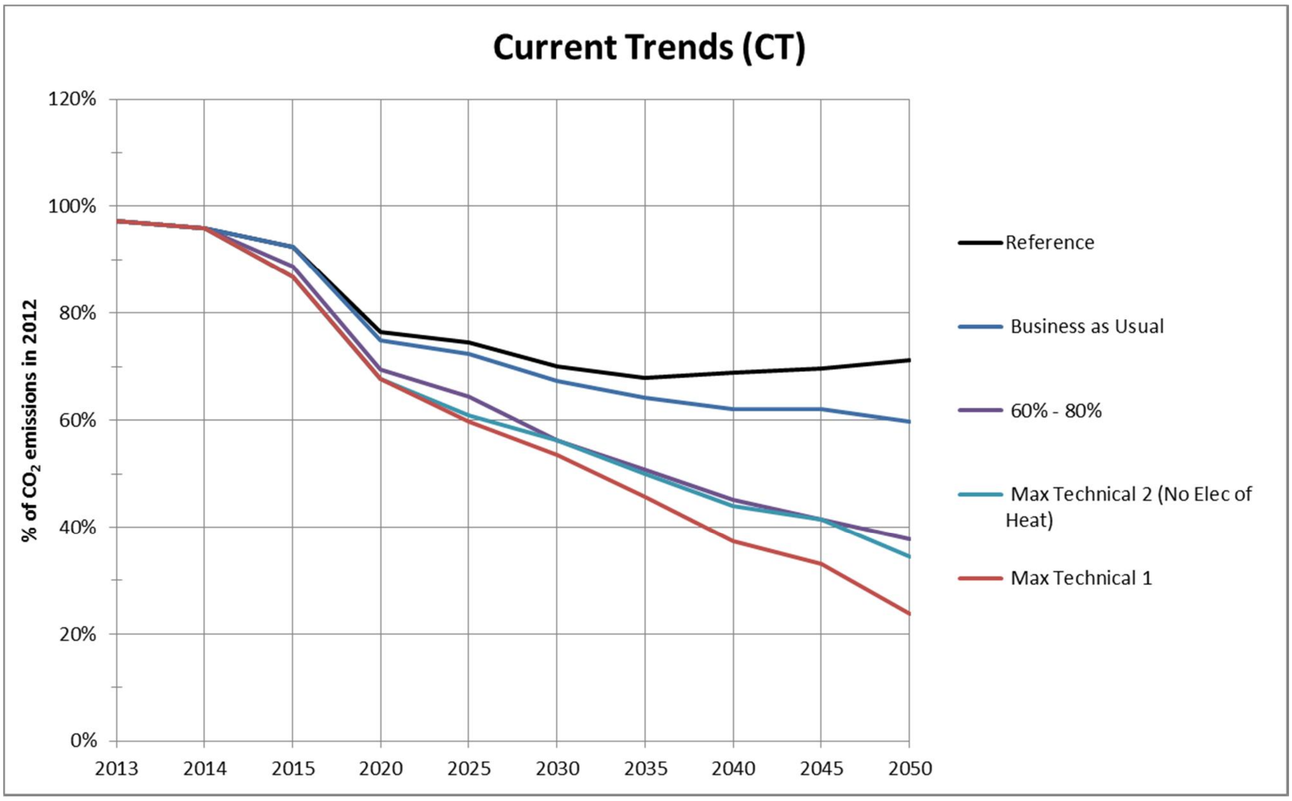

Figure 1: Overview of the different decarbonisation and energy efficiency pathways

Analysis of the costs of the pathways used order of magnitude estimates to add up the capital cost of each pathway. As an indication, the net present capital cost for the pathways, discounted at 3.5%, falls within an estimated range of £2 billion[4] to £13 billion[5]. There is a large degree of uncertainty attached to the cost analysis, especially for options which are still in the research and development stage. Also, costs of operation, energy use, research, development, demonstration, civil works, modifications to plant and costs to other stakeholders are significant for some options, but not included here. The costs presented are for the study period and are adjusted to exclude residual value after 2050, thus a proportion of the costs of high capex items deployed close to 2050 is excluded. Great care must be taken in how these costs are interpreted. While implementation of some of the options within the pathways may reduce energy costs due to increased efficiency, the scale of the investments associated with the pathways must be considered by stakeholders when planning the next steps in the sector.

1.6 Conclusions and Key Technology Groups

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

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

Leadership, Organisation and Strategy

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

Business Case Barriers

The food and drink sector is facing many barriers to implementation of decarbonisation and energy efficiency projects, such as risk of implementing new technology, lack of skills, lack of management time, lack of certainty of business case, and the perception of an unstable political-economic climate by the industry. Another important barrier is lack of funding for such projects, either because the return of investment is not sufficiently attractive, or there is a lack of capital available.

Industrial Energy Policy Context

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

Value Chain Collaboration

There is a need for greater consideration for collaboration across the value chain, to share the risks and speed up innovation. The food and drink sector in the UK is diverse in terms of types of products and thus can be characterised by a complex value chain. Retail chains have strong bargaining power over manufacturers and, in turn, manufacturers pass on that pressure to raw material suppliers. There is a need for greater incentives to support collaboration.

Research, Development and Demonstration

There is significant RD&D activity taking place in the UK food and drink sector, driven by organisations such as FDF, the centre for Studies in Economics and Finance and universities (such as Sheffield Hallam University). Still, academia finds it challenging to run projects in the industry, especially PhD projects, meaning that the sector could fall behind other regions with regards to strategy and leadership, knowledge, expertise, training and skills, technologies, and the supply chain. RD&D would form an important part of a vibrant sector in the future, including the contribution to increased decarbonisation and improved energy efficiency.

People and Skills

To implement and use advanced technologies, skilled labour is needed, even at operator level. Knowledge is needed to choose between ‘standard’ equipment and more energy-efficient equipment when making investments. This knowledge acquisition and transfer is, and will continue to be, key to decarbonising the sector. Advanced technologies are attractive to the younger generation so it is also an opportunity to attract more young people to start working in the sector.

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

Electricity Grid Decarbonisation

Decarbonisation of the national electricity grid could provide a significant contribution to the overall decarbonisation of the sector. The government's reforms of the electricity market are already driving electricity grid decarbonisation, and this report uses the assumptions of a future electricity decarbonisation trajectory that is consistent with government methodology and modelling. Future policy work streams – regarding future electricity grid decarbonisation and changing configurations of generation, distribution and use – need to include assessment of the impacts of industry sectors such as food and drink, given the importance of grid decarbonisation for the electrification of heat option.

Electrification of Heat

Electrification of heat is one of the most important options available for the food and drink sector. Considering the current trends towards renewable energy, there is potential for a continued shift towards using renewable electricity for low-heat applications possibly reserving fossil fuels for applications where high-value heat is required.

Fuel and Feedstock Availability (Including Biomass)

Biomass clearly has significant potential as an alternative fuel for the food and drink industry, and provides an opportunity to decarbonise the sector. The sector can use a part of its own product flow to convert to green energy, and is already using biomass in this way. Feedstock availability is considered less of a barrier than in other sectors, but it remains a very complex issue for the food and drink sector as the biomass it produces on site is often used as animal feed. Considering food waste as biomass source would require a full carbon accounting approach to understand the benefits and consequences, which has not been carried out within the scope of this project. It is noted that there is significant added value to use biomass for heat and power (via CHP technology) compared to power generation only, and this is recognised in government electricity market support policy.

Energy Efficiency and Heat Recovery Technology

Energy management and improved process design are key for a structured approach in the evolution towards an energy-efficient and low-emissions process. Implementation of these two options on new installations and plant layout can result in significant improvement steps. Energy management should be given a more important role in the decision-making process in companies. Another point of focus to improve energy efficiency in the food and drink sector should be the implementation of a state-of-the-art steam system.

Next Steps

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

2. INTRODUCTION, INCLUDING METHODOLOGY

2.1 Project Aims and Research Questions

2.1.1 Introduction

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

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

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

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

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

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

Table 2: Industrial sectors evaluated in this project

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

2.1.2 Aims of the Project

The DECC 2011 Carbon Plan outlined the UK's plans to reduce greenhouse gas emissions and make the transition to a low-carbon economy while maintaining energy security and minimising negative economic impacts. This project aims to improve evidence on decarbonisation and energy efficiency for eight energy-intensive industry sectors, with the food and drink sector the subject of this report.

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

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

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

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

2.1.3 What is a Roadmap?

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

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

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

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

The views of contributing organisations

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

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

2.2 Overall Methodology

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

Figure 2: Roadmap methodology

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

Key to the overall roadmap methodology was engagement with all stakeholders, including with business and trade association representatives, academics and civil servants, to contribute to the evidence, validate its quality and interpret the analysis. We have worked closely with FDF (Food and Drink Federation), SWA (Scotch Whisky Association), BBPA (British Beer and Pub Association), Dairy UK, AIC (Agricultural Industries Confederation), DECC and BIS to identify and involve the most appropriate people from the food and drink sector, relevant academics and other stakeholders, such as representatives from the financial sector.

2.2.1 Findings

Evidence Gathering

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

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

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

- **Literature review:** A short, focussed review of over 150 documents all published after 2000 was completed. The documents were either related to energy efficiency and decarbonisation of the sector or to energy-intensive industries in general. This was not a thorough literature review or rapid evidence assessment (REA) but a desktop research exercise deemed sufficient by the project team[8] in its breadth and depth to capture the evidence required for the purpose of this project. The literature review was not intended to be exhaustive and aimed to capture key documentation that applied to the UK. This included the sector structure, recent history and context including consumption, demand patterns and emissions, the business environment, organisational and decision-making structures and the impacts of UK policy and regulation. Further details are provided in appendix A.
- **Interviews:** In liaison with FDF, DECC and BIS, six semi-structured interviews were conducted representing technical operations via environment and energy managers. The purpose of the interviews was to obtain further details on the different subsectors within the food and drink sector and gain a deeper understanding of the principal questions, including details of decision-making processes and how companies make investment decisions, how advanced technologies are financed, what a company's strategic priorities are and where climate change sits within this. The interviewees were interviewed using an 'interview protocol' template, developed in liaison with DECC and BIS. This template was used to ensure consistency across interviews, fill gaps in the literature review, identify key success stories and extract key barriers to investment in low-carbon technologies. The interview protocol can be found in appendix A. Interviewees were selected to maximise coverage across sub-sectors and emissions and also take into account company headquarters location, production processes and company size.
- **Survey:** As part of the evidence gathering exercise and to help build a list of the enablers and barriers, a short bespoke survey was conducted with some of the many UK food and drink manufacturing industries. The questions were drawn up in consultation with DECC and the sample of respondents were selected based on coverage of a high proportion of sector emissions (the survey was not a census). The key questions focused on the respondents view on the level of impact of the top enablers and barriers on the implementation of energy and carbon reduction options as identified from the interviews and literature review. The number of respondents was limited to 19 out of the survey requests that have been sent out to management representatives from the sector. The low response rate was due to lack of resources (predominantly time) by manufacturers. Respondents were mostly mid- and large-size companies from various subsectors of the UK food and drink industry.

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

- **Workshops:** Two workshops were held, attendees for which were identified in consultation with FDF, DECC and BIS. The first workshop focused on reviewing potential technological decarbonisation and energy efficiency options (that had been provisionally generated from the literature review) and discussing adoption rate, applicability, improvement potential, ease of implementation, capex, return on investment (ROI), savings potential and timeline for the different options. This was done through two breakout sessions: one focused on collecting more data and the other one on timelines under different scenarios. The second activity involved group discussions on enablers and barriers to energy efficiency and decarbonisation investment, and how to overcome them. The second workshop focused on reviewing the draft pathways and identifying potential actions for delivering them. The workshop participants included the relevant trade associations, large companies with the aim of achieving representation of key companies or subsectors and academics with expert knowledge of the sector, PB and DNV GL consultants, DECC and BIS project managers and senior civil servants. The average size of a workshop was 40 people.

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

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

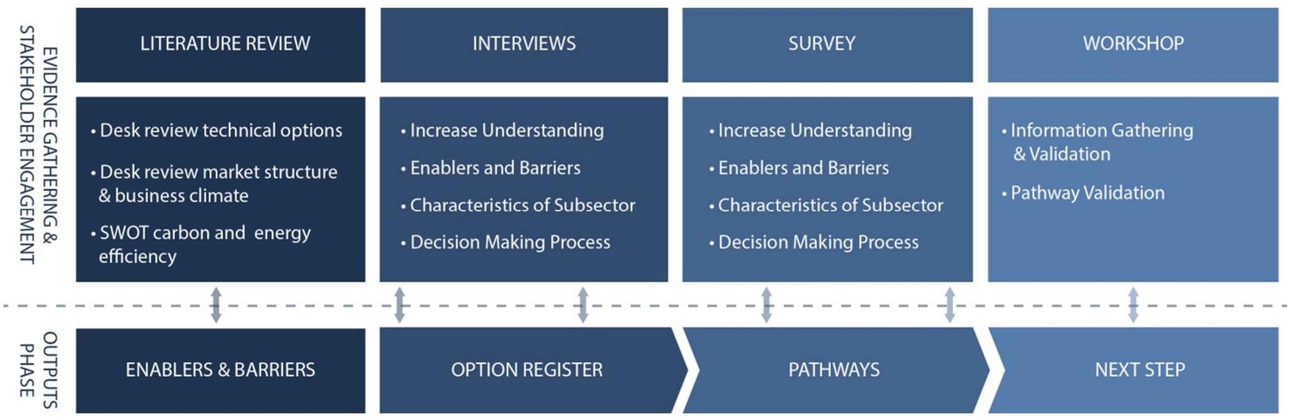

Figure 3: Evidence- gathering process

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

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

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

The evidence gathering exercise (see appendix A for details) was subject to inherent limitations based upon the scale of activities and sample sizes that could be conducted within the time and resources available. Due to the size and diversity of the food and drink sector, companies interviewed represented only a minor amount of carbon emissions produced in the UK sector. The interviews included UK decision-makers and technical specialists in the food and drink sector, and were conducted to provide greater depth and insight to the issues faced by companies. However, because many UK food and drink companies are rather small, it was difficult to gain involvement in a project that focuses on decarbonisation strategies towards 2050. The small companies are primarily focusing on production and competition, not on long-term energy and environmental policies. This aspect also applied to workshop attendees. It may be worth noting that, at the time of the report preparation, the major challenges being faced by the sector were (i) a very challenging trading environment due to major structural changes in the food retail market, (ii) the intense focus on prices and costs, and (iii) the focus on diet and health issues.

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

Options examined (see appendix C) were classified into six categories: general energy efficiency, energy-efficient technologies, IEEA (Industrial Energy Efficiency Accelerator projects – carried out by Carbon Trust) technologies, low-carbon energy sources, supply chain, and carbon capture (CC). These options considered dairy, bakery, sugar, confectionery, malting, brewing, spirits distilling, soft drinks, ambient food, fish and seafood, poultry, meat, rendering, animal feed, starch, (frozen and chilled) meals, and (frozen and chilled) fruit and vegetables.

Evidence Analysis

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

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

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

Limitations of these Findings

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

2.2.2 Pathways

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

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

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

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

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

The BAU pathway consisted of the continued roll-out of technologies that are presently being deployed across the sector as each plant or site reaches the appropriate point to implement the technology. For the food and drink industry, the 60-80% CO_2 reduction pathway is the same as the Max Tech pathway.

Pathways were developed in an iterative manual process and not through a mathematical optimisation process. This was done to facilitate the exploration of uncertain relationships that would be difficult to express analytically. This process started with data collected in the evidence gathering phase regarding the different decarbonisation options, current production levels and the current use of energy or CO_2 emissions of the sector. This data was then enriched through discussion with the sector team and in the first workshop. Logic reasoning (largely driven by option interaction), sector knowledge and technical expertise were applied when selecting technical options for the different pathways. These pathways were discussed by the sector team, modelled, and finally tested by the stakeholders participating in the second workshop. This feedback was then taken into account and final pathways were developed. All quantitative data and references are detailed in the options register and relevant worksheets of the model. The pathway model methodology is available through DECC and BIS, and is summarised in appendix A.

Scenario Testing

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

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

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

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

Key Assumptions and Limitations

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

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

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

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

Assumptions in relation to the maximum technical pathway

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

The following assumptions apply:

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

Option Interaction Calculation

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

Cumulative Emissions

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

Scope of Emissions Considered

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

Complexity of the Model

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

Material Efficiency

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

Base Year (2012)

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

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

2.2.3 Conclusions and Next Steps

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

- Strategy, leadership and organisation
- Business case barriers
- Future energy costs, energy supply security, market structure and competition
- Industrial energy policy context
- Life-cycle accounting
- Value chain collaboration
- Research, development and demonstration
- People and skills

The main technology groups as presented in section 5 are:

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

3. FINDINGS

3.1 Key Points

The food and drink manufacturing industry is the single largest manufacturing sector in the UK, with a turnover of £95.4 billion and gross value added (GVA) of £25.7 billion, accounting for 18.3% of the total manufacturing sector by turnover (FDF 2014), and directly employing up to 400,000 people as part of a wider chain accounting for some 3.7 million jobs in total (DEFRA, 2014).

The sector is the fourth-highest industrial energy user in the country. In 2012, it consumed 33.97 TWh final energy and emitted 9.48 million tonnes of CO_2 (Dukes, 2014). Direct emissions originate largely from the high heat demand of several processes (drying, evaporation, baking ovens, pasteurisation, kilning, steam production, etc.), and indirect emissions from electricity from the grid (used for refrigeration and cooling, mixing, conveying, compressed air, pumps and fans, stirring, grinding, etc.). The fossil fuel use for heat production in the sector is dominated by natural gas (gas oil is only used where there is no access to the gas grid), whereas another significant part of the energy consumption includes electricity.

Since the 1990s, the food and drink sector has lowered its carbon footprint considerably (41% emissions reduction in 2012), especially regarding fossil fuel consumption, whereas electricity consumption has stayed more or less at the same level (FDF, 2014).

The UK food and drink sector currently counts over 7,800 companies, and is mainly dominated by small and medium enterprises (SMEs) with 86% of the companies having fewer than ten employees (IBIS, 2014). The heterogeneous nature of the sector establishes a healthy dose of competition and a strong innovation drive (product development innovation in response to changing consumer tastes and demand), but also makes it challenging to achieve economies of scale which will allow the reduction of overall and specific energy consumption.

Energy efficiency is perceived by industry as important, but decarbonisation is generally not yet a priority in the current investment climate, because energy presents only a low proportion (2-5%) of total production costs (FDF, 2014). Moreover, the high market heterogeneity and product diversity put a constant pressure on product innovation and differentiation, consuming most of the available financial resources. Product quality cannot be jeopardised, and therefore companies are often only willing to invest in technologies that have already been proven to be successful. Large upfront costs and long lifecycles of equipment (20-40 years) are other disincentives to regularly invest in new technologies. The main enablers for decarbonisation for the food and drink sector are:

- Strong, evidence-based business case
- Projects providing multiple benefits
- Leadership commitment to climate change
- Effective best practice sharing within the organisation
- Realistic commitments
- Collaboration in the value chain
- Compliance to regulation

Main barriers that hamper decarbonisation are:

- High capital cost and long investment cycles
- Limited financing
- Risk of not meeting required product quality or changing character

- Risk of production disruption
- Shortage of skilled labour
- Shortage of demonstrated technologies
- Lack of reliable and complete information

The UK population is expected to grow, and therefore future production for the UK food and drink sector is projected to increase. Depending on the scenario, the overall sector is estimated to grow (tonnes of products) by 1% under current trends and 2% under collaborative growth. Under the challenging world scenario, production is assumed constant (0% growth).

The food and drink sector is very diverse with many subsectors. Each of these subsectors has very specific processing technologies, although some common technologies can be identified throughout the entire sector. The energy-saving opportunities for the sector distilled from the literature review, interviews and workshops can be classified into six categories including 25 options: general energy efficiency, energy-efficient technologies, IEEA (Industrial Energy Efficiency Accelerator projects – carried out by Carbon Trust) technologies, low-carbon energy sources, supply chain, and carbon capture (CC).

3.2 Food and Drink Processes

The food and drink sector is very diverse with many subsectors such as dairy, brewery, distilling, sugar, confectionery, bakery, rendering, meat processing, fish and seafood, poultry, malting, soft drinks, animal feed, oil and fat, glucose, canned food, ice cream, and pet food. Manufacturing in the food and drink sector is very diverse, using numerous individual processes. There are variations even in the production of similar products. Covering each of these processes, together with their energy use and emissions, is not possible within the scope of this project. Therefore, focus will be on the main processing techniques and unit operations applied throughout the entire sector (EC, 2006), being:

- Materials reception and preparation
- Size reduction, mixing and forming
- Separation techniques
- Product processing technologies
- Heat processing
- Concentration by heat
- Chilling and freezing
- Post-processing operations
- Utility processes

3.2.1 Materials Reception and Preparation

Materials handling applies to the **receipt, unpacking, storage** and internal conveying of raw materials, intermediate products, final products, by-products and waste. It is applied in all food and drink subsectors.

After receipt, unpacking and storage, solid raw materials can be **conveyed** by water (e.g. vegetables), air (e.g. powder) or conveyor belts, elevators, screw conveyors and pumps. Liquid materials are pumped through a pipework system, and gases (like N_2 and CO_2 for packing and chilling, or SO_2 for processing sugar and wine) are transported through a pipework system by pressure differences (EC, 2006).

Most raw materials contain some components that are inedible or have different physical characteristics. To obtain the required uniformity for further processing, techniques like **sorting and screening** (separation based on shape, size, weight or colour), grading (human inspection), de-hulling (removing hulls and shells), de-stemming or de-stalking (removing stems from fruit and vegetables), and trimming (removing inedible parts or parts with defects, or cutting the raw material to suitable sizes, manually or by rotating knives) are necessary (EC, 2006). These techniques are used as a first step in the processing of fruit, vegetables, meat, eggs and fish.

Fruits, vegetables, roots, tubers and potatoes might also require **peeling** to remove the skin or peel from the raw materials, improving the appearance and taste of the final products (Sokhna Seck et al., 2013). Different peeling techniques exist, depending on the product and the manufacturing site: steam, knife, abrasion, caustic and flame peeling (EC, 2006).

A next step in the materials preparation is **washing**, to remove and separate (often by sedimentation) unwanted components (like dirt, residual peel, brine used for preservation, soil, micro-organisms, pesticide residues and salts) and to ensure that the surface of the food is in a good condition for further processing. Washing is widely applied for root crops, potatoes, cereals, fruit and vegetables. It can be carried out by vigorous water spraying, or by immersion with the aid of brushes, or by shaking and stirring (EC, 2006).

When raw fish and meat products are received frozen, **thawing** (or de-frosting) is needed before further processing. Traditional thawing takes place under running water or with air at controlled temperatures.

However, to avoid the growth of micro-organisms, microwave energy can be used, which is faster and less damaging (EC, 2006).

3.2.2 Size Reduction, Mixing and Forming

The next step in food processing is **size reduction**, either for further processing or to improve the eating quality or suitability for direct consumption. Size reduction includes cutting, slicing, chopping, mincing, pulping and pressing. The equipment is adapted to the product to be processed, and can be power- or hand-operated depending on the size of the operations. These techniques are widely applied in the entire sector for processing meat, fish, cheese, vegetables, fruit, potatoes and various crops (EC, 2006).

To obtain a uniform mixture of two or more components, to obtain an even particle size distribution in food material, or to improve characteristics and eating quality, materials can be further processed by **mixing and blending** (the combination of different materials), **homogenisation** (to obtain a more even particle size distribution or homogeneous blend) or **conching** (a special method of kneading used in the chocolate industry) (EC, 2006).

Grinding, milling and crushing are used to reduce the size of solid material. Grinding or milling is applied for processing dry solid materials, e.g. in flour milling, animal feed, brewing, sugar and dairy. Wet grinding and milling can obtain smaller particle sizes. Cyclones are often used to recover dust from the mills (hammer, ball, roller, disc mills). Crushing facilitates yeast multiplication and conducts traditional macerations before pressing (EC, 2006).

When a specified shape of solid materials is required, **forming, moulding or extruding** can be applied. Forming and moulding is widely used in the production of chocolate, bread, biscuits, confectionery and pies, and it is also an important process step in cheese-making. Extruding is used in the production of meat sausages, confectionery products and starch-based snack foods (EC, 2006).

3.2.3 Separation Techniques

Extraction is a separation technique to recover valuable soluble components from raw materials. Soluble components can be separated from insoluble or less soluble components by dissolving them in a suitable solvent. This technique is widely applied in the food and drink sector for the extraction of sugar from sugar beets or sugar cane, oil from oil seeds and virgin pomace, coffee extracts from coffee beans, caffeine from coffee beans, and various other compounds (proteins, pectins, vitamins, pigments, essential oils, aromas, flavour compounds) from many different materials (EC, 2006).

Centrifugation and sedimentation are used to separate immiscible liquids and solids from liquids. Separation happens by either centrifugal forces or natural gravity. These techniques are typically used in the dairy industry, in the production of drinks (vegetable and fruit juices, coffee, tea, beer, wine, soy milk), in the processing and recovery of oils and fats, in cocoa butter and sugar manufacturing, and in wastewater treatment (EC, 2006).

Solids from a suspension in a liquid can also be separated by **filtration**, using a porous medium, screen or filter cloth that retains the solids and allows the liquid to pass through. This technique is used to clarify liquid products by removing small amounts of solid particles with subsequent recovery of the filtrate. It is applied in the production of wine, beer, oils and syrups, fruit juices, etc. The technique operates either by applying pressure to the feed site (pressure filtration) or by applying vacuum to the filtrate side (vacuum filtration) (EC, 2006).

Distillation is a separation technique for liquid mixtures by partial vaporisation: the more volatile components of the original mixture are obtained at a higher concentration in the vapour, the less volatile in a higher concentration in the liquid residue. This technique can be used to separate flavours or essential oils, but is mainly applied for the production of potable alcohol and spirits. Distillation can be carried out using pot stills or column stills (EC, 2006).

Other separation techniques are very specific to certain subsectors and include (EC, 2006):

- De-ionisation or ion exchange: to remove unwanted constituents from water and food products, e.g. in the dairy industry
- Fining: clarifying liquids, e.g. in the production of sparkling wines and beer
- Membrane separation: semi-permeable membranes to selectively remove water, solutes or suspended material from a solution, mainly applied in the dairy industry
- Crystallisation: separating a solute from a solvent, e.g. in the dairy and edible oil industry
- Bleaching: removing pigments, metals, residual soaps and phospholipids from edible oils or fats
- Chemical neutralisation and de-odorisation by steam stripping: removing free fatty acids and other highly volatile compounds from edible oils or fats
- De-colourisation: improving colour, ageing, microbiological stability and shelf-life of certain food products in the sugar, glucose, syrup and fermentation industry

3.2.4 Product Processing Technologies

Soaking is used to moisten and soften seeds or grains, to reduce the cooking time, to aid in seed coat removal, or to activate the germination process (of malting) by the uptake of water. Water temperatures can be adjusted depending on the process (EC, 2006).

Fermentation is the controlled action of selected micro-organisms to alter the texture of foods, to preserve foods by the production of acids or alcohol, or to produce or modify flavours and aromas. It also preserves products by lowering the pH tolerance limits of many micro-organisms. Fermentation is an important processing step for a number of food and drink products, typically including beer and wine (alcoholic fermentation), and dairy products, vegetables, meat and fish (lactic acid fermentation). Alcoholic fermentation breaks down simple sugars into alcohol by using yeast, and is an anaerobic process usually in a temperature range of 8-30°C. Carbon dioxide is produced as a by-product in this fermentation process. Lactic acid fermentation converts lactose or other sugars into lactic acid and small amounts of other components. The formation of lactic acid causes a decrease in pH, which is important for the taste, the aroma and the preservation of the product. It is also an anaerobic process, usually carried out at 20-40°C (EC, 2006).

Other product processing techniques include (EC, 2006):

- Dissolving: adding powder to liquid to produce solutions or suspensions, e.g. for reformulating milk in the dairy industry
- Solubilisation or alkalising: neutralisation of cocoa nibs or liquor with an alkaline solution, resulting in a darker colour and a milder taste
- Coagulation: agglomeration of suspended particles and separate solids from liquids or vice versa, often used in the dairy industry
- Germination: in the malting process of cereals
- Brining and curing: salt treatment of cheese, meat, fish, vegetables and mushrooms
- Pickling: adding organic acids to vegetables until the pH is below 4.3
- Smoking: preservation of fish, cheese and meat
- Hardening: production of margarine and other edible fats
- Sulphitation: preventing microbiological degradation or unwanted colour formation in winemaking, potato and shellfish processing, or adjusting pH in sugar production

- Carbonation: dissolving carbonic gas into different products, e.g. in the soft drink production
- Coating: covering food with a layer of material to improve the eating quality, provide barrier to the movement of moisture and gases or protect against mechanical damage
- Ageing: to mature wine and brown spirits

3.2.5 Heat Processing

Food conservation is achieved by killing the micro-organisms which are present, and one of the main techniques is heat treatment. This stops bacterial and enzyme activity, preventing loss of quality and reducing perishability. Various time and temperature combinations can be applied depending on the product properties and shelf-life requirements.

Pasteurisation is a controlled heating process that eliminates viable forms or any micro-organism that may be present in milk, fruit-based drinks, some meat products or other food, or to extend the shelf-life (e.g. of beer). Generally, a heating temperature below 100°C is applied, only using the minimum heat requirement to deactivate specific micro-organisms or enzymes and minimising any quality changes in the food itself. The incoming product is rapidly heated to the pasteurisation temperature, ensuring that the pasteurisation temperature is held for the correct time to destroy the bacteria. The product is then passed through a regeneration zone, giving its heat to the incoming cold product, and cooled to a level where the growth of any surviving bacteria is slowed to a minimum. The pasteurisation process is typically carried out in-line with the heating and cooling conducted in a plate heat exchanger (Xu and Flapper, 2010). **Sterilisation**, which includes canning, is the heat processing of preserved foods, by moist heat, dry heat, filtration, irradiation or chemical methods. Compared to pasteurisation, sterilisation applies a heat treatment of over 100°C for a period long enough to lead to a stable shelf-life (EC, 2006).

Baking is a heat-processing technique, basically to make food edible, but which can also change the taste and structure. Baking can also be used to preserve food by destroying micro-organisms. The shelf-life of most baked foods is, however, limited, unless products are also refrigerated or packaged. In a baking oven, the food is exposed to hot air at 110-240°C or to infrared radiation, evaporating the moisture at the surface and removing it by hot air. When the rate of moisture loss at the surface exceeds the rate of transport of moisture from the interior of the product to the surface, the surface dries and a crust is formed. Different types of ovens can be used: direct heating, indirect heating, electric and infrared ovens, either batch (with heated walls and base) or continuous (with radiators located above, alongside and below the conveyor belt) (EC, 2006).

Other heat processing techniques include (EC, 2006):

- Melting: chocolate moulding, production of processed cheese, processing of oils and fats, recovery of animal fat from meat residues
- Blanching: exposing fruit or vegetables to high temperatures for a short period of time to inactivate or retard bacterial and enzyme action
- Cooking and boiling: preparing ready-to-eat meals or facilitating later processing
- Roasting: coffee, nuts, cacao, chicory, fruit and cereals
- Frying: cooking fish, potatoes and chicken in edible oil at temperatures of ca. 200°C
- Tempering: for chocolate products

3.2.6 Concentration by Heat

Evaporation is the partial removal of water from liquid food by boiling. It is used to pre-concentrate food, to increase the solid content, to change the colour of food or to reduce the water content of a liquid product.

This technique is used in many food and drink subsectors, e.g. for processing milk, starch derivatives, coffee, fruit juices, vegetable pastes and concentrates, seasonings, sauces, sugar and edible oil (EC, 2006).

Drying applies heat under controlled conditions to remove water from liquid foods by evaporation to yield solid products. The main purpose of drying is to extend the shelf-life of foods. This technique is often applied to dairy products, coffee, tea, flavours, powdered drinks and processed cereal-based foods. When solid foods are being dried, the technique is called dehydration (EC, 2006).

Freeze-drying is the process of removing water from a product by sublimation and desorption, to preserve sensitive material that cannot be dried by evaporation. This technique is used for drying coffee extracts, spices, soup vegetables, instant meals, fish and meat (EC, 2006).

3.2.7 Chilling and Freezing

Worldwide it is estimated that 40% of all foods require refrigeration, using 15% of the electricity consumed (James and James, 2006). The UK food and drink sector is one of the largest users of **refrigeration** technology, making up a large part of the energy bill. Without refrigeration, companies would not be able to meet customers' specifications on food product quality. It is essential in the production of many perishable foods: it helps to prevent food spoilage by reducing microbial growth and assists in retaining the nutritional content, flavour and texture of the food. Typical storage applications range from small, stand-alone refrigerators to large walk-in cold rooms. The major use of refrigeration is process heat exchangers to cool liquids (e.g. plate heat exchangers in dairies or breweries) or solids (Carbon Trust, 2012).

The electricity consumption for refrigeration will vary for different subsectors: liquid milk processing (25%), breweries (35%), confectionery (40%), meat, poultry and fish processing (50%), chilled ready meals (50%), frozen food (60%), ice cream manufacturing (70%) and cold storage (85%) (Carbon Trust, 2011; FDF and Carbon Trust, 2007).

Cooling or chilling is used to reduce the temperature of food from one processing temperature to another, or to a required storage temperature, typically between -1 and 8°C. The objective of both cooling and chilling is to reduce the rate of biochemical and microbiological changes in food, to extend the shelf-life of processed and fresh food, or to maintain a certain temperature in a food process. Cooling is also used to promote a change of state of aggregation (e.g. crystallisation). Both cooling and chilling are used in a variety of processes throughout the food and drink sector (EC, 2006).

Freezing is a preservation method, reducing the temperature of the food to below the freezing point (generally -18°C). It is applied to several types of food such as pizza, fruit, vegetables, fish, meat, baked goods and prepared food (EC, 2006).

3.2.8 Post-Processing Operations

After the different processing stages, food undergoes some additional operations including (EC, 2006) **packing and filling** (using textile, wood, metal, glass, plastic, paper and board packaging materials under modified or vacuum atmosphere), and **gas flushing** (storage of products in an artificially produced atmosphere, mainly used for meat, bakery products and wine).

3.2.9 Utility Processes

Processing equipment and production installations are **cleaned and disinfected** periodically to comply with legal hygiene requirements, and to remove product remnants and other contaminants. Cleaning-in-place (CIP) is especially used for closed-process equipment (like pipes and vessels) and tanks, pumping a cleaning solution through the equipment or distributing it by sprayers in vessels, tanks and reactors, without needing to remove them (Carbon Trust, 2010). CIP systems typically work at temperatures of 50-90°C. Cleaning out of place is used when several of the machine's components need to be dismantled, and includes high-pressure jet cleaning and foam cleaning, where water is sprayed at the surface to be cleaned at pressures of 40-65 bar, and cleaning agents are injected into the water at ca. 60°C (EC, 2006).

A large part of the food and drink sector cannot operate without a substantial amount of good quality **water**, the production of which may require additional energy-intensive processing such as reverse osmosis. Water is used for food processing, equipment cleaning, installation cleaning, washing of raw materials, firefighting and water used in boilers, cooling circuits, refrigeration, chillers, air conditioning and heating (EC, 2006).

Vacuums are used primarily to reduce the temperature at which operations take place, thereby reducing potential deterioration in the quality of the food being processed or to avoid unwanted oxidation of the product during processing at higher temperatures. Vacuums are applied to many different unit operations in the sector, including drying, evaporation, neutralisation and filtration. Vacuums can be produced by steam jet ejectors, reciprocating pumps and rotary vacuum pumps (EC, 2006).

Compressed air is generated to run simple air tools (e.g. for pneumatic transfer) or for more complicated tasks such as the operation of pneumatic controls. Compressed air is widely used in the food and drink sector, e.g. on manufacturing and packaging lines (EC, 2006).

3.2.10 Technologies for Delivering Heat and Power

Food and drink manufacturing requires electrical and thermal energy for virtually every step of the process. Electricity is needed for lighting, process control of the installation, heating, refrigeration and as the driving power for machinery. It is usually generated and supplied by utility companies, but companies can also generate steam and electricity on site (EC, 2006).

Thermal energy is needed for heating processes in production lines and buildings. Heat generated by the combustion of fossil fuels is transferred to the consumers by heat transfer media (steam, hot water, air or thermal oil, depending on the requirements). Direct-fired equipment – like ovens, grills, and dryers – do not use an intermediate medium, but directly use the heat from combustion. Heat can be generated by combustion of fuels in boilers and generators, or by in-house combined heat and power (CHP) generation: high-pressure steam boilers and steam turbine, (combined cycle) gas turbines, gas engines, or diesel generators with waste heat recovery for steam or hot water generation (EC, 2006). Other technologies for heat generation include biomass boilers, whereas anaerobic digesters (AD) produce methane gas that can be combusted to produce heat or power (DSCF, 2010).

The UK food and drink industry has a mix of technologies for delivering heat and power (EC, 2006). Examples include:

- For melting, processing kettles are used. Heating may be carried out by direct steam injection or indirectly by steam jackets.
- Blanching may be accomplished by direct or indirect heating systems, depending on the product. Direct heating is carried out by immersion into hot water (80-100°C) or by exposure to live steam. When direct contact with water or steam has to be avoided, heat-exchangers working with hot water or vapour can be applied.
- Cooking takes place in ovens (water bath, shower, steam, hot air or microwave), while boiling is carried out in water bath ovens.
- Baking is carried out in baking ovens, exposing food to hot air at 110-350°C or to infrared irradiation. Four types of baking ovens exist: direct heating, indirect heating, electric ovens and infrared ovens.

- Typical equipment for roasting includes drum roasters, rotating disc roasters, fluidised bed roasters and spouting bed roasters. In all roasting equipment, the product is heated and agitated at the same time.
- Evaporation often uses steam as a heating medium. The most commonly used equipment is a multi-stage shell-and-tube evaporator or a plate evaporator.
- Drying can be done by hot-air drying (in direct or indirect contact with the liquid product) or by surface drying (indirect heating through conduction).
- Dehydration of solid food is carried out in dryers: fluidised bed, cabinet or tray, conveyor or belt, pneumatic, flash or ring, rotary, tunnel, steam bundle, steam, kiln or vacuum dryers.
- Cooling is commonly carried out by passing the product through a heat exchanger or cooler, or by cooling the vessels. The cooler medium is often water mixed with agents like glycol, which is circulated via a mechanical refrigeration system or ice-water system. In cryogenic cooling, the food is in direct contact with the refrigerant (solid or liquid CO_2 or liquid nitrogen).
- For freezing, a whole range of methods and equipment is available. The most common freezers are blast, belt, cooled surface, immersion and cryogenic freezers.
- Freeze-drying equipment consists of a drying chamber with temperature-controlled shelves, a condenser to trap water removed from the food, a cooling system to supply refrigerant to the shelves and the condenser, and a vacuum system to reduce the pressure in the chamber.
- In a mechanical refrigeration system, the refrigerant circulates through the evaporator, the compressor, the condenser and the expansion chamber, changing in state from liquid to gas and back to liquid again. In the evaporator, heat is absorbed from the surroundings (cold storage, blast tunnel, evaporator), resulting in cooling or freezing the product.
- Certain subsectors also use CHP systems.

3.3 Current Emissions and Energy Use – Principal Question 1

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

3.3.1 Evolution of Energy Consumption and CO_2 Emissions

Since the 1990s, the food and drink sector has lowered its energy and carbon footprint considerably, especially regarding fossil fuel consumption (resulting in direct emissions), whereas electricity consumption (responsible for indirect emissions) has stayed more or less at the same level. These trends are depicted in Figure 4 and Figure 5 below.

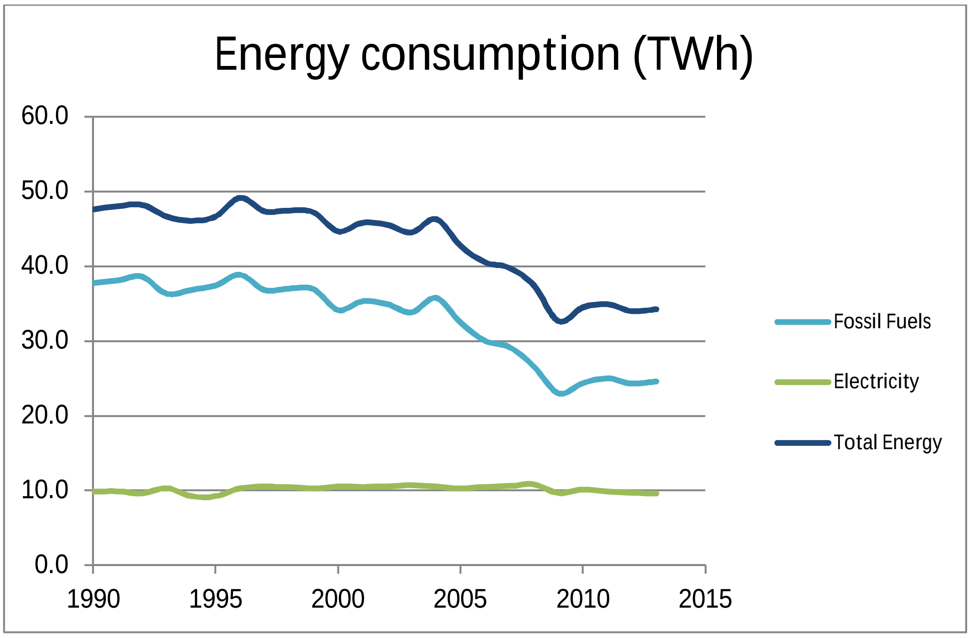

Figure 4: Energy consumption (TWh) trend in the UK food and drink sector (Dukes, 2014)

As can be seen in Figure 4, the food and drink sector has reduced its energy consumption from 47.60 TWh in 1990 to 33.97 TWh in 2012, a reduction of 13.63 TWh or 28.6% in 22 years or a sustained annual average reduction in energy consumption of 1.3% (Dukes, 2014). Over the same period, the sector has seen its GVA grow by 13.8% (equivalent to an average annual growth rate of 0.63%).

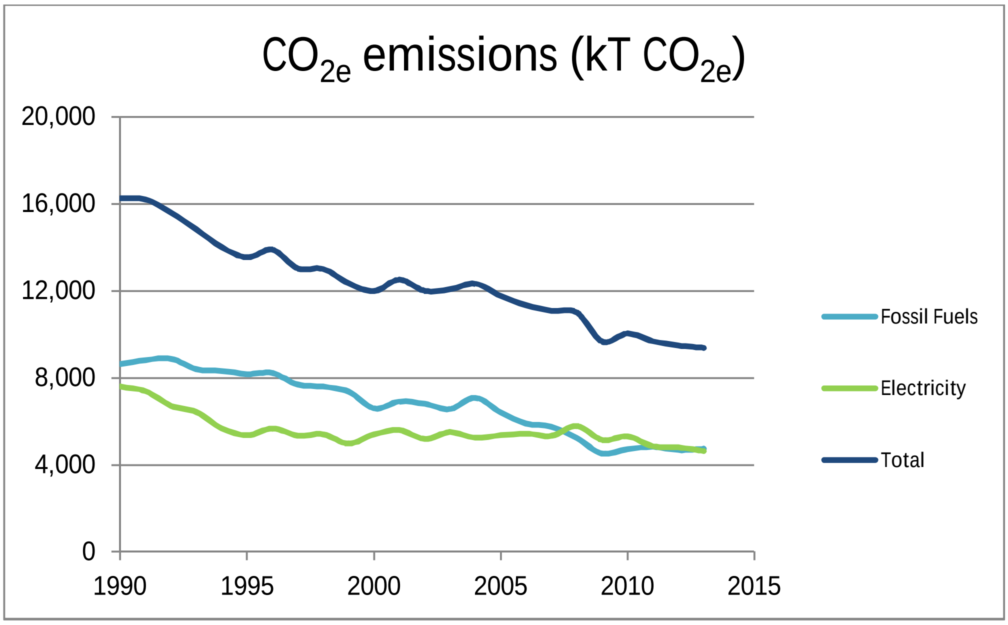

Figure 5: CO_2 emissions (ktonnes CO_2) reduction trend in the UK food and drink sector (Dukes, 2014)

The emissions trend illustrated in Figure 5 shows a steady decline from 16,244 ktonnes CO_2 in 1990 to 9,482 ktonnes CO_2 in 2012, resulting in 41% emissions reduction over 22 years. This reduction in CO_2 emissions is a result of (FDF, 2014):

- Switching from high-carbon fuels such as coal and petroleum to gas in on-site heat-raising processes, particularly during the 1990s
- Reduction in the carbon intensity of electricity generation, particularly with the increased use of gas and (more recently) renewables generation
- Extensive rationalisation, concentrating production in fewer but more-efficient factories, particularly from the mid-1990s to 2002
- Installation of over 400 MW_e CHP capacity within the sector
- Great strides in improving energy efficiency, e.g. the sites participating in the FDF CCA (Climate Change Agreement) improved their energy efficiency by 20% from 1990 to 2010

3.3.2 Emissions

The UK food and drink processing industry is the fourth-highest industrial energy user in the country. In 2012, the industry consumed nearly 33.97 TWh final energy and emitted 9.48 million tonnes of CO2 (Dukes, July 2014).

The main sources of greenhouse gas emissions from food and drink manufacturing sites relate to the use of energy, although other food factory emissions can originate from sources such as leaking refrigerants, methane from effluent treatment and process CO_2 from fermentation. The main energy-related emissions are (FDF, 2008):

- Burning of fossil fuels such as oil and gas, leading to direct CO_2 emissions at the factory site. The key uses of fossil fuel are for steam boilers and other heating systems such as ovens and dryers.
- The use of grid electricity leads to indirect CO_2 emissions at the power station producing the electricity. The key uses of electricity include refrigeration, compressed air, pumps, fans and processing and packaging equipment.
- All transport of raw materials, finished goods and staff also gives rise to emissions from vehicles. These emissions are, however, out of scope of this project.

For all UK food and drink factories, the overall split of emissions between fossil fuels and grid electricity is approximately equal. However, different subsectors have very varied emissions profiles. Some processes – such as food canning and baking – are very heat intensive, whereas others – like frozen foods and flour milling – use relatively much more electricity (FDF, 2008). Figure 6 shows the average breakdown of emissions for the whole food and drink sector. Examples of how this average breakdown can change are:

- Food canning is very steam intensive, with boilers using 70% of the energy
- Baking requires large ovens using 60% of the energy
- Frozen and chilled foods have large refrigeration loads using 60% of the energy
- Flour milling plants have large electrical loads using 80% of the energy

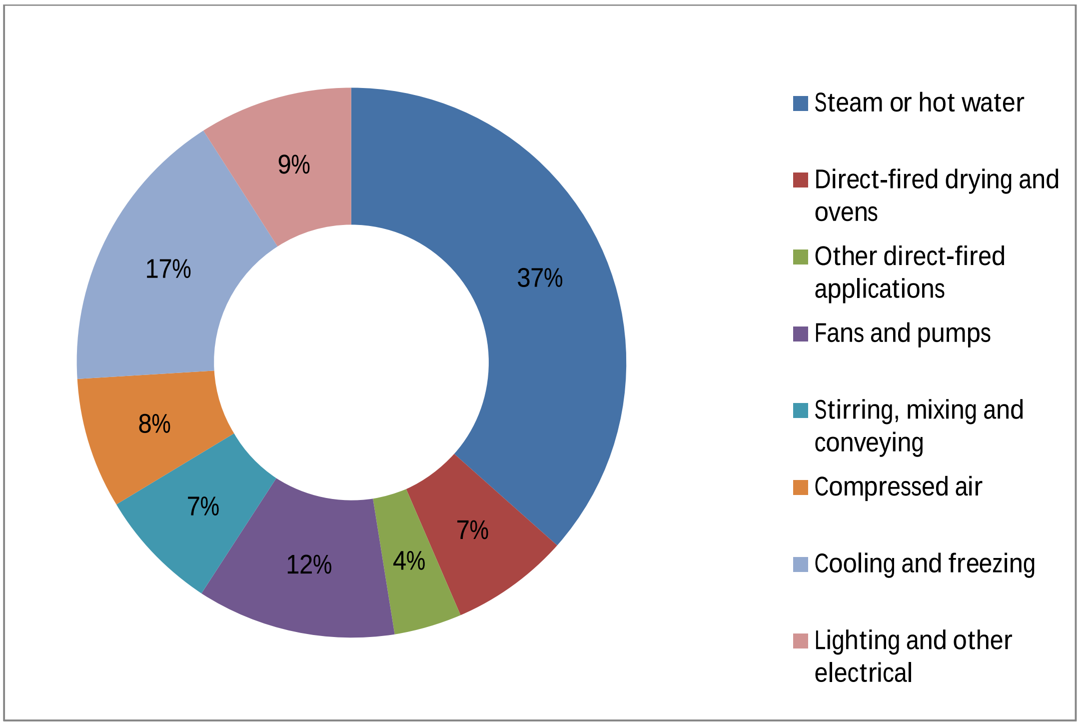

Figure 6: Breakdown of FDF CCA food and drink sector emissions (FDF, 2008)

3.3.3 Heat and Power Demand

The most common technologies for the food and drink sector and its share in energy consumption are: boilers (54%), direct-fired applications (21%), cooling and freezing (10%) and fans and pumps (7%) (FDF, 2008).

Heat and power demand depend on the type of food and drink production, as illustrated by the examples below.

- In **dairy** production, pasteurisation is one of the largest emissions sources, with intense heating and cooling demands (although much of the heat is regenerated and reused in the pasteuriser (Carbon Trust, 2010). Other heat consumers are evaporation, spray drying and CIP, whereas electricity is mainly used for cooling, separation and homogenisation. The majority of the energy consumption in dairy is gas- (or fossil fuel-) driven, the rest is electricity consumption.
- In industrial **bakeries**, heat is mainly used for direct-fired ovens and proving, whereas power is mainly used for refrigeration and cooling, fans and pumps, stirring, mixing and conveying and compressed air (FDF, 2014).
- **Chocolate and sugar** production require over 90% of the heat consumption for generating steam and hot water, whereas power consumption by equipment is comparable with bakeries (FDF, 2014),
- In **malting**, kilning (to evaporate water and cure the malt) is the dominant user of heat and power (Carbon Trust, 2011).
- In small **breweries and soft drink** producing plants, heat demand is almost exclusively used for steam and hot water generation, whereas power is mainly used for refrigeration and cooling, fans and pumps, and compressed air (Carbon Trust, 2011). The same heat and power demand profiles apply to processing of fruit and vegetables, and the production of meat, fish and poultry products (VITO, 1999).

- On average in the British **meat processing** industry, 50-80% of the energy used in an abattoir and cutting plant is provided by electricity (process equipment for cooling), with the other 20-50% coming from thermal energy (hot water, with cleaning and disinfecting taking ±80% from the total heat demand). For meat and canning companies, 40% of the electricity goes to cooling and 40% to the process equipment; for fossil fuels, 60% of the energy goes to cooking, drying and smoking (EBLEX, 2011).
- A typical **animal feed** mill uses the majority of its power consumption in the presses, whereas heat is mainly used in the conditioners (for steam and hot water generation) (Carbon Trust, 2010a).
- In **starch** processing the majority of the heat demand is used for dewatering, evaporation and drying after the wet milling of the starch products. In addition, significant amounts of power are required for the large motors for grinding (Berkeley National Lab, 2003).

3.3.4 Fuels Used

The 2012 fuel mix for the UK food and drink sector is shown in Figure 7. For the sector as a whole, the distribution of the energy carriers is: 66% natural gas, 28% electricity and 5% petroleum products and coal.

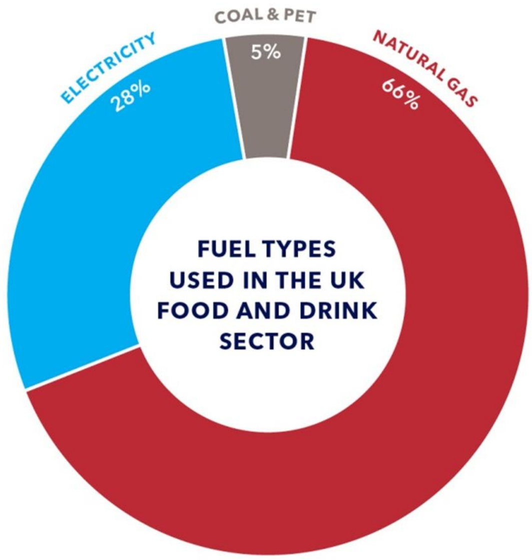

Figure 7: 2012 distribution of energy carriers used in the UK food and drink industry (FDF, 2014)

The total energy use in the food and drink sector in 2012 was nearly 34 TWh (Dukes, 2014). The fossil fuel use for heat production in the sector is dominated by natural gas (gas oil is only used where there is no access to the gas grid), whereas another significant part of the energy consumption includes electricity.

3.3.5 Lifespan of Equipment and Key Timings

Food and drink plants and the process equipment tend to be built (or purchased) as complete plants through some turnkey suppliers and typically have a life expectancy of over 30 years. In many sectors, the change in processing lines can be more frequent due to changes in product mix or because of new product development, but the utilities services equipment (such as boilers, ovens, refrigeration plants, etc.) can have long life cycles.

The majority of the plants have equipment from different investment periods. As a consequence, there is no consensus or publicly available information on key dates for replacement of major equipment. Often equipment has been refurbished or rebuilt, making it difficult to determine its exact age.

CHPs and turbines have a typical life span of around 20 years (with a major refurbishment after ten years). Vacuum pumps can also easily reach 25 years' life whereas smaller utilities (compressed air, HVAC (heating, ventilation and air conditioning), lighting) have typical lifetimes of 10-15 years before replacement or major upgrade. ESP filters in exhaust systems can last for several decades (EC, 2013). Boilers typically last for at least 30 years.

3.4 Business Environment – Principal Question 2

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

Enablers and barriers were prioritised based on the evidence gathering process and workshop exercises.

#	Category	Top Enablers	Prevalence in occurrence		Level of impact	
			Literature	Interviews	Survey	Workshop
1	Investment	Strong, evidence-based business case	3	3	High	High
2	Investment	Projects providing multiple benefits	3	2	High	Medium-High
3	Management	Leadership commitment to climate change	3	2	High	High
4	Management	Effective best practice sharing within the organisation	2	1	Medium-High	High
5	Management	Realistic commitments	4	5	Medium-High	High
6	Supply Chain	Collaboration in the value chain	4	1	Medium	High
7	Regulation	Compliance to regulation	11	2	Medium-High	Medium-High

Table 5 and

#	Category	Top Barriers	Prevalence of occurrence		Level of impact	
			Literature	Interviews	Survey	Workshops
1	Investment	High capital costs and long investment cycles	8	1	High	High
2	Investment	Limited financing	11	3	Medium-High	High
3	Market	Risk of not meeting required product quality or changing character	6	1	Medium	High
4	Operations	Risk of production disruption	4	1	Medium	High
5	Organisation	Shortage of skilled labour	9	2	Medium-High	High
6	Innovation	Shortage of demonstrated technologies	4	0	Medium-High	High
7	Innovation	Lack of reliable and complete information	12	1	Medium-High	High

Table 6 below indicate how many times the enabler or barrier was mentioned across the different evidence gathering research methods. The categories were simply used as a means of identification for the workshops based on interpretation of the content of the enabler and barrier. Although the number of times an enabler or barrier is highlighted in the literature review and referred to in the interviews provides an indication as to the importance of a particular barrier or enabler, the discussions during workshops and interviews provided a greater understanding as to the detail and context behind each barrier and enabler.

3.4.1 Market Structure

The food and drink manufacturing industry is the single largest manufacturing sector in the UK, with a turnover of £95.4 billion and gross value added (GVA) of £25.7 billion, accounting for 18.3% of the total manufacturing sector by turnover (FDF 2014), and directly employing up to 400,000 people as part of a wider chain accounting for some 3.7 million jobs in total (DEFRA, 2014). The industry has a major role to play in the realisation of government priorities on economic growth, exports, employment, environmental sustainability and public health through the provision of safe, nutritious, affordable and sustainable food (FDF, 2012).

FDF's 'Vision for innovation in food and drink manufacturing' (2012) describes the sector as highly heterogeneous, with a very broad diversity of businesses which, regardless of size, are often characterised by relatively low margins, making investment and development difficult. The sector currently includes over 7,800 companies, and is mainly dominated by SMEs with 86% of companies having fewer than ten employees (IBIS, 2014), which establishes a certain level of competition and a strong innovation drive. Yet such significant sector heterogeneity makes it challenging to achieve economies of scale which will allow the reduction of energy consumption overall and on a per-product basis.

The UK's population, is expected to reach 71.3 million in 2030 (15% growth over 2010), according to EU-28 population projections (Eurostat, 2013). This presents an opportunity for the food and drink sector to service the needs of a growing yet ageing consumer base.

Export is another area of potential growth, especially for products with longer shelf-life, such as spirits. In 2013-2014, total exports for food and non-alcoholic drinks increased by 4.8% to £6.5 billion. The export of all UK products fell by 15% in 2013 (worth £155 billion), impacted by stronger sterling in 2014 (FDF, 2014). The five biggest subsectors are:

1. Other groceries £1,714 million
2. Cereals and bakery £1,034 million
3. Meat £865 million
4. Dairy £780 million
5. Fish and seafood: £743 million

'Food and drink manufacturing relies on very complex, often global, supply chains and depends on a sophisticated and demanding retail environment.' (FDF, 2012)

Growth will also depend on the ability of the UK food and drink manufacturers to predict and satisfy the changing preferences of the diverse and complex consumer base in the UK. Some of the key factors to consider, as identified by the Strategy Unit (2008), include increasing demand for provenance – locally sourced, organically produced and certified products with traceable origins of ingredients. Change of diet and lifestyle is perceived to increase the demand for healthier and readily available options and expected to alter product mix, portion size and production routines. At the same time, workshop participants shared that consumers are still not willing to pay a price premium for more environmentally sustainable options, which puts extra pressure on profit margins and investment budgets.

The UK Government's Business Taskforce on Sustainable Consumption and Production, 2008, Decentralised Energy: business opportunity in resource efficiency and carbon management – *'Widespread* *operations at a range of scales with a significant overall carbon footprint – growing consumer pressure to account for carbon in the supply chain – potential product or brand differentiator.'*

The majority of food and drink products are sold by retailers, constituting 57% of consumer expenditure in 2014 (DEFRA, 2014). Workshop attendees and interviewees expressed the view that retailers hold a strong position in the market and can exercise considerable bargaining power towards food and drink manufacturers. In most cases, this is focused on reducing retail prices, limiting contractual periods and extending payment periods. This continuous process has driven down the margins and reduced the ability of manufacturers, especially small ones, to invest in new and more energy-efficient technologies.

A manager in charge of environmental issues for a major manufacturer shared: *"While some retailers require manufacturers to report on their initiatives to reduce carbon emissions, this has been more an exception than an industry-wide trend."*

3.4.2 Business Strategies

"The ageing population (both in the UK and worldwide), as well as the health agendas increasingly promoted in the Western world, are expected to impact the demand for Health and Wellness (H&W) products and, therefore, be one of the main categories to drive the industry's growth. Both in the UK and globally, the forecasted population growth will result in a larger consumer base, which should drive demand within the food and soft drinks market. The UK is amongst the European countries with the fastest population growth, forecast to reach 71.3 million in 2030 (15% growth from 62.3 million in 2010)." (FDF, 2012)

At the evidence gathering workshop it was concluded that while consumer preferences have been continuously changing to increase the demand for provenance and sustainable sourcing, this has not gained enough traction for retailers in the UK to exert power over their food and drink suppliers – the manufacturers. Literature (Carbon Trust, 2010) and most of the interviewees, on the other hand, claim that corporate responsibility and changing consumer demand plays an important role in driving decarbonisation. All sources of evidence encountered in the project recognise the value of taking a product life-cycle approach to reducing CO_2 emissions. Although an evaluation of the impact of life-cycle assessments (LCA) on carbon emissions was not in the scope of this project, workshop participants (in particular) expressed the concern that there needs to be a unified standard for product LCAs across the industry in order to yield real benefits.

Carbon Trust, 2010 – *'Changing customer demand – Consumers and major retailers are starting to demand information on embedded carbon in consumer goods. This is driving farmers to reduce the carbon footprint of animal products.*'

Carbon Trust, 2010 – *'Corporate responsibility is also a key driver for carbon reduction, driven by key stakeholders: retailers and consumers.'*

The food and drink manufacturing industry is a dynamic sector focused on improving its competitiveness and efficiency in response to the challenges and opportunities of globalisation. This has led to consumer benefits of lower prices and greater choice. Innovation is a key focus of the industry, which accounts for over 4% of total R&D (research and development) spend, reported in the annual R&D scoreboard (BIS, 2010). Yet financial uncertainty has hampered large investments in decarbonisation, as it is not perceived as a top business priority by the majority of the sector. This has been confirmed by all interviews conducted in the scope of this project.

If the market conditions do not improve, the risk-averse attitude to innovation for decarbonisation will continue to prevail. Multiple literature sources, including Hollins (2011) and McKenna (2009), and two managers responsible for environmental issues indicated that conservatism is widespread in the industry:

companies are only willing to invest in technologies that have already been proven to be successful. To support that, workshop participants reinforced the view that companies would not implement any technology that risks diminishing end product quality or character, key drivers for sales; nor would they risk potential production disruption, which would affect profit margins.

There are other external pressures which drive this short-term thinking and risk-aversion in the food and drink sector, according to workshop participants. Top management is focused on achieving quarterly and annual financial goals under investors' pressure for immediate results. Big retail chains, which are the key customers for the food and drink manufacturers, seldom sign contracts for more than a year, adding to the uncertainty of the business environment.

Current regulatory context is perceived by industry to be detrimental to decarbonisation in the long term as investors look for energy price stability, energy security and an indication of the direction in which the government would like to take the energy market. Despite the regulatory uncertainty, workshop participants perceive compliance with environmental regulations and meeting CCA and EU ETS (European Union Emissions Trading System) commitments as key drivers of decarbonisation in the food and drink sector.

This work has not evaluated the extensive body of work on LCA as it is out of scope, but we recommend it is included in future studies.

> *"Clear commitment from the Government will be good on what they want to be achieved in the area of Climate Change and Resource efficiency. And, it doesn't need to be financial only as long as there is a stable policy in the long term."* – Manager with environmental responsibilities for a major manufacturer

In response to Environment and Climate Change (FDF, 2013), FDF argues that there is a need for harmonised legislation at EU level in order to provide a level playing field for companies competing both within a single market and globally. This perception was further supported at the workshop as concerns were expressed over losing competitive advantage to other EU markets and emerging economies with lower energy prices than in the UK. In fact, 14 of survey respondents share the view that rising energy prices and supply constraints are key threats to their competitiveness in the global market.

If the sector as a whole can maintain its competitiveness against international competition, growth will be sustained to enable an improved business environment for investing in decarbonisation technologies.

Decarbonisation Strategies

The survey results on business decision-making related to decarbonisation showed that all respondents either agreed or strongly agreed that their organisation has well defined goals or targets in place. This finding is shared by all interviewed manufacturers, who reported that they have a strategy or targets in place, and well defined roles in terms of energy and carbon.

Various discussions at the two workshops highlighted that while energy efficiency or energy savings are often perceived as important to the sustainability of the company, decarbonisation is not a priority in the current investment climate. According to industry and trade associations, energy cost represents a relatively small portion of total production costs (2-15%), compared to other costs such as marketing and labour. While energy price increase is a considerable risk, marketing and product innovation costs are the primary focus of senior management attention.

Sustainability strategies and corporate social responsibility trends have been identified by the majority of the interviewed manufacturers as the backbone of any initiatives related to decarbonisation.

One interviewee, responsible for environmental issues in the UK, shared that: *"Often the only reason an investment in energy-efficient technologies gets approved is because of the company's sustainability commitments."*

When survey respondents were asked what their position was in regards to carbon and energy efficiency reduction, 13 respondents considered themselves to be a first mover or early adopter. However, the majority of interviewees indicated that their companies were risk-averse, and would be unlikely to pursue unproven technologies without demonstrations elsewhere. Furthermore, workshop participants confirmed that due to commercial secrets companies rarely collaborate in proving new technologies and in sharing the risk and cost, which has been suggested as a potential action for the sector.

Another area that has gained management attention in recent years is meeting CCA targets and participation in the EU ETS scheme. As expressed by workshop participants, industry-wide support in clarifying the requirements and benefits of these regulatory mechanisms have played a crucial role in the advancement of CO_2 reduction in the UK food and drink sector. These policy instruments are applicable to the vast majority of the food and drink business, with the exception of the subsectors or certain processes (e.g. spirits bottling at stand-alone facilities) not included in the CCA or EU ETS schemes[11].

Industry-driven long-term targets, roadmaps and initiatives on decarbonisation and energy efficiency have been identified by workshop participants as contributing factors to the decarbonisation of the food and drink manufacturing. Indeed, many subsectors have already established plans and targets to reduce environmental impacts from manufacturing and the value chain as whole, including carbon.

Some examples include:

The Dairy Roadmap, set up in 2008 and jointly managed by NFU (the National Farmers Union), DairyCo and Dairy UK

Growing for the Future – An environmental roadmap for the UK cereals and oilseeds industry, prepared by UK Home Grown Cereals Authority, a division of the Agriculture and Horticulture Development Board in 2012

Scotch Whisky Industry Environmental Strategy Report 2013, launched by the Scotch Whisky Association in 2013 (SWA, 2013)

Soft Drinks Sustainability Roadmap Report, prepared by the British Soft Drinks Association in 2014 (BSDA, 2014)

These plans help to create awareness among senior management and mobilise resources, in the form of time, money and expertise, to investigate what is possible to achieve. Integrated sector plans and initiatives have been identified by four of the interviewees as a key driver to decarbonisation in the future.

3.4.3 Decision-Making Processes

Based on the conducted interviews, it was identified that decision-making processes for investing in energy efficiency and carbon emissions reduction vary by company. The majority of companies select projects based on annual capital expenditure programmes, with a small number appraising projects on an ongoing basis as they are identified.

[11] About 98% of the UK food and drink sector is covered by EU ETS or CCA (FDF, 2014).

Projects will typically be identified at a site level by engineering and technical experts. Site managers will then prioritise projects and make recommendations to the next level of decision-making, which is typically at country or business unit level. If the projects are low-value (typically below £100,000), then they may be authorised at this level and do not need to progress further. For large and capital-intensive projects, another filtering process will take place and recommendations for projects may move to the next level of decision-making, at corporate or board level. The level of decision-making depends on the size of the project, the capital requirements, and the level of risk.

Business cases are required at all levels, and the degree of detail and interrogation will tend to increase as projects move up the decision-making hierarchy. Although climate change policies are considered as part of the decision-making process, for the majority of the manufacturers interviewed, environmental and climate change benefits are not the primary criteria for decision-making. Projects are not commonly labelled as being a 'decarbonisation project', and it is the financial and operational performance of a proposed project that is a key determinant for the final decision.

There were several references in publications and academic journals (e.g. CSE and ECI, 2012; Carbon Trust, 2010) revealing a lack of reliable and complete information about technical feasibility or savings potential of innovative energy reduction technologies. A number of workshop participants also highlighted this as an issue. This is further supported by universities reducing their facilities and resources necessary for R&D activities (McKenna, 2009). Workshop participants reported that, especially in SMEs, there is shortage of engineers that can assess the technical viability of breakthrough technologies and build a robust business case for investment. Lack of technical expertise is also shared at management level which hinders additionally the ability of businesses to seek and assess best available technologies (BAT) and breakthrough technologies. This contributes to the conclusions of literature sources that the sector is reluctant to invest in unproven technologies (DECC, 2013) or measures with a payback period of more than approximately 1.5 to two years (Carbon Trust, 2011). The majority of interviewees confirmed that for most of the investments they look for a maximum payback period of two years to be able to compete for funding against other internal projects, i.e. new product development.

The situation differs with regards to incremental improvements. Interviews with trade associations representing the multiple food and drink subsectors converged around the notion that the food and drink sector has been at the forefront of achieving substantial CO_2 reductions in the past decade by continuously improving existing manufacturing technologies. This is also supported by the view that such improvements in general require smaller upfront capital and decisions can be made at a site or national corporate level instead of competing for financing globally. Interviewees also confirmed that incremental energy efficiency improvements are often well embedded in the process at site level. Yet it is important to provide management with more enablers to overcome the risks concerning product quality and character.

The survey results displayed in the table below show that all responding companies have corporate energy and carbon reduction targets in place, and have set site-level targets. 18 respondents indicated that they have systematic decision-making processes in place with regards to energy and carbon reduction, and energy and carbon reduction were tracked at management meetings. Overall, the survey results suggest that carbon and energy reduction receives appropriate attention within organisations, and that decision-making processes are established. Survey results are shown in Table 4 below.

Question	No. of responders who agree or strongly agree
Our company goals and objectives get translated to targets at site level	9
We have a systematic decision-making process for new initiatives w.r.t energy and carbon reduction that work well	18
We track progress of energy and carbon improvement projects in management meetings	18
We have some specific roles or allocated responsibilities within the company w.r.t. energy or carbon reduction	15
Our organisation has strong communication and information sharing channels that support the implementation of options w.r.t. energy and carbon reduction successfully	15
We have understanding of which energy and carbon reduction technologies can be implemented in our organisation	17
We have a sufficiently skilled workforce to implement and handle energy and carbon reduction technologies	14

Table 4: Survey responses to company policies and targets

3.4.4 Financing Investments

The need for financing carbon-reducing and energy efficiency technologies varies between companies as identified by all evidence sources. It was reported by some interviews and workshop attendees that the availability of capital remains a real challenge, whilst others have access to capital, and in their view it is the issue of current disincentives for investing in the UK (and Europe) that presents an obstacle, often driven by lower energy prices overseas.

A key barrier perceived by industry is the limited availability of capital for improvement projects due to the high level of competition for internal funds in multinational companies and other projects that are more closely related to the core business. Internal financing is generally available, but decision-making processes tend to go against UK sites and operations as the business case is stronger elsewhere. The primary reasons are the lower cost of energy and labour, and government incentives (e.g. in France and Germany), which result in shorter payback times compared to the UK. These factors were discussed by interviews and supported by various studies such as Carbon Trust (2010, 2011), and CSE and ECI (2012). The age of UK assets does not help in this regard, with operators being less willing to invest heavily in sites with a low book value.

The majority of interviewed manufacturers reported that investments would be financed internally, and be subject to the decision-making issues outlined above. The level of risk that an investment presents is a key determinant in whether a project is approved and subsequently financed. One of the interviewees, responsible for environmental issues in the UK, explained that capital allowances and financial incentives are a key enabler to improving current equipment.

Payback periods of one to two years were commonly cited by interviewees as a threshold used internally. Paybacks beyond this timescale were reported to be unattractive to boards, particularly given the uncertainty around future energy and relevant policy costs in the medium to long term. One interviewee, responsible for environmental issues, indicated that when attractive grant and financial support schemes are available, this gives confidence to (overseas) boards as it demonstrates government commitment.

3.4.5 Enablers and Barriers

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

#	Category	Top Enablers	Prevalence in occurrence		Level of impact	
			Literature	Interviews	Survey	Workshop
1	Investment	Strong, evidence-based business case	3	3	High	High
2	Investment	Projects providing multiple benefits	3	2	High	Medium-High
3	Management	Leadership commitment to climate change	3	2	High	High
4	Management	Effective best practice sharing within the organisation	2	1	Medium-High	High
5	Management	Realistic commitments	4	5	Medium-High	High
6	Supply Chain	Collaboration in the value chain	4	1	Medium	High
7	Regulation	Compliance to regulation	11	2	Medium-High	Medium-High

Table 5 and

#	Category	Top Barriers	Prevalence of occurrence		Level of impact	
			Literature	Interviews	Survey	Workshops
1	Investment	High capital costs and long investment cycles	8	1	High	High
2	Investment	Limited financing	11	3	Medium-High	High
3	Market	Risk of not meeting required product quality or changing character	6	1	Medium	High
4	Operations	Risk of production disruption	4	1	Medium	High
5	Organisation	Shortage of skilled labour	9	2	Medium-High	High
6	Innovation	Shortage of demonstrated technologies	4	0	Medium-High	High
7	Innovation	Lack of reliable and complete information	12	1	Medium-High	High

Table 6 below indicate the most prevalent enablers and barriers across literature and interviews, as well as the perceived level of impact to decarbonisation as assessed by survey respondents and workshop participants. Although the number of times an enabler or barrier was referenced or highlighted could provide some guidance as to the strength of sentiment towards a particular enabler or barrier, the discussions during workshops and interviews provided a greater understanding as to the detail and context behind each barrier and enabler.

- There were 42 documents reviewed as part of the literature review. The number in the literature column below represents the prevalence in occurrence of the enabler or barrier; or in other words the number of sources that discuss it.
- There were six telephone semi-structured interviews in total. The number in the interview column below represents the prevalence in occurrence of the enabler or barrier; or in other words the number of interviewees that discussed it.
- The survey column shows the impact level of the enabler and barrier as assessed by 19 survey respondents, predominantly management-level representatives of UK food and drink manufacturers.
- The workshop column shows the impact level of the enabler and barrier as discussed and agreed by the evidence gathering workshop group.
- The numbers on the left-hand side do not present a ranking but provide an easy point of reference to the order of analysis.

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

Enablers

#	Category	Top Enablers	Prevalence in occurrence		Level of impact	
			Literature	Interviews	Survey	Workshop
1	Investment	Strong, evidence-based business case	3	3	High	High
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4	Management	Effective best practice sharing within the organisation	2	1	Medium-High	High
5	Management	Realistic commitments	4	5	Medium-High	High
6	Supply Chain	Collaboration in the value chain	4	1	Medium	High
7	Regulation	Compliance to regulation	11	2	Medium-High	Medium-High

Table 5: Enablers

The first enabler – **a strong, evidence-based business case** – was identified by literature (Carbon Trust, 2011; HMG, 2011; Lavery, 2014) and was confirmed by interviewees, workshop participants and survey respondents as having a high impact on implementing decarbonising options. Capturing all costs and financial savings can provide support to obtain executive buy-in and pursue more energy-efficient technologies. Most of the interviewed manufacturers and workshop participants agreed that this enabler is an absolute necessity for senior management to even consider any energy-related projects, more so than for product development or marketing projects. According to the industry, this is mostly driven by increased risk-averseness due to the weak economic climate and rising pressure from food and drink retailers to reduce cost. A robust business case is often difficult to develop for breakthrough technologies as there is a view that there is not sufficient and reliable information about the savings potential and profitability of such technologies. This enabler is applicable now and will continue to grow in importance once and if the economic climate stabilises and new technologies are commercialised.

"Business case – this will need to be robust, which means capturing all costs and financial savings (which must be deliverable). The sector would like to see all potential and knock-on benefits captured, e.g. could a

carbon reduction measure also help increase productivity or reduce maintenance requirements?" (Carbon Trust, 2008)

"Benefits justify the costs, as well as providing a robust, credible and long-term policy framework to increase business certainty of payback from investment." (HMG, 2011)

The second enabler – **projects providing multiple benefits** – was identified by literature (CSE and ECI, 2012; Carbon Trust, 2005 and 2011) and confirmed by two interviews, workshop participants and survey respondents as having a high impact on implementing decarbonising options. To cope with the rising pressure from shareholders to reduce production costs and improve profitability margins, managers in the food and drink sector favour projects that can not only help reduce energy and its associated costs, but also increase productivity, reduce labour costs or achieve overall process optimisation. On the other hand, technologies that have the potential to improve product quality are well received by management. As explained by workshop participants, this stems from the fact that energy is not perceived as a priority in many businesses due to the low percentage that energy costs contribute to total production costs (2-15%). This enabler is applicable now.

Manager with responsibilities for environmental issues a major manufacturer stated: "*Modern bottling production lines are much more compact than 20 years ago. They can be fitted in a smaller place, which reduces the need for conveyers, allows better monitoring and lowers the staff needed. All these benefits help us justify the 30% reduction in energy use as only then the investment meets our internal requirements."*

A workshop attendee, environmental manager for a local SLE manufacturer, concluded that: *"Clearly more benefits, especially such with direct economic impact on bottom-line results, will help justify the cost."*

"Other financial co-benefits or co-costs of new equipment (e.g. improved control) are drivers in the industry." (Carbon Trust, 2005)

The third enabler – **leadership commitment to climate change** – was identified by literature (DECC, 2013; Lavery, 2014; Hollins, 2011) and confirmed both by workshop participants and survey respondents as having a high impact on implementing decarbonising options. Senior management buy-in and commitment from top management to make climate change a priority is essential for embedding the company's carbon strategy in the business day-to-day operations. This can create a ripple effect across the business and increase the importance of decarbonisation. Unilever's Sustainable Living Plan and Marks & Spencer's 'Plan A' were identified by workshop participants as success stories of such a leadership commitment from the UK food and drink sector. This enabler is applicable now.

One workshop attendee, an energy manager, concluded: *"It is very simple. Top management is under a lot of pressure to deliver short-term financial results. The only way to get energy efficiency projects past the investment criteria threshold and to compete with other projects internally, is if carbon reduction is a company priority and is owned at the highest level possible."*

"A key organisational driver is the willingness of top management to make climate change a priority. This is crucial as it affects the overall culture of the firm." (DECC, 2013)

"'CEO leadership and genuine commitment to resource efficiency is a key driver." (Lavery, 2014)

The fourth enabler – **effective best practice sharing within the organisation** – was identified by literature (BPEX, 2011; Lavery, 2014) and confirmed both by workshop participants and survey respondents as having a medium to high impact on implementing decarbonising options. One challenge that companies, especially large multinationals, identified is the lack of effective exchange of best practice among production facilities and the head office. As Lavery (2014) rightfully suggests, this involves not only sharing what is done well at one site but also actively looking for what other plant managers are doing to reduce their carbon emissions and improve energy efficiency. Workshop attendees suggest that case studies work very well to capture best practice and increase awareness. This enabler is applicable now.

"The enthusiastic engagement and active participation of all those involved in the production process is a crucial factor." (BPEX, 2011)

"Staff taking responsibility for both disseminating and looking for good practice between sites and divisions." (Lavery, 2014)

A workshop attendee, technical manager, concluded: *"Case studies are a good way of increasing general awareness, as well as industry benchmarking which shows hard evidence on the benefits of innovations. The only issue with benchmarking is that it is hard to get companies to share certain information. The way of presenting environmental innovation to companies has a large effect on uptake as perceptions play a large part in investment."*

The fifth enabler – **realistic commitments** – was identified by literature (Carbon Trust; Lavery, 2014) and confirmed by interviews, workshop participants and survey respondents as having a medium to high impact on implementing decarbonising options. Setting targets and establishing corporate and site-level key performance indicators (KPIs) with regards to reducing carbon emissions and energy consumption are perceived as essential to keeping the momentum and mobilising the workforce. When such commitments are made public, companies can exert a certain influence over suppliers and customers and engage them on the journey of achieving these targets. As a result, workshop participants perceive commitments as the first step to embed decarbonisation and energy efficiency in the strategic agenda of the business and ensure everyone in the business – from the production floor to the board – is doing something to achieve those commitments. Targets need to be realistic and time-bound to allow the business to adapt but stretching enough to provide direction and nurture an innovation-driven culture. Several interviewees, responsible for the energy and carbon reduction strategy of their companies, confirmed that long-term corporate-wide targets on reducing carbon emissions drive investment, even if the case is weaker, and influence staff behaviour and engagement. This enabler is applicable now.

"Setting realistic targets for energy savings will help to keep the momentum going and to maintain employee awareness and interest. Set deadlines for the completion of each improvement detailed on the action plan and check to ensure that each has been completed." (Carbon Trust, 2011)

One workshop attendee, technical manager, concluded: *"It is important to have targets that are realistic and measurable in order for them to be managed. The question is how to use KPIs to drive performance. It is important to take note of KPIs that vary from the norm. The issue with having targets for carbon reduction is getting companies to understand exactly what carbon means and how it can be reduced using targets."*

The sixth enabler – **collaboration in the value chain** – was identified by literature (AIC, 2012) and confirmed by one interviewee and by workshop participants as having a high impact on implementing decarbonising options. Close supply chain co-operation is needed to secure resources, improve skills (including resource efficiency management), and to create system solutions with low-impact products, which better meet customer needs (including servicing) and drive improvements in scale. The food and drink sector in the UK is quite diverse in terms of types of products and thus can be characterised by a fairly complex value chain. Retail chains have strong bargaining power over manufacturers and, in turn, manufacturers pass on that pressure to raw material suppliers. Workshop attendees have expressed the concern that for retailers the key focus is reducing costs rather than environmental impacts, including decarbonisation. A product life-cycle approach has already been considered by the UK food and drink manufacturers and this will require stronger collaboration across the entire value chain in the future. This type of opportunity supports the overall need for greater consideration for collaboration across the value chain, to share the risks and speed up innovation. One potential challenge to effective collaboration, expressed by workshop participants, is that due to high competition levels companies are generally not willing to share information about innovation with peers. Therefore, strong incentives and senior-level commitment are crucial to successful collaboration. This enabler is relevant now and will become increasingly important in the future.

> "*"Collaboration with the supply chain – offering practical information and demonstration."* (AIC, 2012)
>
> A manager responsible for environmental issues for a major manufacturer stated: *"There is no integrated approach for the food and drink sector in the R&D area. We need more collaboration to support implementation, especially in terms of funding and R&D."*
>
> A workshop attendee, technical manager, concluded: *"Collaboration in our industry is crucial, as it helps share the risk and speeds up innovation."*

The seventh enabler – **compliance to regulation** – was identified by literature (Carbon Trust, 2012) and confirmed by all sources as having a medium impact on implementing decarbonising options. Compliance with environmental regulation is already a norm in the UK food and drink sector as manufacturers cannot afford to jeopardise their reputation and brand value, or incur unnecessary cost in the form of fines. Several workshop attendees highlighted the fact that their commitments with regards to the CCA as well as the EU ETS have been key drivers to reducing CO_2 emissions from manufacturing. Many of the subsectors have signed up to climate change agreements that allow certain energy-intensive subsectors to receive up to 90% reduction in the Climate Change Levy (CCL). Volatile energy prices, insecurity of energy supply and the low price of carbon, coupled with the long-term uncertainty around relevant legislative direction, can transform this enabler into a barrier if incentives are reduced or the bureaucratic burden increases. Thus, this enabler is relevant now and will become increasingly important in the future.

> "*The major energy-related legislation for this sector is the Climate Change Levy and the associated Climate Change Agreements, which most of the manufacturers hold though the Food and Drink Federation."* (Carbon Trust, 2011)
>
> *"Continued participation in the Climate Change Levy Rebate Scheme, and requirements of EPR Permits are drivers for change along with minimising the impact of energy inflation."* (BPEX, 2011)

Barriers

#	Category	Top Barriers	Prevalence of occurrence		Level of impact	
			Literature	Interviews	Survey	Workshops
1	Investment	High capital costs and long investment cycles	8	1	High	High
2	Investment	Limited financing	11	3	Medium-High	High
3	Market	Risk of not meeting required product quality or changing character	6	1	Medium	High
4	Operations	Risk of production disruption	4	1	Medium	High
5	Organisation	Shortage of skilled labour	9	2	Medium-High	High
6	Innovation	Shortage of demonstrated technologies	4	0	Medium-High	High
7	Innovation	Lack of reliable and complete information	12	1	Medium-High	High

Table 6: Barriers

The first barrier – **high capital cost and long investment cycles** – was identified by literature (DECC, 2012) and confirmed by both workshop participants and survey respondents as having a high impact on implementing decarbonising options. The sector investment cycles are to a large extent dictated by the lifespan of manufacturing equipment, usually in the range of 20-30 years but often as long as 40 years. This in itself presents very few opportunities to upgrade the entire production line and achieve major energy and carbon savings until 2050 – as there will only be one or at most two investment cycles, depending on the company and asset type. Additionally, the high upfront cost of such investments often limits the financial ability of UK food and drink manufacturers to upgrade multiple production lines at the same time. Rather, companies take a gradual approach to upgrading equipment. SMEs in particular find the upfront cost of advanced technologies such as robotics prohibitively expensive. Interviews with large manufacturers did not identify upfront cost as barrier, however they highlighted the low appetite to invest in major equipment as upgrading existing equipment is often more financially feasible. This is a barrier now and will remain so in the future.

"Upfront costs are cited as a significant disincentive." (CSE and ECI, 2012)

"Investment cycles and capital costs: Investment in new more efficient plant requires major investment, and is unlikely to be possible outside normal investment cycles, which can sometimes be 40 years or longer. Also returns from energy efficiency investment are low and can be uncertain, and in many companies, bids for investment will compete at a global level against spend on process and products." (DECC, 2014)

One interviewee, environmental manager, stated: *"I only have the opportunity to make big changes [to plant] if new lines are brought in or there is production down time. Otherwise, I cannot justify financially the disruption of production cycle and the opportunity cost."*

The second barrier – **limited financing** – was identified by literature (Carbon Trust, 2011) and confirmed by all sources as having a medium to high impact on implementing decarbonisation options. Financing may be available, but improving energy efficiency does not rank highly on the investment hierarchy of companies. Preference is given to growth, acquisitions, marketing, product development and adapting production equipment to changing customer demands (FDF, 2014). Lack of resources deployed to identifying available funding, and the reluctance to move to third-party financing are seen as additional barriers to finding financing. Workshop attendees and some of interviewees also indicated that there is a lack of collaboration on financing demonstration projects as this is seen as a competitive advantage and thus sharing the financial burden amongst manufacturers is limited. Large multinational companies expressed concern that energy reduction projects often compete with core business capex; product innovation projects overseas and longer payback times do not help secure that funding as risk is seen as too high. Establishing a long-term regulatory framework is perceived by industry to play an important role in reducing that risk in the future. This is a barrier now and will remain so in the future.

"Available capital: Lack of available capital resources has been cited as a reason why breweries do not take up utility saving technologies. For example, modernising a brewhouse or replacing packaging equipment could be a multimillion pound investment which may not be justifiable on utility savings alone." (Carbon Trust, 2011)

"Access to capital is considered a key barrier for efficiency investment particularly for smaller organisations. However, some studies argue that when energy efficiency is reconfigured as having strategic value, access to finance becomes easier – particularly in larger organisations." (CSE and ECI, 2012)

*"Technology, Research and Development is critically important in improving the competitiveness and environmental performance. It is essential that funding and time continues. Not only through the industry levy body, but through continued Government investment in research that challenges current best practic*e." (Dairyco, 2010)

The third barrier – **risk of not meeting required product quality or changing character** – was identified by literature (Carbon Trust, 2011) and interviews, and confirmed by both workshop participants and survey respondents as having a medium to high impact on implementing decarbonising options. It is very unlikely for a UK food and drink manufacturer to invest in and deploy a technology that may diminish product quality or change a product's character and texture. This can be explained by the fact that strong brands attract a price premium in the sector and any unwanted change to the product may erode brand and economic value. Thus the sector perceives unproven technologies as an unnecessary business risk. Subsector-specific regulation maintains the high impact of this barrier. In the spirits subsector, for example, the production of Scotch whisky is set in the law and thus distillers cannot deviate from the prescribed production process. As a result, producers are limited in their choice of opportunities for technology improvement or new build. This is a barrier now and will remain so in the future.

One workshop attendee, technical manager, concluded: *"One of the strongest assets of the industry is branding and product quality. If any of these is compromised, companies may lose their position in the market or go out of business. In some cases, there are very strong regulatory requirements on production process or product specifications and thus these cannot be changed."*

"Product quality – if an innovation could affect product quality then this would be a key barrier. Innovations would need to have a proven track record to gain credibility with the sector." (Carbon Trust, 2010)

"Product quality – The quality and texture of the sweets is intrinsically associated with the product brands. Therefore, manufacturers are nervous about introducing any process changes that might change these." (Carbon Trust, 2011)

The fourth barrier – **risk of production disruption** – was identified by literature (Carbon Trust, 2011) and confirmed by both workshop participants and survey respondents as having a medium to high impact on implementing decarbonising options. The potential impact of any changes in operations on machine operability and disruption of production is a barrier to decarbonisation. Some of the manufacturing in the sector is on a non-stop basis, in particular in the soft drinks and dairy subsectors. Other subsectors such as bakery, frozen food and meat production operate only in a limited time window during the day. Therefore, any downtime in a production line is carefully planned and reduced to an absolute minimum. This is driven by constant and increasing pressure to maintain profitability margins and reduce cost. Thus the sector perceives lines upgrades and retrofits as risky unless equipment is approaching the end of its lifespan. An additional factor that reinforces this barrier is the lack of proven and commercially tested technologies which makes management reluctant to implement, even during downtime, as this may cause disruption and operational challenges in the future. This is a barrier now and will remain so in the future.

"Another important barrier to the adoption of low carbon and energy efficient technologies is the risk of disruption to production. Continuity of production is of primary importance to firms. This is one of the reasons that energy efficiency technologies tend to have more stringent economic criteria compared to investments that are more closely related to the core business." (DECC, 2013)

One workshop attendee, environmental manager, concluded: *"Production is fundamental to running business, hence risks are unacceptable. Retrofitting means downtime of the production process, but it is often very difficult to interrupt the production process because companies have no stock or risk turning bad their fresh feedstock."*

The fifth barrier – **shortage of skilled labour** – was identified by literature (Carbon Trust, 2011; CSE and ECI, 2012) and confirmed by both workshop participants and survey respondents as having a medium to high impact on implementing decarbonising options. A shortage of technically competent staff and a lack of funding for training are still perceived to prevent further advancement of the UK food and drink sector. A further challenge to the sector is attracting new recruits and talent. There is an increased demand in the sector for engineers who understand the technical aspects of the industry that support energy efficiency implementation, such as heat engineers. This growing need has been recognised by the FDF and its members as a key issue for the sector and initiatives are being rolled out. These include the establishment of 'National Centre of Excellence for Food Engineering' in cooperation with the Sheffield Hallam University and the National Skills Academy, and the 'Apprenticeship Trailblazers' initiative, which aims to build on the success of the apprenticeships programme in 2012 (FDF, 2015).

On the other hand, internally, engineers are currently not appraised adequately and not perceived as a key resource. However, some large manufacturers stated during interviews that their reputable brands help them secure qualified engineers and that their internal skill development programmes help them train and educate new staff. Other interviewees expressed the concern that there is a need to change outsiders' perceptions of the industry, and to invest in training to make industry more attractive to graduates and other professionals. This is a particular barrier now as the profile of the workforce of the sector is ageing without sufficient succession planning in place.

"Lack of internal skills to interpret technical information and the time and capacity to plan energy management is a major barrier for smaller SMEs." (CSE and ECI, 2012)

"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." (DECC, 2014)

One workshop attendee, energy manager, concluded that: *"… this is a very big barrier for the industry. Currently, companies are facing the challenge of not being able to recruit engineering graduates into food and drink manufacturing."*

The sixth barrier – **shortage of demonstrated technologies** – was identified by literature (Carbon Trust, 2011; CSE and ECI, 2012) and confirmed by both workshop participants and survey respondents as having a medium to high impact on implementing decarbonising options. The UK food and drink manufacturers are risk-averse and are not likely to implement technologies that might lead to production disruptions due to malfunctioning retrofits, or which could compromise product quality or increase production costs. Therefore, technologies which have been tried and proven, ideally in the food and drink sector, are more likely to gain traction. As a result, the sector enjoys a slow pace of technological change. At the workshop it was suggested that stronger collaboration across the food and drink value chain can strengthen the research base in the UK and help reduce the risk of investment in innovative technologies by sharing it among several players. This is a barrier now.

"Proven technology – the sector has previously implemented innovations, most notably heat recovery on ovens. However, because a number of test applications have failed, there are concerns about the potential to deliver proven solutions with the longevity to maximise savings." (Carbon Trust, 2010)

"Brewers may agree that beer made with new technology on a pilot scale tastes just as good, or even better at times but confidence is lacking that this can then be produced on an industrial scale with sufficiently mitigated risks, as there may be no reasonable way to go back." (Carbon Trust, 2010)

The seventh barrier – **lack of reliable and complete information** – was identified by literature (Carbon Trust; CSE, ECI, 2012) and interviews, and confirmed by both workshop participants and survey respondents as having a medium to high impact on implementing decarbonising options. There is a need for greater knowledge sharing and R&D collaboration within the sector to accelerate technology advancement along the curve from demonstration to commercialisation. The FDF membership also recognised the need for academia, research institutions, the sector and government to agree on a shared vision for innovation in the sector as recognised by the FDF members (FDF, 2015).

Shortage of technical knowledge and capacity within the UK food and drink businesses to identify new technologies and measures is a common challenge. Workshop attendees expressed a concern that managers do not know where to start looking for new options and industry-wide support can be a key to resolve this. Independently verified data on savings potential can further reduce the hesitations of management to consider new technologies. One interviewee, environmental manager of a large multinational, disagreed and stated that the business case is not there for the majority of the technologies compared to other investment projects. This has been identified as a stronger barrier for SMEs in the sector and is a barrier now.

"Cost-effective energy efficiency measures are often not undertaken as a result of lack of information and indifference toward environmental problems on the part of the managers. Additionally, energy study results or data are not robust enough to support investment decisions." (CSE and ECI, 2012)

Workshop attendees concluded: *"Proof that technology will work is fundamental and that proof needs to come from an independent source. This is an engineering led issue so the solution should come from engineers. It requires independently verified data and trials in the business. Difficult to produce information that fits all. Evidence should be not only on what works but what doesn't too."*

3.5 Technologies to Reduce Carbon Emissions

The food and drink sector is very diverse with many subsectors such as dairy, brewery, distilling, sugar, confectionery, bakery, rendering, meat processing, fish and seafood, poultry, malting, soft drinks, animal feed, oil and fat, glucose, canned food, ice cream and pet food. Each of these subsectors has very specific processing technologies, although there are some common technologies throughout the entire sector.

The options distilled from the literature review, interviews, evidence gathering workshop, discussions with trade associations and input from academia are presented in appendix C (the data for these options are also listed). The energy-saving opportunities selected from a long list of options are classified into six categories containing 25 options in total: general energy efficiency, energy-efficient technologies, IEEA technologies, low-carbon energy sources, supply chain, and carbon capture (CC).

General energy efficiency (the four CCA[12] options) options includes:

- Energy management and good maintenance practice: energy metering, process control and measurement, energy monitoring and targeting, process optimisation and pinch analysis, production scheduling, and avoiding idle equipment

[12] Climate Change Agreements (CCAs) are voluntary agreements that allow eligible energy-intensive sectors to receive up to 90% reduction in the Climate Change Levy (CCL) if they sign up to stretching energy efficiency targets agreed with government. Targets apply from 2013 to 2020, and the UK food and drink sector has agreed to reach 18% final sector energy efficiency improvement in that period, by focusing on energy management, utilities, compressed air and steam.

- Motors, pumps and drives, lighting and HVAC: correct sizing and controls, maintenance, energy-efficient motors, VSDs (variable speed drives), voltage optimisation, sequential air ventilation, and LED lighting
- Compressed air: general recommendations, avoiding unnecessary or wrong usage, system design, maintenance, leak detection, and waste heat recovery
- Steam production, distribution and end-use: state-of-the-art boiler and steam systems, inspection and maintenance, insulation, water quality, and direct-fired process heating

Energy-efficient technologies include:

- Waste heat recovery, CHP and avoiding heat loss: insulation of equipment and piping, and heat pumps
- Process design: improving layout and process flows through changing existing plant layout or when designing new plants
- Factories of the future: impact of new trends on food production, e.g. 3D-printing of food closer to the end-user
- New refrigeration technologies

IEEA technologies refer to the Industrial Energy Efficiency Accelerator[13] projects carried out by Carbon Trust and include:

- Mechanical and thermal vapour recompression (MVR and TVR)
- Homogenisation: partial homogenisation, reduced head pressure, and ultrasonic homogenisation
- Increased use of enzymes: to prepare food and limit energy use during production
- Pasteurisation: improved regeneration efficiency, pasteuriser hibernation, low-temperature pasteurisation, UV pasteurisation, tunnel pasteurisation and tunnel optimisation, flash pasteurisation, cold sterile filtration with new filler, UV pasteurisation with new filler, high-pressure pasteurisation, non-thermal pasteurisation, and scorching and scalding
- Cleaning-in-place (CIP): process optimisation, reduction of water volume and temperature, reduction of number of cleanings, avoiding unnecessary cleaning, CIP design, CIP novel technologies and low-temperature detergents, dry ice cleaning, membrane technology, infrastructure loss reduction, optimised set-up and operation, ice pigging and whirlwind pigging, and ultrasonic cleaning
- Microwave drying and heating
- Advanced oven technology: water bath oven (cooking water or using water instead of brine), shower oven, steam oven, hot-air oven, and microwave oven, optimise damper settings, balance oven airflows, direct-drive or no-slip-drive on fans, improved (integrated) oven controls in all circumstances, improved combustion efficiency in ovens (direct- and indirect-fired), oven burner fire rate modulation, high-efficiency ovens, reduction of the baking tin thermal mass, heat recovery from oven, and gas-fired proving
- Dewatering before drying;
- New drying technologies: using less water in the initial product mixture, using starch hybrids, special drying techniques for dairy production, spent-yeast and spent-grains drying, alternative methods for milk powder production, increased product solids before stoving, continuous drying, retrofitting conventional heat pumps, enhanced heat pumps, combined heat pumps, vacuum drying,

[13] The IEEA studies sponsored by Carbon Trust examined six of the food and drink subsectors, accounting for ca. 20% of the sector's energy consumption. If all subsectors would be examined in a similar way, this could unlock further emissions reduction potential across the sector.

superheated steam, di-electric drying (microwave technology), germ de-watering, starch de-watering, fluidised bed dryers, and direct use of gas turbine off-gases

- Fluidised bed dryers

Low-carbon energy sources include:

- Electrification of heat: using low-carbon electricity instead of fossil fuels to lower the CO_2 footprint
- Fuel shift: biomass boilers and CHPs, fuel switching from oil to gas, and burning malting co-products or wood chips
- Biomass and bio-energy

Supply chain options include:

- Food waste reduction
- Packaging reduction: optimal packaging (design, efficiency) and reduction of resources, use of renewable materials in packaging, avoiding re-packaging, food-grade recycling of plastics and increased recycling)
- Supply chain collaboration (avoiding unnecessary handling, treatment, transport through improved collaboration with third parties such as clients, suppliers, etc.).

Carbon capture (CC) is a technique for capturing carbon dioxide emitted from large point sources and compressing it. Carbon capture and storage (CCS) also includes transporting it to a suitable geological storage site where it is injected into a stable geological formation, generally more than one kilometre below the surface. Rather than treating the carbon dioxide as waste (as is the case with CCS), carbon capture and utilisation (CCU) attempts to convert it into commercially saleable products such as bio-oils, chemicals, fertilisers and fuels. This technology is not yet commercialised on a large scale and requires more investigation to demonstrate whether it is commercially viable (CO_2 Chem, 2015). CCU is not considered as an option in this report.

3.5.1 Food Waste

Sending food waste to landfill not only wastes the resources and energy used in their production, but also adds to total greenhouse gas emissions through decomposition (production of methane). Most food waste is generated downstream rather than by manufacturers, and therefore reducing food waste is not considered a significant option to decarbonise the food and drink sector. However, considering food waste in the supply chain is very important, and food and drink companies often want to lead by example in their own operations (FDF, 2014). Food waste reduction is therefore deployed in the pathways modelling (see section 4), but shows only very limited contribution to the decarbonisation potential of the sector.

In 2007, FDF launched its **Five-Fold Environmental Ambition** to improve the food and drink sector's environmental performance. FDF members are working collectively to (i) reduce CO_2 emissions by 35% by 2020 against a 1990 baseline; (ii) achieve zero waste to landfill by 2015; (iii) make a significant contribution to WRAP's Courtauld Commitment (see below); (iv) reduce water use by 20% by 2020 compared to 2007; and (v) achieve fewer food transport miles and contribute to the Logistics Carbon Reduction Scheme target to reduce the carbon intensity of freight operations by 8% by 2015 compared to 2010 (FDF, 2013).

The **Courtauld Commitment** is a voluntary agreement aimed at improving resource efficiency and reducing waste within the UK grocery sector. The commitment was launched in 2005 and is now in its third phase. During the first phase (2005-2009), 1.2 million tonnes of packaging and food waste was prevented, resulting in 3.3 million tonnes of CO2 emissions reduction. Phase 2 (2010-2012) resulted in an additional 1.7 million tonnes of waste reduction, and thereby reducing emissions by 4.8 million tonnes. Phase 3 includes three targets for the sector: (i) to reduce household food and drink waste by 5%; (ii) to reduce traditional grocery ingredient, product and packaging waste in the grocery supply chain by 3%; and (iii) to improve packaging design through the supply chain to maximise the recycled content, improve recyclability and deliver product protection to reduce food waste without increasing the carbon impact of packaging by 2015. Achieving these targets would result in 1.1 million tonnes of waste reduction and 2.9 million tonnes of CO_2 emissions reduction (WRAP, 2015).

Other WRAP initiatives regarding food waste reduction include the 'Hospitality and Food Service Agreement' supporting hotels, hospitals, schools and restaurants; the 'Federation House Commitment' focusing on water savings; the 'Product Sustainability Forum' exploring the environmental impacts of products across their lifecycle; and the 'Love Food Hate Waste' campaign encouraging consumers to waste less. These initiatives bring relevant stakeholders together, aiming to accelerate a change in behavior (WRAP, 2015).

Based on reductions in food waste and related emissions, UK projections state that in the period between 2007 and 2015, around 12 million tonnes of food waste will have been prevented, with a value of ca. £24 million and avoiding approximately 40 million tonnes of CO_2 equivalents (WRAP, 2015).

Data collection on food and packaging waste from FDF members' manufacturing sites was carried out in 2013 to track progress towards FDF's Five-Fold Environmental Ambition target to send zero food and packaging waste to landfill by 2015. The total breakdown of waste management routes used in 2012 was: 37% land-spreading, 28% recycling, 19% thermal treatment with energy recovery, 8% anaerobic digestion, 4% composting, and only 3% landfill. These results show that FDF members are making good progress towards meeting the target (WRAP, 2014).

Food and drink manufacturing frequently produces by-products that are not legally classified as waste (e.g. peelings). FDF members also donate food to charity or send food as an ingredient for use in animal feed, which is also not classified as waste but are termed redistribution. Redistribution provides an alternative to landfill, fully utilizes the resources (including energy) that went into producing these materials, and saves resources that would otherwise have been consumed in the production of animal feed (WRAP, 2014).

3.5.2 Biomass Carbon Intensity

Pathways including biomass reflect biomass carbon intensity (unless the biomass in the pathway is assumed to be waste biomass). The carbon intensities (below) are applied to two scenarios to help reflect and bound the uncertainties around biomass carbon availability; these are (i) unlimited availability – as deployed in the Max Tech pathway or (ii) no availability.

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

Given the wide variation in pre-combustion emissions, a carbon intensity (based on pre-combustion emissions) was derived from a low scenario from the DECC-commissioned Bioenergy Emissions and Counterfactual Model report (published 2014) for modelling purposes. An emission value of 20 kgCO2e/MWh(th) has been used for solid biomass use, and this has been modified to 25 kgCO2e/MWh(th) if the pathways includes pyrolysis, and 30 kgCO2e/MWh(th) if the pathways includes production of biogas.

3.5.3 Cost of Options

Limited information related to the capital cost of technologies was identified in this project as summarised in appendix C. In gathering capital cost-related data, literature or engagement with stakeholders, together with expert judgement, were used to establish an initial order of magnitude dataset for use in the cost analysis assessment. The degree of stakeholder engagement in relation to the cost dataset was lower than for the carbon reduction pathways. Operating costs such as energy use changes, energy costs and labour are not included in this analysis, although we recognise that operating costs will have a major impact on the decarbonisation pathways. For example, some options (e.g. carbon capture and electrification of firing) will greatly increase energy use and costs of a process plant.

Costs analysis was carried out for the pathways, which is presented in section 4. There is a large degree of uncertainty attached to the cost analysis, especially for options which are still in the research and development stage. As well as costs of operation and energy use, other significant costs not included in the analysis are research, development, demonstration, civil works, modifications to plant and costs to other stakeholders, which are significant for many options. Great care must be taken in how these costs are interpreted and it is recommended to check with trade associations.

4. PATHWAYS

4.1 Key Points

The pathways development and analysis shows that the maximum decarbonisation potential of the sector (not taking into account cost) in the current trends scenario, is a reduction to 7.22 Mt CO_2 emitted in 2050 in the maximum technical (Max Tech) pathway, which corresponds to a reduction in emissions of 77% compared with emissions in 2012. Significant reductions of 68.7% and 80.4% could be achieved under challenging world and collaborative growth scenarios respectively. Such reductions have been achieved through a range of options, the most significant being:

- Electrification of heat, which delivers increasing decarbonisation with increasing grid decarbonisation. Electricity grid decarbonisation is a scenario parameter: the higher the rate and magnitude of grid decarbonisation, the more carbon emissions are reduced by this option
- Process design
- Steam production, distribution and end-use
- Packaging reduction
- Biomass and bio-energy

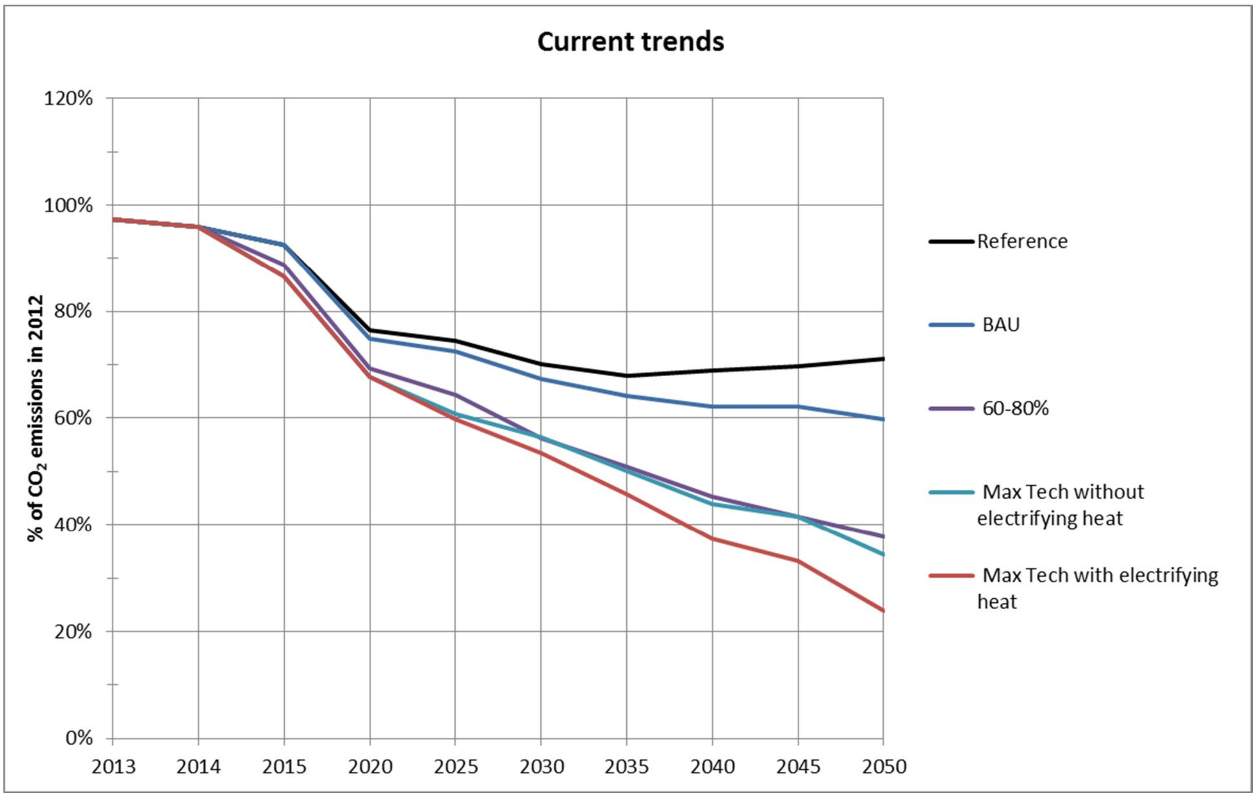

Figure 8: Performance of pathways for the current trends scenario

Figure 8 shows the wide range of decarbonisation and energy efficiency pathways that are possible for the current trends scenario:

- BAU (business as usual) represents a pathway where existing trends in decarbonisation and energy efficiency continue, and technologies are deployed starting in 2020 with most of them deployed to

15-25% by 2050. This pathway is in line with the current CCA for the food and drink sector and aims for savings of 16% (weighed sector average) by the year 2020 (18% FDF companies). Four options have been identified as likely to be deployed to 25-33% by 2050: energy management, utility services, compressed air, and steam.

- 60-80% CO_2 reduction pathway includes an enhanced deployment of all options and some more advanced equipment requiring significant investment. This pathway starts developing biomass and bio-energy from 2020 onwards to a maximum of 33% in 2040.
- Two Max Tech pathways were developed which include deployment of all options: one with and one without electrifying heat. As the technological development of the options in the Max Tech pathways is considered to be very high, these pathways result in the biggest savings.

4.2 Pathways and Scenarios – Introduction and Guide

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

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

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

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

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

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

The methodology is summarised in Figure 9.

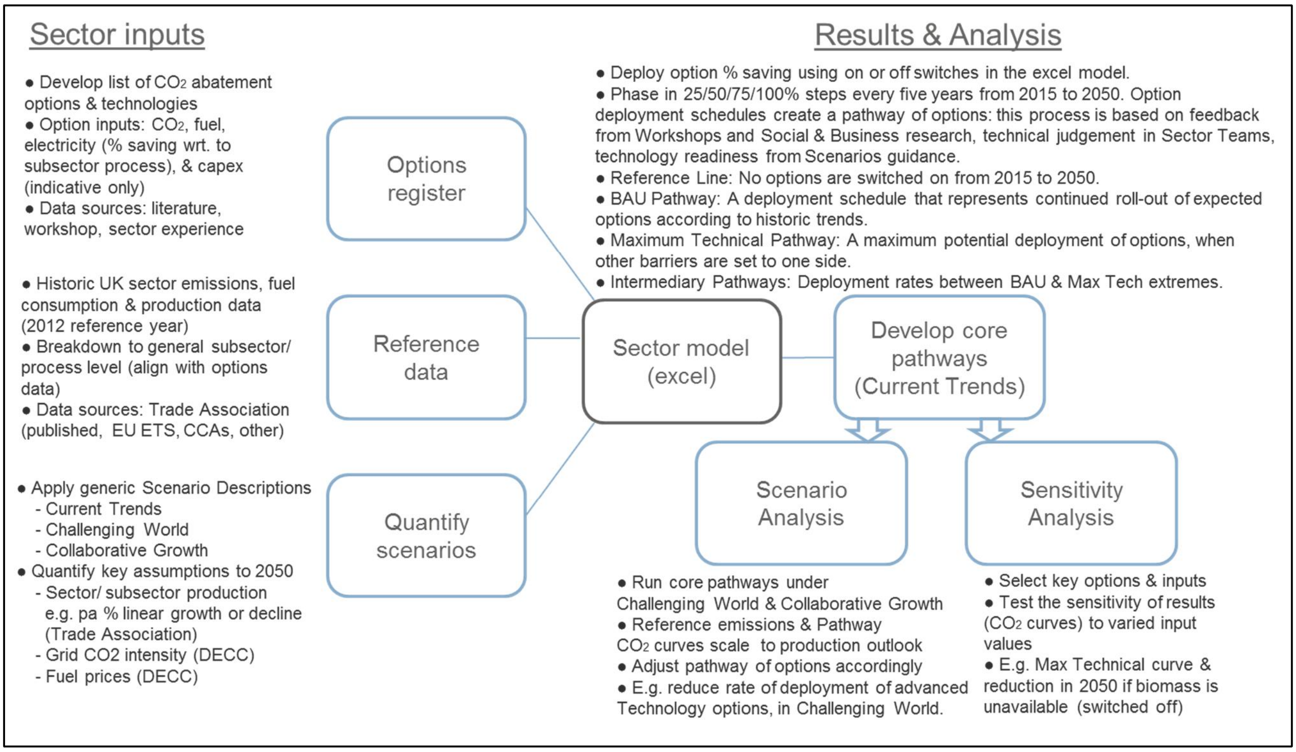

Figure 9: Summary of analysis methodology

This section of the report is structured to present the pathways in the current trends scenario (section 4.4), whilst also briefly describing how the pathways change when modelled under other scenarios. Table 7 illustrates this structure and acts as a guide to the section. Appendix D summarises the pathway analysis in the other two scenarios (challenging world and collaborative growth).

Pathway	Current Trends Scenario	Challenging World Scenario	Collaborative Growth Scenario
Reference Emissions Trend	*Scenario assumptions only linked to production outlook and grid decarbonisation No options deployed in the model*		
BAU	Builds on the reference line by deploying options from 2015 to 2050 in the model, to construct a BAU pathway. Run model under current trends.	Builds on BAU pathway current trends by adjusting option selections and deployment schedule, to reflect the scenario assumptions and technology constraints. Run model under challenging world.	Adjust BAU pathway current trends, i.e. option selections and deployment schedule, to reflect scenario assumptions and technology constraints. Run model under collaborative growth.
20-40%[14]	Builds on BAU for example by: deploying	Builds on 20-40% pathway current trends in	Adjust 20-40% pathway current trends in the

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

	more advanced options, extending further across sector, deploying options earlier. Run under current trends.	the same way. Run under challenging world.	same way. Run under collaborative growth.
40-60%	Builds on 20-40% in the same way. Run under current trends.	Builds on 20-40% pathway current trends in the same way. Run under challenging world.	Adjust 20-40% pathway current trends in the same way. Run under collaborative growth.
60-80%	Builds on 40-60% in the same way. Run model under current trends.	Builds on 40-60% pathway current trends in the same way. Run under challenging world	Adjust 40-60% pathway current trends in the same way. Run under collaborative growth.
Max Tech	Configure a schedule of options from 2015 to 2050 that broadly represents a maximum rate and spread across the sector. Run model under current trends.	Adjust Max Tech pathway current trends in the same way. Run under challenging world.	Adjust Max Tech pathway current trends in the same way. Run under collaborative growth.

Table 7: Pathways and scenarios matrix

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

4.3 Baseline Evolution – Principal Question 3

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

The population in the UK is expected to grow (at a much faster rate than the rest of Europe (Eurostat, 2014), which would increase the total food and drink market. There is assumed to be increased consumption of ready-meals and specialised food (e.g. gluten-free, healthy and local, fast food, halal food, eating out, vegetarian food, etc.). This complex mix of trends is predicted to lead to a very dynamic market, where innovative producers will take the lead in the innovation of the sector.

The evolution of the sector was varied under the three scenarios, using different assumptions of sector growth or decline from 2014 to 2050, based on discussions with FDF:

- Current trends – food and drink production assumed to rise by 1% per annum[15]
- Challenging world – food and drink production assumed flat (0% growth)
- Collaborative growth – food and drink production assumed to rise by 2% per annum

[15] Historically the growth in the food and drink sector has been 0.7%. These scenarios are for illustration purposes only, and do not try to represent reality.

4.4 Emission-Reduction Potential and Pathway Analysis – Principal Questions 4 and 5

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

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

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

The list of enablers and barriers has informed the list of technical options that are being deployed in the different pathways. They also informed the deployment of the different technical options both with regards to time and degree of deployment. For example, the barrier 'risk of not meeting required product quality or changing character' is a typical example of companies being hesitant to implement new energy-efficient technologies. In addition to the growth and decline projections for the different scenarios, the following electricity grid emission factors were used in the modelling:

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

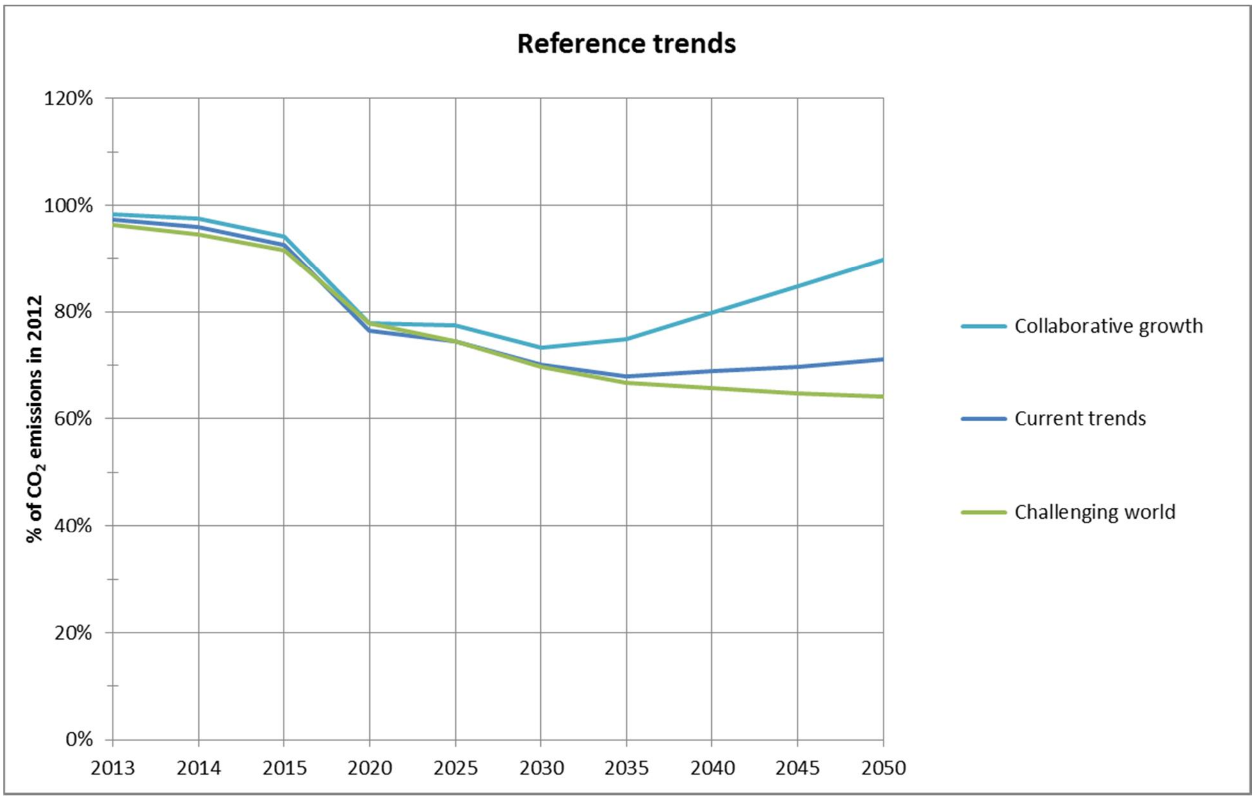

Figure 10: Reference trends for the different scenarios

For all of the pathways, to have the total CO_2 reduction, growth or decline of the sector, indirect (emissions from using electricity from the electricity grid) and direct emissions need to be accounted for. The indirect emissions and growth or decline of the sector are illustrated by the reference trends. In Figure 10, the reference trends for the different scenarios are shown. The shape of the line is linked both to growth and decline of the sector and the different levels of decarbonisation of the electricity grid.

4.4.1 Business as Usual Pathway

Pathway Summary

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

Deployment for the Current Trends Scenario

Figure 11 shows the option deployment for the BAU pathway for the current trends scenario. The first column lists the decarbonisation options on the left. The next two columns are the estimated adoption (ADOPT.) rate in 2012 and the applicability rate (APP.) assumption for the option. The applicability rate indicates to what level this option is applicable to the sector, or its relevant subsector. To the right of the applicability rate column is the actual deployment of the option over time to 2050. The CO_2 savings are estimated based on the direct CO_2 saving assumed for the option for its relevant process, the adoption rate, applicability rate, and deployment.

OPTION	ADOP.	APP.	DEPLOYMENT								
			2014	2015	2020	2025	2030	2035	2040	2045	2050
01 ELECTRIFICATION OF HEAT	10%	90%	0%	0%	0%	0%	0%	0%	0%	0%	0%
02 ENERGY MANAGEMENT & GMP	30%	80%	0%	0%	5%	5%	10%	10%	15%	25%	33%
03 WASTE HEAT RECOVERY / CHP / NO HEAT LOSSES	45%	90%	0%	0%	0%	0%	5%	5%	10%	10%	15%
04 FUEL SHIFT	2%	20%	0%	0%	0%	0%	0%	0%	0%	5%	5%
05 CCS / CCU / CCUS	0%	20%	0%	0%	0%	0%	0%	0%	0%	0%	0%
06 FOOD WASTE REDUCTION	5%	10%	0%	0%	0%	5%	5%	10%	15%	25%	25%
07 PACKAGING REDUCTION	5%	80%	0%	0%	0%	5%	5%	10%	10%	15%	15%
08 SUPPLY CHAIN COLLABORATION	80%	90%	0%	0%	0%	5%	5%	10%	10%	15%	25%
09 MOTORS, PUMPS & DRIVES, HVAC & LIGHTING	20%	100%	0%	0%	5%	10%	15%	15%	25%	25%	33%
10 PROCESS DESIGN	10%	100%	0%	0%	5%	5%	5%	10%	15%	15%	20%
11 FACTORIES OF THE FUTURE	0%	25%	0%	0%	0%	0%	0%	0%	0%	0%	5%
12 COMPRESSED AIR	20%	100%	0%	0%	5%	5%	10%	10%	25%	25%	33%
13 BIOMASS / BIOENERGY	0%	50%	0%	0%	0%	0%	0%	0%	5%	5%	10%
14 MVR & TVR	25%	75%	0%	0%	0%	0%	0%	0%	0%	0%	5%
15 ULTRASONIC HOMOGENISATION	0%	25%	0%	0%	0%	0%	0%	0%	0%	0%	5%
16 INCREASED USE OF ENZYMES TO PREPARE FOOD	0%	50%	0%	0%	0%	0%	0%	0%	0%	5%	10%
17 NEW REFRIGERATION TECHNOLOGIES	20%	95%	0%	0%	0%	0%	5%	10%	15%	25%	25%
18 PASTEURISATION	0%	50%	0%	0%	0%	0%	0%	0%	0%	5%	10%
19 CLEANING (CIP)	50%	100%	0%	0%	0%	0%	0%	0%	0%	5%	10%
20 STEAM PRODUCTION, DISTRIBUTION & END USE	20%	100%	0%	0%	5%	5%	10%	10%	15%	15%	25%
21 MICROWAVE DRYING AND HEATING	5%	25%	0%	0%	0%	0%	0%	0%	0%	5%	10%
22 ADVANCED OVEN TECHNOLOGY	15%	90%	0%	0%	0%	0%	0%	0%	0%	0%	10%
23 DEWATERING BEFORE DRYING	20%	80%	0%	0%	0%	0%	0%	0%	10%	15%	25%
24 NEW DRYING TECHNOLOGIES	10%	70%	0%	0%	0%	0%	0%	0%	0%	5%	10%
25 FLUIDISED BED DRYERS	0%	10%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Figure 11: Option deployment for the BAU pathway, current trends scenario

In this pathway, the principal options that contribute to the emissions reduction in 2050 are (Figure 12):

- **Process design**: deployed to 20% in 2050, accounting for 31.5% of the total emissions reduction from deployment of options in 2050

- **Biomass and bio-energy**: deployed to 10% in 2050, accounting for 28.0% of the total emissions reduction from deployment of options in 2050
- **Steam production, distribution and end-use**: deployed to 25% in 2050, accounting for 17.9% of the total emissions reduction from deployment of options in 2050

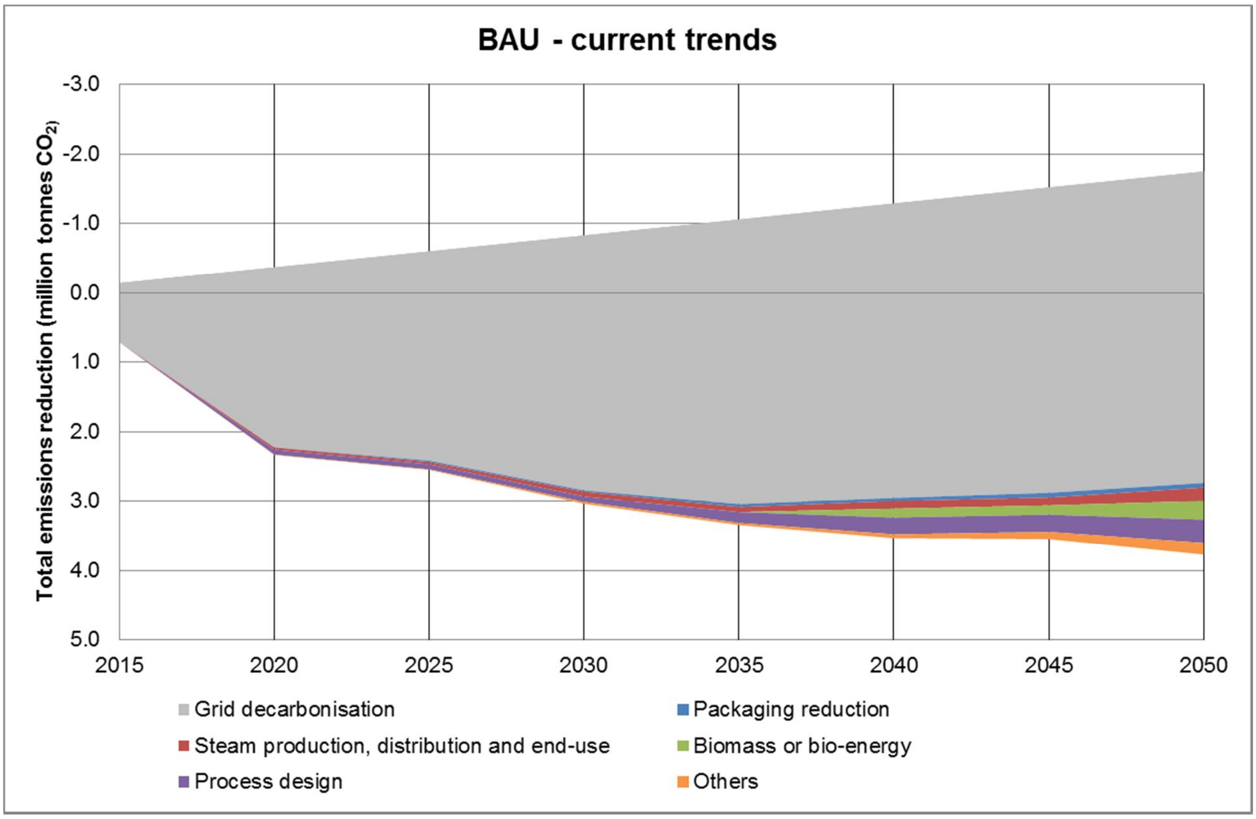

Figure 12: Contribution of principal options to the absolute emissions reduction throughout study period, for the BAU pathway, current trends scenario

For the current trends scenario, the options deployed in the BAU pathway give an overall reduction of 41% in 2050, compared to 2012. This includes the emission reductions linked to the deployment of options and decarbonisation of the grid.

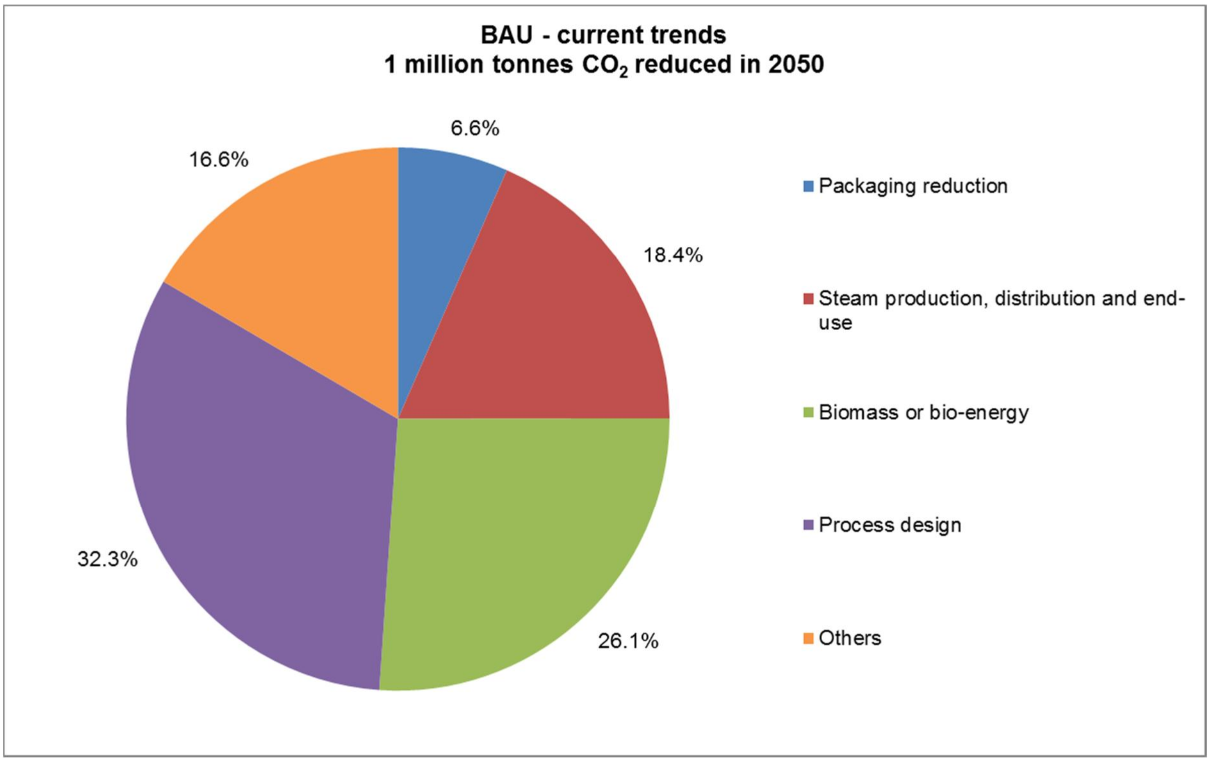

Figure 13: Breakdown of 2050 emissions reduction, for the BAU pathway, current trends scenario

The CO_2 emissions reduction contribution in 2050 revealed that the most of the carbon savings in BAU came from a few key options[16]: process design; biomass and bio-energy; and steam production, distribution and end-use (Figure 13).

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

Option Deployment for other Scenarios

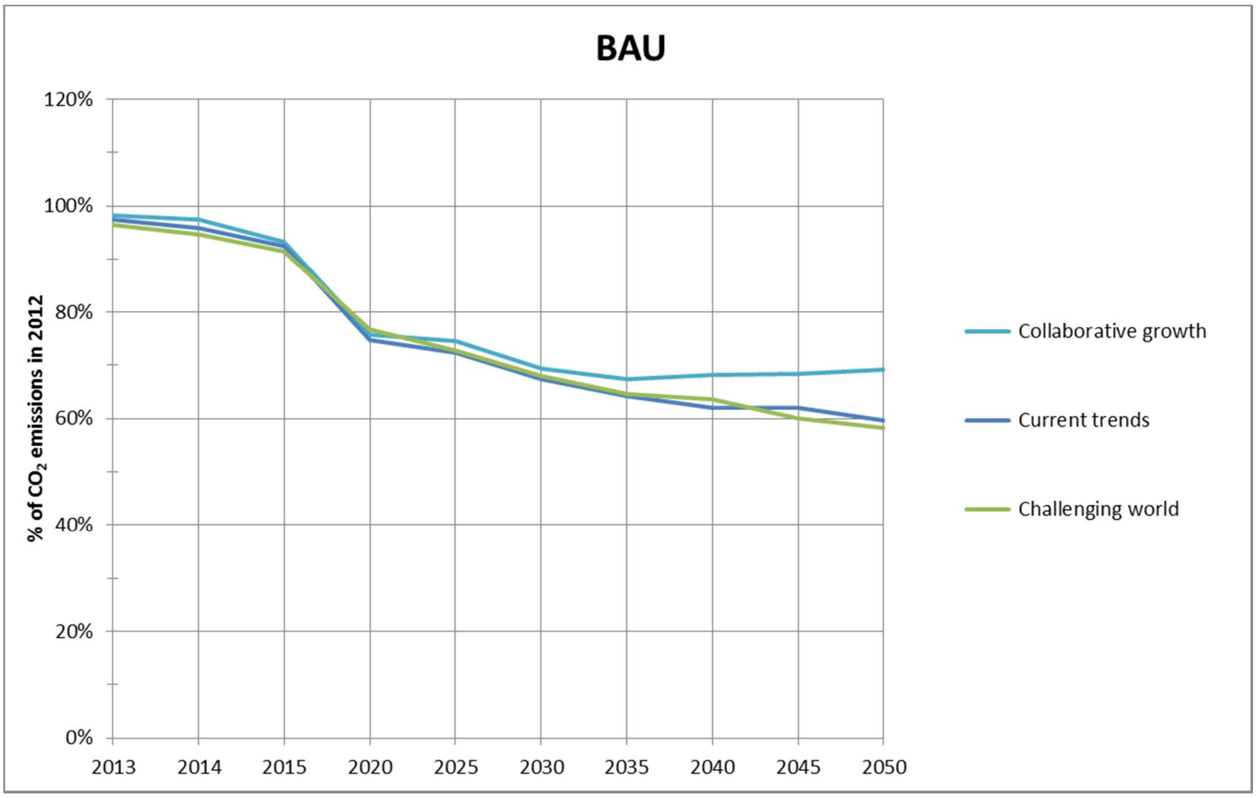

Figure 14: BAU pathways for the different scenarios

Figure 14 shows the BAU pathways for the different scenarios. As can be seen, the current trends scenario delivers an overall CO_2 reduction of 41%, the challenging world scenario delivers an overall CO_2 reduction of 42%, and the collaborative growth scenario delivers an overall CO_2 reduction of 31% compared to 2012.

In the challenging world scenario, all options of the BAU pathway included under the current trends scenario were deployed with a later starting point, thus not reaching the same deployment as is the case in the current trends scenario. The reduction in CO_2 emissions was mainly driven by the different production output forecast compared to the other scenarios.

In the collaborative growth scenario, all options included under the current trends scenario were deployed with an earlier starting point (or a higher pick-up rate), reflecting the assumed rate at which the sector could adopt new technologies in this scenario. Also, electrifying heat is developed at a higher rate, as the lower carbon footprint of the grid is assumed to be an extra stimulant for this option.

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

4.4.2 60-80% CO_2 Reduction Pathway

Pathway Summary

The BAU pathway reaches over 40% CO_2 reduction compared to 2012 for both the current trends and challenging world scenarios. Therefore, no additional pathways for the 20-40% CO_2 reduction band and the 40-60% CO_2 reduction band were developed (also not for the collaborative growth scenario).

60-80% CO_2 reduction pathway under current trends shows a rapid deployment of options compared to BAU. The main difference in this pathway is the deployment of biomass, which starts at 5% in 2020 and reaches its maximum of 33% in 2040. Biomass was chosen as it is a carbon-neutral technology that is available today and has good potential for development. The maximum deployment of 33% was agreed as a reasonable maximum limit, considering the limited actual potential in the UK for biomass use as a fuel in food and drink sector manufacturing.

Deployment for the Current Trends Scenario

Figure 15 shows the option deployment for the 60-80% CO_2 reduction pathway for the current trends scenario. The pathway includes biomass specifically as an early adopted technology. This shows a big biomass and bio-energy deployment, from 5% in 2020 to a maximum of 33% in 2030. The four food and drink CCA options (energy management, utilities, compressed air, and steam) are deployed to 75% in 2050. It is assumed that some sites may not implement higher-cost options (or those options that may be disruptive to the operation of the plant), so the deployment of these technologies has been assumed to only reach 75%.

OPTION	ADOP.	APP.	DEPLOYMENT								
			2014	2015	2020	2025	2030	2035	2040	2045	2050
01 ELECTRIFICATION OF HEAT	10%	90%	0%	0%	0%	0%	0%	0%	5%	5%	10%
02 ENERGY MANAGEMENT & GMP	30%	80%	0%	10%	10%	25%	25%	33%	33%	50%	75%
03 WASTE HEAT RECOVERY / CHP / NO HEAT LOSSES	45%	90%	0%	5%	10%	10%	25%	25%	33%	33%	50%
04 FUEL SHIFT	2%	20%	0%	0%	0%	5%	10%	10%	25%	25%	33%
05 CCS / CCU / CCUS	0%	20%	0%	0%	0%	0%	0%	0%	0%	5%	10%
06 FOOD WASTE REDUCTION	5%	10%	0%	10%	10%	25%	25%	33%	33%	50%	50%
07 PACKAGING REDUCTION	5%	80%	0%	5%	10%	10%	15%	15%	25%	25%	33%
08 SUPPLY CHAIN COLLABORATION	80%	90%	0%	0%	10%	10%	25%	25%	33%	33%	50%
09 MOTORS, PUMPS & DRIVES, HVAC & LIGHTING	20%	100%	0%	15%	15%	25%	25%	33%	33%	50%	75%
10 PROCESS DESIGN	10%	100%	0%	5%	15%	20%	30%	30%	38%	55%	55%
11 FACTORIES OF THE FUTURE	0%	25%	0%	0%	0%	5%	10%	25%	25%	33%	33%
12 COMPRESSED AIR	20%	100%	0%	10%	25%	25%	33%	33%	50%	50%	75%
13 BIOMASS / BIOENERGY	0%	50%	0%	0%	5%	10%	15%	25%	33%	33%	33%
14 MVR & TVR	25%	75%	0%	0%	0%	0%	0%	10%	10%	25%	25%
15 ULTRASONIC HOMOGENISATION	0%	25%	0%	0%	0%	0%	5%	10%	25%	33%	33%
16 INCREASED USE OF ENZYMES TO PREPARE FOOD	0%	50%	0%	0%	0%	0%	10%	15%	25%	25%	33%
17 NEW REFRIGERATION TECHNOLOGIES	20%	95%	0%	0%	10%	10%	15%	25%	25%	33%	33%
18 PASTEURISATION	0%	50%	0%	0%	0%	0%	5%	10%	25%	25%	33%
19 CLEANING (CIP)	50%	100%	0%	0%	5%	10%	25%	25%	33%	33%	50%
20 STEAM PRODUCTION, DISTRIBUTION & END USE	20%	100%	0%	10%	10%	15%	15%	25%	33%	50%	75%
21 MICROWAVE DRYING AND HEATING	5%	25%	0%	0%	0%	5%	10%	25%	33%	33%	50%
22 ADVANCED OVEN TECHNOLOGY	15%	90%	0%	0%	0%	5%	10%	25%	25%	33%	33%
23 DEWATERING BEFORE DRYING	20%	80%	0%	5%	10%	10%	25%	25%	33%	33%	50%
24 NEW DRYING TECHNOLOGIES	10%	70%	0%	0%	0%	5%	10%	25%	25%	33%	50%
25 FLUIDISED BED DRYERS	0%	10%	0%	0%	0%	0%	5%	10%	25%	33%	33%

Figure 15: Option deployment for the 60-80% CO_2 reduction pathway, current trends scenario

In this pathway, the principal options that contribute to the emissions reduction in 2050 are (Figure 16):

- **Biomass and bio-energy**: deployed to 33% of sector potential in 2040, accounting for 25.9% of the total emissions reduction from deployment of options in 2050
- **Process design**: deployed to 30% in 2030 and to 55% in 2050, accounting for 24.3% of the total emissions reduction from deployment of options in 2050
- **Steam production, distribution and end-use**: gradually deployed to 15% in 2030 and 75% in 2050, accounting for 15.1% of the total emissions reduction from deployment of options in 2050
- **Electrification of heat**: although only deployed to 10% in 2050, accounting for 14.1% of the total emissions reduction from deployment of options in 2050

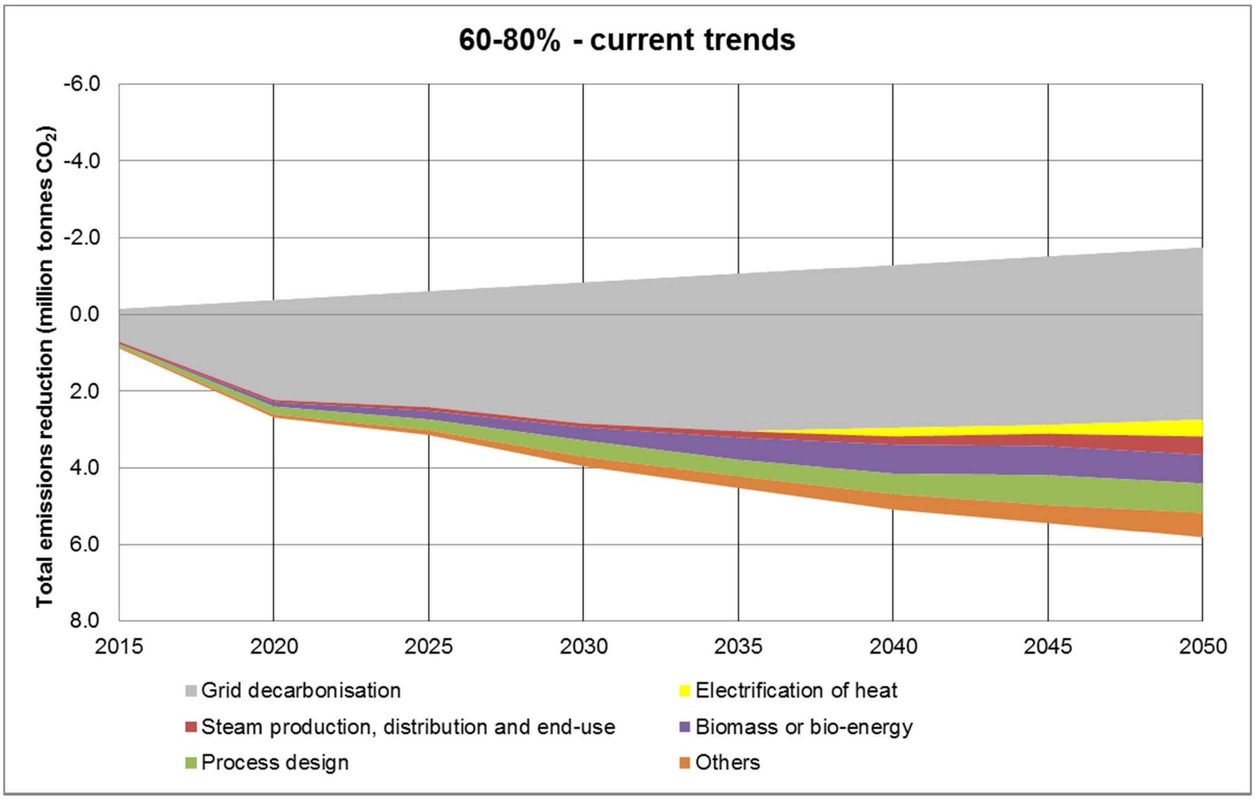

Figure 16: Contribution of principal options to the absolute emissions reduction throughout study period, for the 60-80% CO_2 reduction pathway, current trends scenario

For the current trends scenario, this pathway gives an overall reduction of 63% in 2050, compared to 2012. This includes the emission reductions linked to the deployment of options and decarbonisation of the grid.

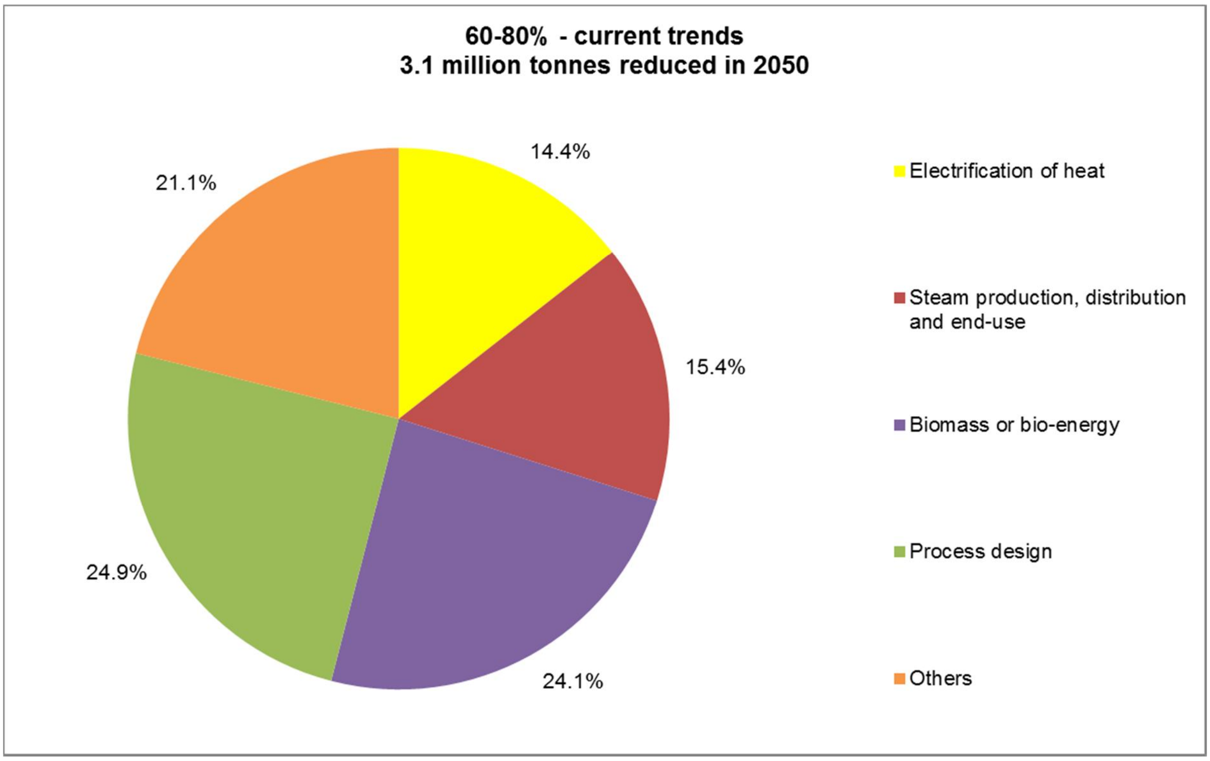

Figure 17: Breakdown of 2050 emissions reduction, for the 60-80% CO_2 reduction pathway, current trends scenario

Most of the CO_2 emissions reduction contributions in 2050 come from: biomass and bio-energy; process design; steam production, distribution and end-use; and electrification of heat (Figure 17).

Option Deployment for other Scenarios

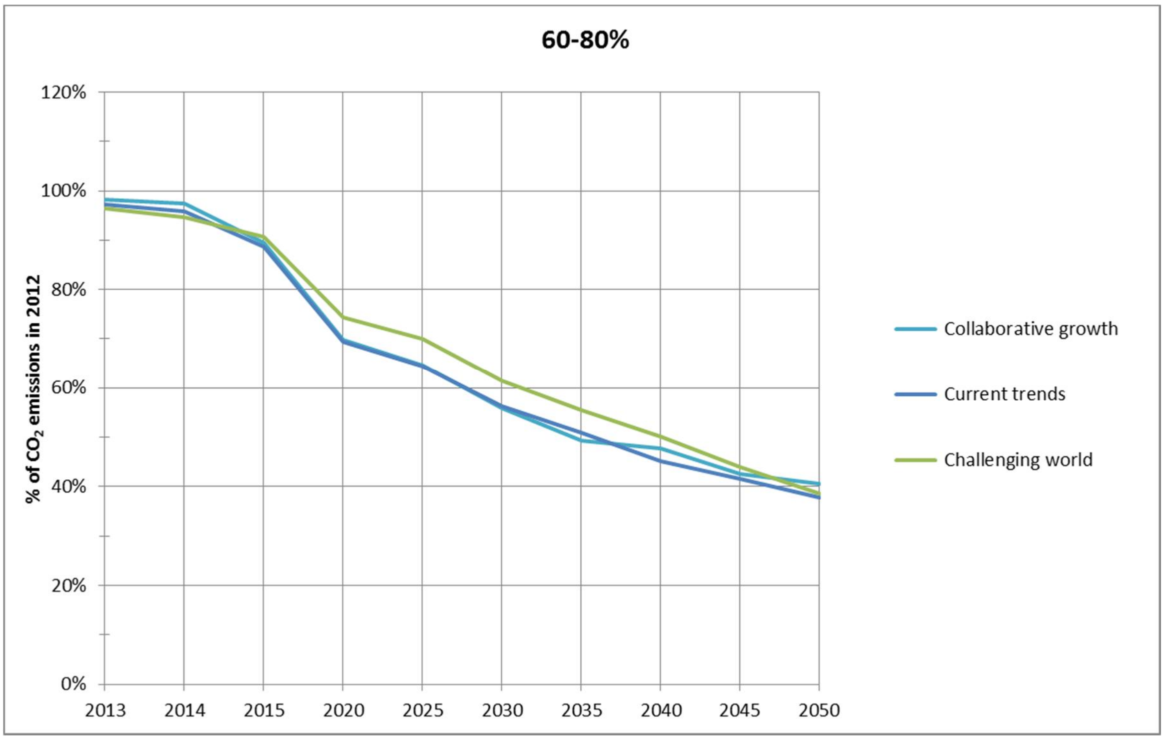

Figure 18: 60-80% CO_2 reduction pathways for the different scenarios

Figure 18 shows the 60-80% CO_2 reduction pathways for the different scenarios. As can be seen, the current trends scenario delivers an overall CO_2 reduction of 63%, the challenging world scenario delivers an overall CO_2 reduction of 62%, and the collaborative growth scenario delivers an overall CO_2 reduction of 60% compared to 2012.

In the challenging world scenario, the biomass deployment is kept at the same rate, while the other options are developing at a later stage (typically shifted five years into the future). The total reduction of CO_2 emissions for this scenario is 61.9% in 2050 compared to 2012.

In the collaborative growth scenario, the biomass deployment is kept at the same rate, while the other options start to develop at an earlier stage (typically shifted five years into the future). The total reduction of CO_2 emissions for this scenario is 60.1% compared to 2012.

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

4.4.3 Maximum Technical Pathway without Electrifying Heat

Pathway Summary

The Max Tech pathway without electrifying heat for the current trends scenario results in a 66% CO_2 reduction for the sector compared to 2012. This pathway has all options deployed to at least 33%, except electrifying heat, which is kept at zero. This represents the maximum possible decarbonisation in a case where there is no trend towards electrifying heat.

Deployment for the Current Trends Scenario

Figure 19 shows the option deployment for the Max Tech pathway without electrifying heat for the current trends scenario. The four CCA options (energy management, utilities services, steam, and compressed air) are assumed to be extensively deployed in the sector at rates to reach 50% in 2040 and 100% in 2050. Other options reaching a high level of deployment are waste-heat recovery, CHP and avoiding heat losses; process design; factories of the future; cleaning (CIP); dewatering before drying; and new drying technologies.

OPTION	ADOP.	APP.	DEPLOYMENT 2014	2015	2020	2025	2030	2035	2040	2045	2050
01 ELECTRIFICATION OF HEAT	10%	90%	0%	0%	0%	0%	0%	0%	0%	0%	0%
02 ENERGY MANAGEMENT & GMP	30%	80%	0%	10%	25%	25%	33%	33%	50%	75%	100%
03 WASTE HEAT RECOVERY / CHP / NO HEAT LOSSES	45%	90%	0%	10%	25%	25%	33%	33%	50%	50%	75%
04 FUEL SHIFT	2%	20%	0%	0%	5%	10%	10%	25%	33%	50%	50%
05 CCS / CCU / CCUS	0%	20%	0%	0%	0%	0%	0%	0%	5%	5%	10%
06 FOOD WASTE REDUCTION	5%	10%	0%	10%	25%	25%	33%	33%	50%	50%	75%
07 PACKAGING REDUCTION	5%	80%	0%	5%	10%	15%	15%	25%	25%	33%	33%
08 SUPPLY CHAIN COLLABORATION	80%	90%	0%	10%	10%	25%	25%	33%	33%	50%	50%
09 MOTORS, PUMPS & DRIVES, HVAC & LIGHTING	20%	100%	0%	10%	15%	25%	33%	50%	50%	75%	100%
10 PROCESS DESIGN	10%	100%	0%	10%	20%	30%	30%	38%	55%	55%	80%
11 FACTORIES OF THE FUTURE	0%	25%	0%	0%	5%	10%	25%	25%	33%	50%	75%
12 COMPRESSED AIR	20%	100%	0%	15%	25%	33%	33%	50%	50%	75%	100%
13 BIOMASS / BIOENERGY	0%	50%	0%	0%	0%	5%	5%	10%	25%	25%	33%
14 MVR & TVR	25%	75%	0%	0%	0%	0%	10%	10%	25%	25%	50%
15 ULTRASONIC HOMOGENISATION	0%	25%	0%	0%	0%	5%	10%	25%	33%	33%	50%
16 INCREASED USE OF ENZYMES TO PREPARE FOOD	0%	50%	0%	0%	0%	10%	15%	25%	25%	33%	33%
17 NEW REFRIGERATION TECHNOLOGIES	20%	95%	0%	10%	10%	25%	25%	33%	33%	50%	50%
18 PASTEURISATION	0%	50%	0%	0%	0%	5%	10%	25%	25%	33%	33%
19 CLEANING (CIP)	50%	100%	0%	5%	10%	25%	25%	33%	33%	50%	75%
20 STEAM PRODUCTION, DISTRIBUTION & END USE	20%	100%	0%	15%	25%	33%	33%	50%	50%	75%	100%
21 MICROWAVE DRYING AND HEATING	5%	25%	0%	0%	5%	10%	25%	33%	33%	50%	50%
22 ADVANCED OVEN TECHNOLOGY	15%	90%	0%	0%	5%	10%	25%	25%	33%	33%	50%
23 DEWATERING BEFORE DRYING	20%	80%	0%	10%	10%	25%	25%	33%	33%	50%	75%
24 NEW DRYING TECHNOLOGIES	10%	70%	0%	0%	5%	10%	25%	25%	33%	50%	75%
25 FLUIDISED BED DRYERS	0%	10%	0%	0%	0%	5%	10%	25%	33%	33%	50%

Figure 19: Option deployment for the Max Tech pathway without electrifying heat

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

- **Process design**: deployed to 30% in 2030 and increasing to 80% in 2050, accounting for 32.5% of the total emissions reduction from deployment of options in 2050
- **Biomass and bio-energy**: deployed to 33% in 2050, accounting for 23.8% of the total emissions reduction from deployment of options in 2050
- **Steam production, distribution and end-use**: deployed from 25% in 2020 to 100% in 2050, accounting for 18.5% of the total emissions reduction from deployment of options in 2050

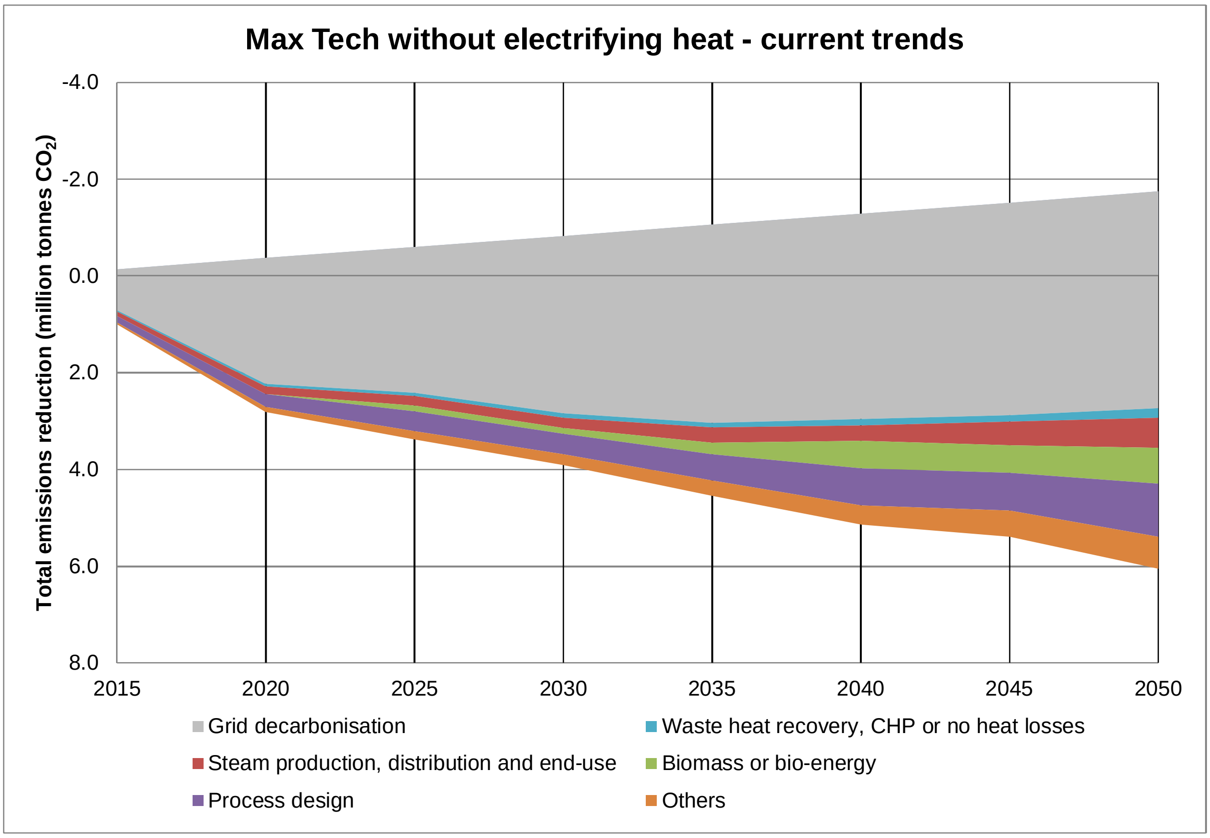

Figure 20: Contribution of principal options to the absolute savings throughout the study period, for the Max Tech pathway without electrifying heat, current trends scenario

For the current trends scenario, this pathway gives an overall reduction of 66% in 2050, compared to 2012. This includes the emission reductions linked to the deployment of options and decarbonisation of the grid.

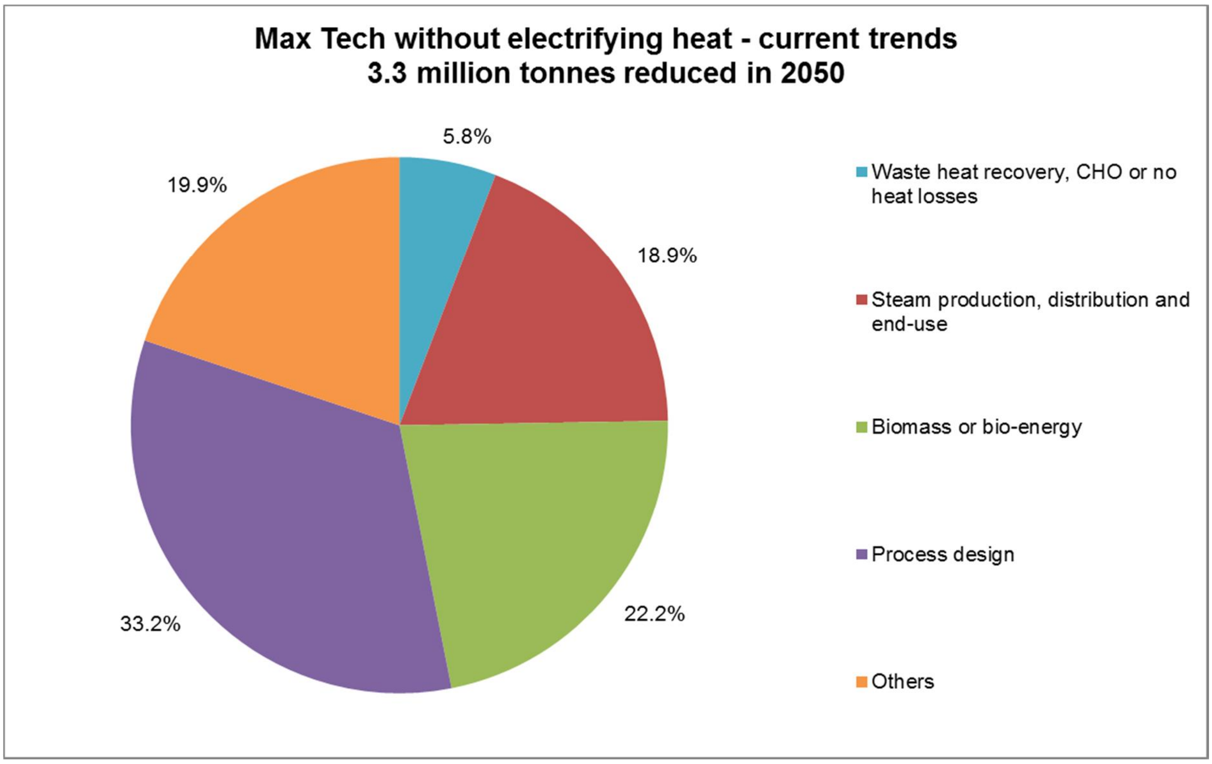

Figure 21: Breakdown of 2050 emissions reduction, for the Max Tech pathway without electrifying heat, current trends scenario

Most of the CO_2 emissions reduction contributions in 2050 come from: process design; biomass and bio-energy; and steam production, distribution and end-use (Figure 21).

Option Deployment for Other Scenarios

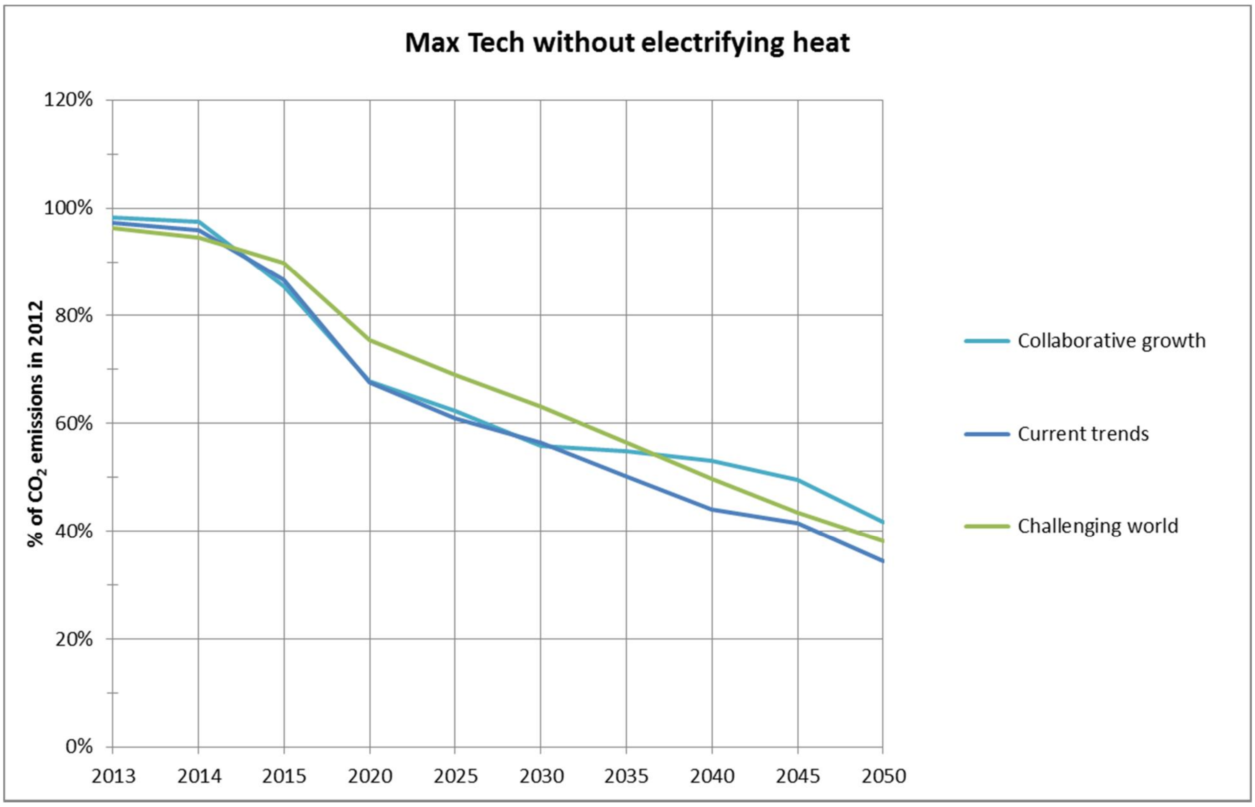

Figure 22: Max Tech pathway without electrifying heat for the different scenarios

Figure 22 shows the Max Tech pathways without electrifying heat for the different scenarios. As can be seen, the current trends scenario delivers a CO_2 reduction of 66%, the challenging world scenario delivers a CO_2 reduction of 62%, and the collaborative growth scenario delivers CO_2 reduction of 59%.

For the challenging world scenario, all options are deployed at a slower rate. The steam option is only deployed at 50% (compared to 75% of the other CCA options), because of the big investment cycle for boilers and steam-producing equipment.

In the collaborative growth scenario, all options are deployed for at least 33% (except CC (25%), because of discussions during the workshop). Again, all options are estimated to start early and deploy to a very high rate. The total reduction of CO_2 emissions for this scenario is 59.1% in 2050 compared to 2012.

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

4.4.4 Maximum Technical Pathway with Electrifying Heat

Pathway Summary

The Max Tech pathway with electrifying heat for the current trends scenario results in a 77% CO_2 reduction for the sector compared to 2012. This pathway is a copy of the Max Tech pathway without electrifying heat, but now with the option of electrifying deployed.

Deployment for the Current Trends Scenario

Figure 23 shows the option deployment for the Max Tech pathway with electrifying heat for the current trends scenario. The big difference with the Max Tech pathway without electrifying heat is that the grid now not only shows the development of the CO_2 emissions reduction per option, but also takes into account the effect electrification of heat has on the options that will be affected by electrifying heat. This means that all fossil fuel options will be affected and their emissions reduction will be reduced, to avoid double counting.

OPTION	ADOP.	APP.	DEPLOYMENT 2014	2015	2020	2025	2030	2035	2040	2045	2050
01 ELECTRIFICATION OF HEAT	10%	90%	0%	0%	0%	5%	10%	15%	25%	33%	50%
02 ENERGY MANAGEMENT & GMP	30%	80%	0%	10%	25%	25%	33%	33%	50%	75%	100%
03 WASTE HEAT RECOVERY / CHP / NO HEAT LOSSES	45%	90%	0%	10%	25%	24%	30%	28%	38%	34%	38%
04 FUEL SHIFT	2%	20%	0%	0%	5%	10%	9%	21%	25%	34%	25%
05 CCS / CCU / CCUS	0%	20%	0%	0%	0%	0%	0%	0%	4%	3%	5%
06 FOOD WASTE REDUCTION	5%	10%	0%	10%	25%	24%	30%	28%	38%	34%	38%
07 PACKAGING REDUCTION	5%	80%	0%	5%	10%	14%	14%	21%	19%	22%	17%
08 SUPPLY CHAIN COLLABORATION	80%	90%	0%	10%	10%	25%	25%	33%	33%	50%	50%
09 MOTORS, PUMPS & DRIVES, HVAC & LIGHTING	20%	100%	0%	10%	15%	25%	33%	50%	50%	75%	100%
10 PROCESS DESIGN	10%	100%	0%	10%	20%	30%	30%	38%	55%	55%	80%
11 FACTORIES OF THE FUTURE	0%	25%	0%	0%	5%	10%	25%	25%	33%	50%	75%
12 COMPRESSED AIR	20%	100%	0%	15%	25%	33%	33%	50%	50%	75%	100%
13 BIOMASS / BIOENERGY	0%	50%	0%	0%	0%	5%	5%	10%	25%	25%	33%
14 MVR & TVR	25%	75%	0%	0%	0%	0%	10%	10%	25%	25%	50%
15 ULTRASONIC HOMOGENISATION	0%	25%	0%	0%	0%	5%	10%	25%	33%	33%	50%
16 INCREASED USE OF ENZYMES TO PREPARE FOOD	0%	50%	0%	0%	0%	10%	14%	21%	19%	22%	17%
17 NEW REFRIGERATION TECHNOLOGIES	20%	95%	0%	10%	10%	25%	25%	33%	33%	50%	50%
18 PASTEURISATION	0%	50%	0%	0%	0%	5%	9%	21%	19%	22%	17%
19 CLEANING (CIP)	50%	100%	0%	5%	10%	24%	23%	28%	25%	34%	38%
20 STEAM PRODUCTION, DISTRIBUTION & END USE	20%	100%	0%	15%	25%	31%	30%	43%	38%	50%	50%
21 MICROWAVE DRYING AND HEATING	5%	25%	0%	0%	5%	10%	25%	33%	33%	50%	50%
22 ADVANCED OVEN TECHNOLOGY	15%	90%	0%	0%	5%	10%	23%	21%	25%	22%	25%
23 DEWATERING BEFORE DRYING	20%	80%	0%	10%	10%	24%	23%	28%	25%	34%	38%
24 NEW DRYING TECHNOLOGIES	10%	70%	0%	0%	5%	10%	23%	21%	25%	34%	38%
25 FLUIDISED BED DRYERS	0%	10%	0%	0%	0%	5%	9%	21%	25%	22%	25%

Figure 23: Option deployment for the Max Tech pathway with electrifying heat

In this pathway, the principal options that contribute to the emissions reduction in 2050 are (Figure 24):

- **Electrifying heat**: deployed to 5% in 2030 and increasing to 50% in 2050, accounting for 44.3% of the total emissions reduction from deployment of options in 2050
- **Process design:** starts at 10% in 2015, and builds up to 80% in 2050, accounting for 22% of the total emissions reduction from deployment of options in 2050
- **Biomass and bio-energy**: not affected by electrifying heat, starts with 5% in 2025 and deploys to 33% in 2050, accounting for 16.3% of the total emissions reduction from deployment of options in 2050

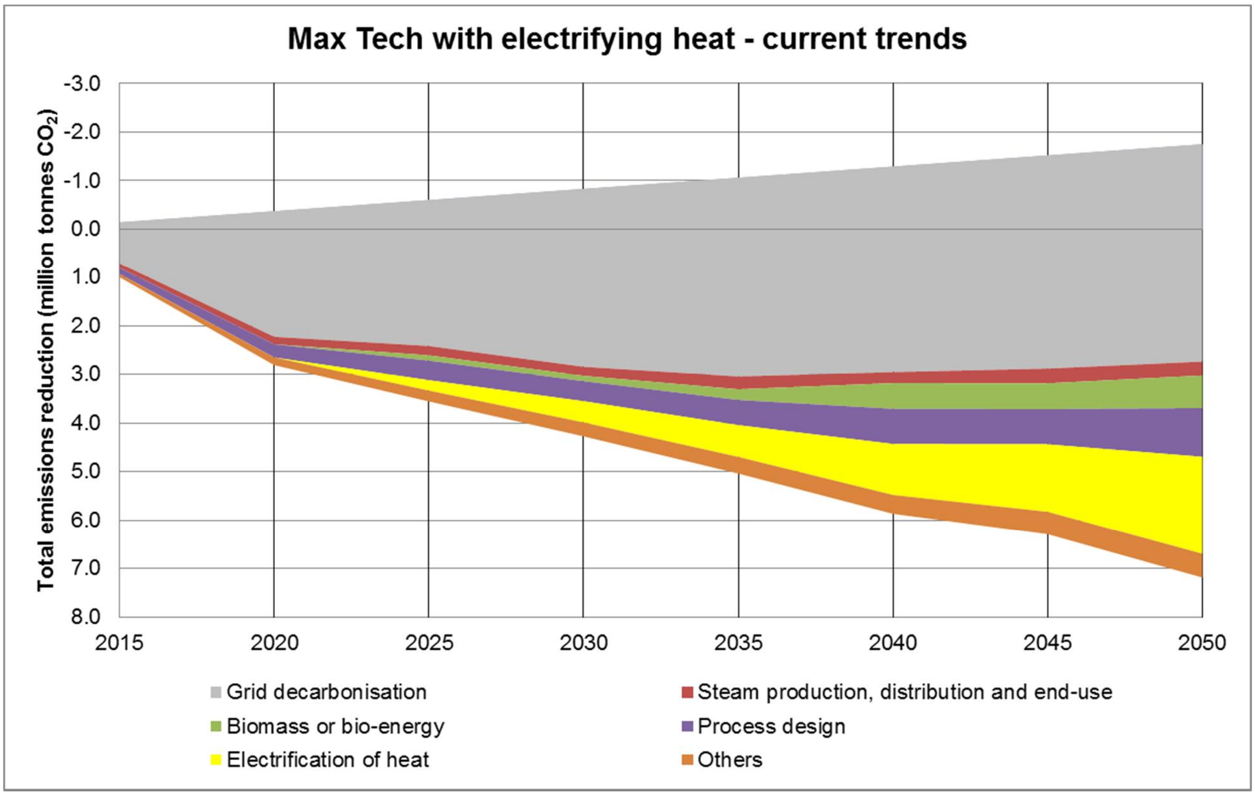

Figure 24: Contribution of principal options to the absolute savings throughout the study period, for the Max Tech pathway with electrifying heat, current trends scenario

For the current trends scenario, this pathway gives an overall reduction of 76.7% in 2050, compared to 2012. As the net contribution of the grid in 2050 is zero, there is no effect on the total emissions reduction.

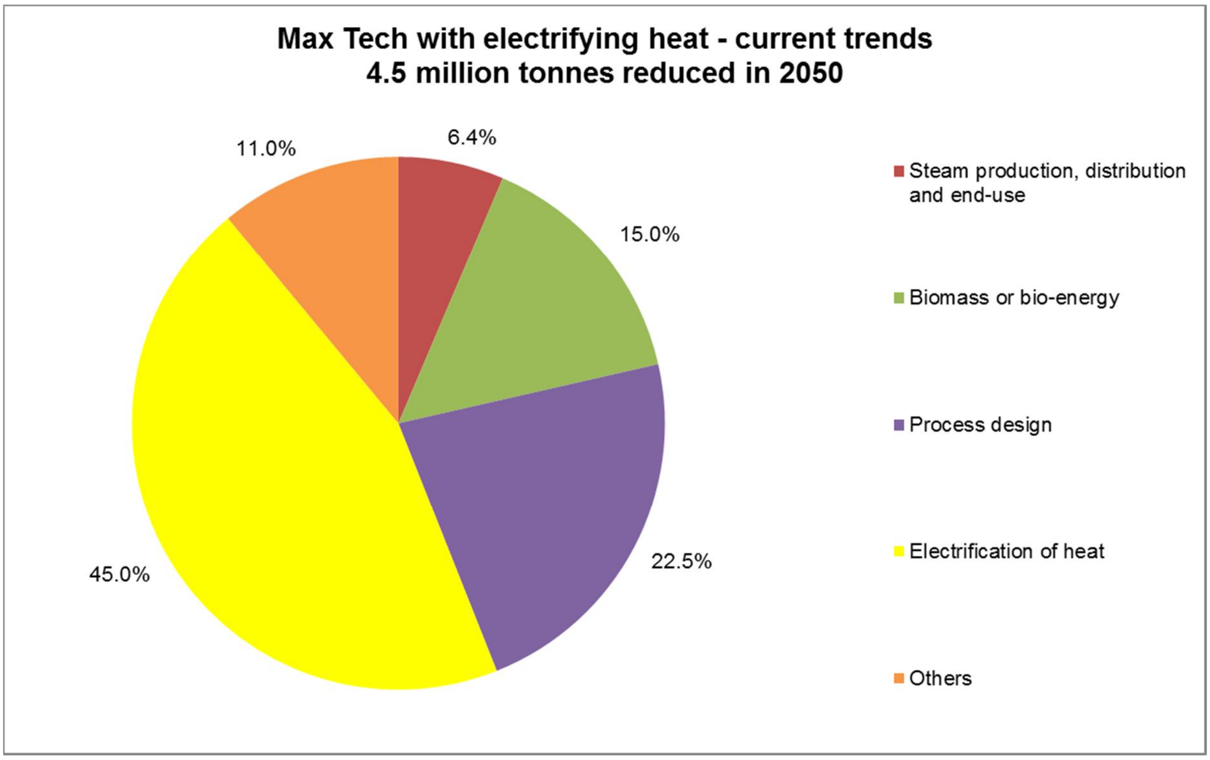

Figure 25: Breakdown of 2050 emissions reduction, for the Max Tech pathway with electrifying heat, current trends scenario

Most of the CO_2 emissions reduction contributions in 2050 come from: electrification of heat; process design; and biomass and bio-energy (Figure 25). This pathway would also have additional revenue streams by participating in demand response and capacity markets[17]. Participating in demand response for a food manufacturer might have other barriers than the ones considered in this work. This should be evaluated further. The financial benefits and operational considerations of participation in such a market have not been considered here. The grid decarbonisation is a very important factor in this pathway.

[17] Demand response relates to any programme that encourages a shift of (demand of) energy by end-consumers. Participation of these end-consumers is a response to factors such as incentive pricing, new tariff schemes, greater awareness and an increases sense of responsibility. Participation may involve active behavioural changes or passive responses, through the use of automation (ENA and Energy UK, 2012). The Capacity Market is part of the UK government's Electricity Market Reform package, and aims to ensure security of electricity supply by providing a payment for reliable sources of capacity (DECC, 2014).

Option Deployment for Other Scenarios

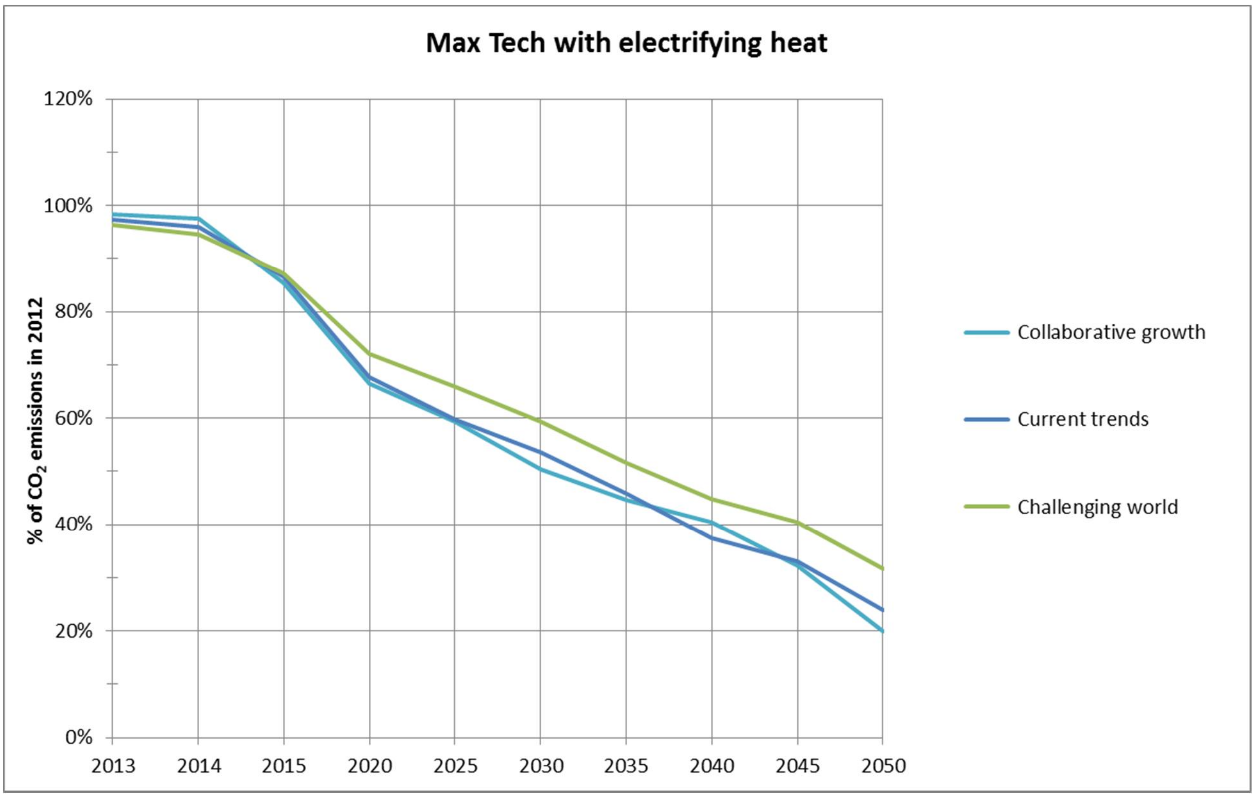

Figure 26: Max Tech pathway with electrifying heat for the different scenarios

Figure 26 shows the Max Tech pathways with electrifying heat for the different scenarios. As can be seen, the current trends scenario delivers a CO_2 reduction of 77%, the challenging world scenario delivers a CO_2 reduction of 69%, and the collaborative growth scenario delivers CO_2 reduction of 80%.

For the challenging world scenario, the options are deployed at a slower rate compared to the current trends scenario.

In the collaborative growth scenario, all options included under the current trends scenario were deployed at a sooner point in time as in the current trends scenario. The total reduction of CO_2 emissions for this scenario is 80.4% in 2050 compared to 2012.

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

4.5 Sensitivity Analysis

The Max Tech (no electrification of heat) pathway described above illustrates the sensitivity of the pathways to the use of this technology.

In the option interaction calculation, the 'no interaction' case adds approximately 20% to the carbon reduction in 2050 in the Max Tech pathway.

4.6 Pathway Costs

4.6.1 Introduction

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

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

4.6.2 Calculation of Pathway Costs

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

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

various pathways are adjusted for the time value of money, so costs (which occur at different points in time) are expressed on a common basis in terms of their 'net present value' using the discount rate of 3.5%. The effect of this standard methodology is to reduce the apparent cost of large investments that are deployed in the pathways later in the study period.

The following specific assumptions apply:

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

4.6.3 Limitations

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

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

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

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

4.6.4 Cost Analysis Results

The results of the cost analysis of decarbonisation for the various pathways within the current trends scenario are summarised in Table 8 below.

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

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

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

Pathway	Total Discounted Capital Cost 2014-2050 (million £)[18]	Cumulative CO_2 Abated 2014-2050 (million tonnes CO_2)[19]	Projected Impact on Fuel or Energy use and Fuel or Energy cost
BAU	2,000	13	This pathway includes deployment of such as improved process design, fuel switch (biomass), and improvements in steam production and distribution. In the period 2014-2050, this pathway would result in an overall saving in energy and fuel used. The projected value of this saving will depend on the fuel cost forecast adopted.
60-80%	10,000	53	This pathway has similar options to BAU but adds electrification of heat. In the period 2014-2050, this pathway would result in an overall saving in energy and fuel used. The projected value of this saving will depend on the fuel cost forecast adopted.
Max Tech	13,000	70	The main characteristic of this pathway is a projected significant transfer of energy use from natural gas to electricity resulting in an overall increase in energy use and costs. The scale of the increased cost will depend on the fuel cost forecast adopted.

Table 8: Summary costs and impacts of decarbonisation for the pathways

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

4.7 Implications of Enablers and Barriers

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

- Increased use of biomass and bio-energy
- Electrified heat
- Low and low-medium cost options such as energy management and utilities services (motors, pumps and fans, compressed air, lighting, steam, etc.)

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

4.7.1 Biomass and Bio-Energy

This option relates to the use of biomass as fuel, replacing natural gas or other fossil fuels. Biomass is interpreted in the widest possible way: not only the use of food waste present in the processing plant, but also second and third generation biomass and biofuels. This option brings a very big emissions reduction assuming that the biomass used in the food and drink industry is carbon neutral. The industry is already using biomass that can be considered carbon neutral (biomass waste, biogas from anaerobic digestion, sludge, algae, etc.), but will there be enough carbon-neutral biomass in the future? It is a very complex issue for this sector as the biomass it produces in-plant is often used as animal feed. A more detailed study will need to clarify which use of biomass provides the best option for the future (see also section 5.1.6).

The high level of uncertainty regarding the supply of low-carbon biomass is one of the key barriers in adopting biomass as fuel. Manufacturers suggested that a national policy on biomass would provide more clarity in the long term and support building solid investment cases. A subsidy scheme for biomass, guaranteed over the lifetime of the equipment, would help in developing this option. The Renewable Heat Incentive[20] already provides long-term subsidies for bio-energy, targeting 6.4 TWh of additional renewable heat by the end of 2015-2016. Compiling a robust business case has been identified by Carbon Trust as a key enabler. Although well-known in the sector, the availability of biomass is a concern, as the food and drink manufacturers in the UK are risk-averse to any potential disruption in production. Having senior management buy-in for decarbonisation would be another enabler for this option as it has such a high impact on decarbonisation.

In addition to biomass availability, other barriers that could hinder this option are regulatory uncertainty, uncertainty about return on capital, and global competition for funding from group headquarters.

Deployment of the biomass and bio-energy option was assumed to take place extensively in the 60-80% CO_2 reduction pathway (independent of the scenario).

[20] The UK Renewable Heat Incentive is the world's first long-term financial support scheme for renewable heat. It pays participants that generate and use renewable energy to heat their buildings (UK Government, 2012).

Enablers	Biomass available in the product flow, technology well-known in the sector Senior management buy-in and formal business commitment Government policy: a stable long-term policy with clear objectives and requirements at the start of biomass and renewable energy projects Government subsidy scheme or support for access to seed funding
Barriers	Long-term biomass availability Regulatory uncertainty Uncertainty about return on capital Global competition for funding from group headquarters Production disruption

4.7.2 Electrified Heat

This option is to replace equipment using fossil fuel with equipment that uses electricity. Replacing fuel-burning boilers, ovens and other heating equipment with equipment that uses electricity would be a fairly non-intrusive solution that would have a very limited impact on the operation of production plant and equipment. Future technology development might lead to process equipment using electricity instead of steam or direct gas fired applications. The option would be very sensitive to electricity (and carbon) prices; given the UK's current and predicted electricity prices, this might completely rule this option (ICF International, 2012).

One enabler to facilitate this would be the presence of appropriate policies to encourage a switch towards the electrification of fossil-fuel driven applications. Senior management buy-in and formal business commitment are important drivers to facilitate the development of this decarbonisation option. A possible barrier related to policies stimulating this option is the possible uncertainty of the longevity of the policy.

Other barriers include rising UK energy prices, which is perceived by workshop participants and interviewees as it makes the UK market non-competitive compared to other markets with lower energy prices, and uncertainty about return on capital. If we assume that future process equipment will use electricity instead of heat, there are additional barriers. Conservatism within the industry could hamper the deployment as it would be new or unproven technology. This is similar to the barrier regarding the impact of new technology on machine operability.

Replacement of equipment would be a challenge to take on immediately, involving high upfront costs which will put the investment in competition for funding from group headquarters.

Lastly, this option would require the electricity from the grid to have lower carbon intensity than current sources of fuel used for heat, e.g. natural gas.

This option only impacts the Max Tech pathway without electrifying heat.

Enablers	Senior management buy-in and formal business commitment Government policy incentives
Barriers	Regulatory uncertainty Conservatism within industry about unproven technologies Uncertainty about return on capital Uncertainty regarding impact of new technology on machine operability Rising UK energy prices perceived as non-competitive Global competition for funding from group headquarters Cost of electrified heat Production capacity and capacity and security of the grid

4.7.3 Low- and Low-Medium-Cost Options

This is a group of options that requires only low or low-medium capital investment. These are largely technologies that are currently implemented, and energy efficiency initiatives such as energy management, focus on maintenance, utilities services, etc. They have been grouped together into four blocks for the purposes of this section as they have similar enablers and barriers. The four options – energy management; steam production, distribution and end-use; compressed air; and motors, pumps and fans, HVAC and lighting – were identified by the food and drink trade associations as the options to be improved first under the CCA targets.

One of the key enablers that drive producers to implement incremental energy efficiency measures is the operational cost savings that can be made once such measures are installed. Workshop attendees also perceived these options as low risk due to their relatively low cost and low technical risk (which reduces the risk of operational disruption post-installation). However, even lower investment costs are sensitive to the lower profit margins in the marketplace. Some of these options are more concerned with organisational changes rather than technical changes and would require awareness and skills to be properly implemented. Interviewees in particular were concerned about the lack of sufficiently skilled energy specialists that can analyse current energy performance, identify opportunities, and select and implement feasible solutions. Some interviewees expressed a concern that energy managers are focused on ensuring compliance to regulations and reporting requirements instead of identifying and implementing energy efficiency options. Thus, an optimisation of the compliance requirements is perceived as an enabler for this group of options.

Small incremental investment was identified during the interviews as an enabler at sites that have access to lower amounts of capital that they can control themselves. The low capital cost options are likely to fall into that category. For the low-medium capital cost options, it is likely that the cost could be spread over several years and financing would be sought from national or regional headquarter capex budgets.

Barriers identified in the workshops include limitations on deployment rate because measures of this kind are often installed only when equipment needs replacement or during wider plant overhauls – it is generally not considered worthwhile to disrupt production simply to install these measures. It was noted by both workshop participants and interviewees that energy efficiency options are often not a priority for limited capital and manpower resources, particularly when the benefits are long term compared with other short-term priorities. It was suggested by workshop participants that commitment from top management can help mitigate this barrier.

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

Enablers	Small incremental investments Operational cost savings Optimisation of environmental management compliance requirements Senior management buy-in and formal business commitment
Barriers	Competitive marketplace with lower profit margins Lack of awareness and information imperfections Lack of skilled labour Limitation on deployment

5. CONCLUSIONS – PRINCIPAL QUESTION 6

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

The section is structured as follows:

- Six 'strategic conclusions' or themes have been developed by analysing the main enablers and barriers. Example next steps or potential actions are also included for each strategic conclusion.
- Four 'key technology groups' are discussed, many of which link to the themes above. As described in section 4, a small group of technologies make a significant contribution to decarbonisation in 2050[21]. Example next steps are included to assist with developing, funding and implementing the technologies.

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

5.1 Key Points

During the development of potential pathways to decarbonisation, the barriers to their implementation and enablers to promote them were summarised in section 3.4.5. Having cross-referenced the enablers and barriers through different research methods, we have summarised the main points in key strategic conclusions (or themes) and key technology groups.

Strategic Conclusions

Leadership, Organisation and Strategy

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

Business Case Barriers

The food and drink sector is facing many barriers to implementation of decarbonisation and energy efficiency projects, such as risk of implementing new technology, lack of skills, lack of management time, lack of certainty of business case, and the perception of an unstable political-economic climate by the industry. Another important barrier is lack of funding for such projects as the return of investment is not sufficiently attractive or there is a lack of capital available.

Industrial Energy Policy Context

Many in the sector have emphasised that the need for a long-term energy and climate change policy is key to investor confidence. Manufacturers often feel that there is a need for incentive schemes to become long-

[21] These technology groups apply to the food and drink sector and also the other seven sector roadmaps.

term commitments, as changes in policy can be damaging, particularly when the business case for investment is marginal and is highly dependent upon factors such as (fluctuating) energy-related costs.

Value Chain Collaboration

The food and drink sector in the UK is quite diverse in terms of types of products and thus can be characterised by a fairly complex value chain. Retail chains have strong bargaining power over manufacturers and, in turn, manufacturers pass on that pressure to raw material suppliers. This type of opportunity supports the overall need for greater consideration for collaboration across the value chain, to share the risks and speed up innovation. Industry and government should discuss what policy and business incentives will enable such collaboration and ways to overcome existing hurdles such as commercial secrecy.

Research, Development and Demonstration

Innovative research, development and demonstration (RD&D) projects are already taking place in the UK food and drink sector. Significant work on innovation is done and published by FDF, the Centre for Studies in Economics and Finance, universities (such as Sheffield Hallam University) and others. Despite this, academia finds it hard to run projects in the industry, especially PhD projects, meaning that the sector could fall behind other regions with regards to strategy and leadership, knowledge, expertise, training and skills, technologies, and the supply chain. RD&D would form an important part of a vibrant sector in the future, including the contribution to increased decarbonisation and improved energy efficiency.

People and Skills

To implement and use advanced technologies, skilled labour is needed, even at operator level. Knowledge is needed to choose between ‘standard’ equipment and more energy-efficient equipment when making investments. This knowledge acquisition and transfer is, and will continue to be, key to decarbonising the sector. Advanced technologies are attractive to the younger generation so it is also an opportunity to attract more young people to start working in the sector.

Key Technology Groups

Electricity Grid Decarbonisation

Decarbonisation of the national electricity grid could provide a significant contribution to the overall decarbonisation of the sector. The government’s reforms of the electricity market are already driving electricity grid decarbonisation, and this report uses the assumptions of a future electricity decarbonisation trajectory that is consistent with government methodology and modelling. Future policy work streams – regarding future electricity grid decarbonisation and changing configurations of generation, distribution and use – need to include assessment of the impacts of industry sectors such as food and drink, given the importance of grid decarbonisation for the electrification of heat option.

Electrification of Heat

Electrification of heat is one of the most important options available for the food and drink sector. Considering the current trends towards renewable energy and the finite sources of fossil fuels, it is very likely there will be a continued shift towards using renewable electricity for low-heat applications, and reserving fossil fuels for applications where high-value heat is required. This option does imply that the industry relies on the grid and the production to be more renewable, shifting the responsibility for emissions reduction towards the power producers.

Fuel and Feedstock Availability (Including Biomass)

Biomass clearly has significant potential as an alternative fuel for the food and drink industry, and provides an opportunity to decarbonise the sector. The sector can use a part of its own product flow to convert to green energy, and is already using biomass that is considered carbon neutral. Feedstock availability is less a barrier than in the pulp and paper sector, as the only competition for using own food waste or by-products is the animal feed sector. There is significant added value in using biomass for CHP compared to power generation only. But compared to the pulp and paper sector, the biomass in the food and drink industry is not always of the same quality (leading to biogas produced with a variable composition), which can pose an additional barrier on successfully implementing biomass CHPs.

Energy Efficiency and Heat Recovery

Energy management and improved process design are key for a structured approach in the evolution towards an energy-efficient and low-emissions process. Implementation of these two options on new installations and plant layout can result in significant improvement steps. Energy management should be given a more important role in the decision-making process in companies. Another point of focus to improve energy efficiency in the food and drink sector should be the implementation of a state-of-the-art steam system.

5.2 Strategic Conclusions

5.2.1 Strategy, Leadership and Organisation

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

This links to all other conclusions below, including RD&D, technology deployment, energy supply and financing.

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

- Leadership and vision to the UK sector, emphasising how food and drink production adds strategic value for the UK and why it is important to face the challenges and develop the opportunities for the sector. This vision could encompass the ambition, drive, passion and creativity required to maximise future opportunities for the sector and in doing so help to continue to spread a positive message and image.
- An approach to the need to drive forward the joint priorities of maintaining competitiveness of the existing food and drink operations (recognising the challenges of operating in the markets within which they reside) and also the need to increase RD&D activity and support technology and product innovation in the sector. A better match between industry needs and a pool of research possibilities at universities is one of the ideas that came forward in the workshops.
- A high-level link between industry, the government and the EU, a clear framework within which production, technology, energy efficiency and decarbonisation agendas can be taken forward, and further assisting the work that is currently being carried out by the sector. Members of the working group could engage with executives in corporate headquarters (both original equipment manufacturers (OEM) and food and drink production companies) to address the current lack of activity and engagement between the UK and the international sector community (for example in RD&D).

- A means to take forward the roadmap agenda with shorter-term action plans, for example, in five-year intervals, making the goals set more realistic and tangible.

Given that the food and drink sector is not currently part of the government's published industrial strategies, the status within government of Energy Intensive Industries (EII), including the food and drink sector, should be investigated and reviewed periodically.

This 'strategy' conclusion is also applicable to individual companies, which have a key role in overcoming barriers and strengthening enablers. This links to a number of strategic conclusions, for example, management commitment to decarbonisation and energy efficiency, value chain opportunities, and shortage of skilled labour.

As none of the companies interviewed has a strategy that looks further than 2025 in terms of carbon-reduction targets, it is important to link longer-term conclusions from this project into shorter-term company-level plans. Short-term goals are more concrete for companies and long-running roadmaps can be better split into a sequence of short-term steps, making the goals to be achieved more tangible for the companies.

5.2.2 Business Case Barriers

One of the most important barriers to decarbonisation and energy efficiency, based on the literature, interviews and workshops, is lack of funding for such projects. While this is not the only barrier to implementation of decarbonisation and energy efficiency projects (others include risk of implementing new technology, lack of skills, lack of management time, lack of certainty of business case, and the perception of an unstable political-economic climate by the industry), it is an important issue. A number of ideas were put forward by the stakeholders at the workshops to address this issue; these potential actions are described below:

- Investigate working with local credit unions, ESCOs and use their financial support
- Use of third-party funds, for example ethical investment funds

Hence, improved banking support to stimulate longer-term investments in decarbonisation is proposed. It is also proposed that government, the food and drink sector, and the finance sector continue to develop mechanisms to support energy efficiency and decarbonisation projects. Considering the potential still available for short-payback projects, this can offer a promising trajectory for implementing energy-efficient options in a short time.

5.2.3 Industrial Energy Policy Context

Many in the sector have emphasised that the need for a long-term energy and climate change policy is key to investor confidence, according to literature and other evidence gathering sources. Manufacturers often feel that there is a need for incentive schemes to become long-term commitments, as changes in policy (around incentive schemes) can be damaging, particularly when the business case for investment is marginal and highly dependent upon factors such as (fluctuating) energy prices. Possible actions as next steps to address this conclusion are as follows:

- As part of government's ongoing carbon pricing policy, both through the EU ETS and the UK's own carbon pricing, government should consider carefully whether policies could be improved to incentivise investment and assess measures to minimise the risk of carbon leakage. Although initiatives have been taken (via the Carbon Price Support), further care must be taken that no discrepancies arise between carbon prices in the UK and continental Europe. Work on this should start now on the assumption that it will take a number of years to implement and many of the decarbonisation options in the pathways depend on investment that needs this policy context to underpin them. A carbon price should be high enough to stimulate change, but low enough to avoid carbon leakage. The revenues of a carbon price fund should go to developing renewable energy sources, which in turn would encourage the industry to switch to options such as electrification of heat.

- Government to explore alternative funding arrangements to recognise mid- to long-term decarbonisation benefits (2015). This would allow the value of these benefits to be taken into account in investment decisions.
- Government to establish a ‘level playing field’ through a global carbon agreement (with regional breakdowns) before 2020. This could provide an alternative means to avoid carbon leakage. Also, preparation for the fourth ETS phase (starting in 2021) can be started now, in order to offer the industry a solid knowledge base for acting in the new ETS schemes (in phase 3, which started in 2013, the caps decrease with 1.74% per year till 2020; in phase 4, from 2021 onwards, they will decline with 2.2%).
- Considering the potential impact of electrification of heat on lowering the CO_2 emissions, the impact of this opportunity on production and grid layout should be studied now.
- There are examples where environmental (or other) legislation interferes with energy efficiency. The government should consider applying an ‘energy management approach’ when developing its legislation, taking into account the effects of legislation on process design and efficiency of the industry concerned. Actions to harmonise EU-legislation in order to avoid ‘legislation leakage’ (as compared to carbon leakage) would also help industry to reach more objective decisions regarding where and when investments are best made.

5.2.4 Value Chain Collaboration

Close supply chain co-operation is needed to secure resources, improve skills, including resource efficiency management, and create system solutions with lower impact products which better meet customer needs (including servicing) and drive improvements in scale. The food and drink sector in the UK is quite diverse in terms of types of products and thus can be characterised by a fairly complex value chain. Retail chains have strong bargaining power over manufacturers and, in turn, manufacturers pass on that pressure to raw material suppliers. This type of opportunity supports the overall need for greater consideration for collaboration across the chain, to share the risks and speed up innovation.

Potential actions to support these conclusions are described below:

- While a product life-cycle approach has already been considered by the UK food and drink manufacturers, it will only succeed with a stronger collaboration across the entire value chain. This would help place food and drink manufacturing carbon emissions within the context of the wider food value chain. It will also offer a reference point to better understand the interactions between the parts of the value chain and the possible impacts on manufacturing energy use and carbon emissions. Industry and government should work together and build on the work of already existing platforms in this area, such as WRAP’s **Product Sustainability Forum** and the **Courtauld 2025 Commitments**.
- Strong incentives and senior-level commitment are crucial to successful collaboration. A key challenge expressed by workshop participants is that due to high competition levels companies are generally not willing to share information about innovation with peers. Industry and government should discuss policy and business incentives that will enable such collaboration, and how to overcome existing hurdles such as commercial secrecy.

The Product Sustainability Forum is a collaboration between UK grocery retailers and suppliers, academics, NGOs and government. It aims to measure, improve and communicate the environmental performance of grocery products. It leads, co-ordinates and progresses existing efforts, alongside similar initiatives being undertaken around the world to provide evidence to industry, government and others to help them prioritise which products to focus their efforts on (WRAP, 2015).

Courtauld 2025 was developed by WRAP to develop a new, 'farm-to-fork', commitment for the UK food and drink industry. This commitment is proposed to start early in 2016, and would focus on optimizing system-wide outcomes, by helping (i) consumers to reduce avoidable food waste and (ii) businesses to share efficiency savings along supply chains, waste less and get more value from unavoidable waste, and thereby increase business resilience (WRAP, 2015).

5.2.5 Research, Development and Demonstration

As highlighted in the interviews and the workshops, innovative RD&D projects are already taking place in the UK, driven by organisations such as FDF, the centre for Studies in Economics and Finance and universities (such as Sheffield Hallam University). Despite this, academia finds it hard to run projects in the industry. This means that the UK food and drink sector could fall behind in a number of ways:

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

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

From the academic world it was noted there is a lack of opportunities to carry out PhD projects in the UK food and drink industry. One of the reasons for this is that the project structure is sometimes not flexible enough for the industry and, in the case of PhD students, they sometimes last too long for companies to follow up. A solution for this may lie in the creation of a centralised pool (database) of research opportunities and PhD students looking for projects.

The UK food and drink industry has an opportunity to take a more leading role in both national and international research. The following paragraphs give some examples of next steps.

The deployment of new manufacturing technologies is crucial. As the application of such technologies is perceived by companies as entailing risk to established processes, the food and drink industry, academia and government should work together to demonstrate the applicability and performance of such technologies.

In the 'green economy', more and more products are being developed based on renewable resources. **The food and drink industry is ideally placed to take a more leading role in the 'green' value chain** and collaborate more with organisations trying to develop new products based unwanted by-products or from new organic sources. Applications such as 3D food printing and new process design open the way for fresh possibilities and change the way the public perceives food.

There are also opportunities to develop biofuels from material currently regarded as organic waste. Biogas from anaerobic waste water treatment plants is already used in some plants, but still more organic waste is now used as animal feed. More research into possible applications of food waste as fuel could help develop a new food-related energy industry.

Potential actions to support these conclusions are described below:

- From the workshops and interviews it became clear that a stable political playing field and a stable support scheme of subsidies for energy-saving projects is key. Legislation from different government departments should be designed with a holistic approach, checking for side effects in other fields.
- It is recommended that the opportunity to collaborate and create higher value-added products with the retail sector is investigated through a programme of applied research.
- Helping to establish knowledge transfer agencies, combining the process, legal and financial knowledge in one place, making it easier for companies to evaluate the options available.
- Agree on a shared vision for innovation in the sector as recognised by the FDF members.

5.2.6 People and Skills

To implement and use advanced technologies, skilled labour is needed, even at operator level. Knowledge is needed to choose between 'standard' equipment and more energy-efficient equipment when making investments. **This knowledge acquisition and transfer is, and will continue to be, key to decarbonising the sector**. Advanced technologies are attractive to the younger generation so it is also an opportunity to attract more young people to start working in the sector.

Potential actions to support this conclusion are described below:

- Use research and pilot project as a way to attract MSc and PhD students to the sector.
- Share generic technical and engineering skills with other major industry sectors. The vast majority of this need can be met by cooperating with (and sharing resources with) other industry sectors (engineering and process industries) with similar requirements. This need can already be met within the UK.
- Bring together training resources from across Europe (the vast majority of training is already delivered in English). It is possible to construct a comprehensive training programme covering all levels from apprentice to master's degree.
- Develop best energy efficiency practices for maintenance, behaviours, and technical competence.
- Seek engagement between the government and the sector with a wider society (and school children in particular) to address the perception of the food and drink industry, to make the industry more attractive for young people. The government should continue to invest in STEM education, an interdisciplinary curriculum based on science, technology, engineering and mathematics, to attract high-school students to the industry.
- Increase cooperation between academia, the sector and government and build on existing initiatives such as national apprenticeships and skills development programmes with specific focus on energy and heat engineers.
- Increase awareness and understanding of all issues in this roadmap.

5.3 Key Technology Groups

5.3.1 Electricity Grid Decarbonisation

Decarbonisation of the national electricity grid could provide a significant contribution to the overall decarbonisation of the sector. The government's reforms of the electricity market are already driving electricity grid decarbonisation, and this report uses the assumptions of a future electricity decarbonisation trajectory that is consistent with government methodology and modelling. Future policy work streams – regarding future electricity grid decarbonisation and changing configurations of generation, distribution and use – need to include assessment of the impacts of industry sectors such as food and drink, given the importance of grid decarbonisation for the electrification of heat option. Decarbonisation of electricity supply is not within the direct control of the sector and so actions here are more likely to lie with government.

Very low carbon electricity is a key part of any decarbonisation plan for the food and drink industry. But decarbonised electricity can only be used by industry if it is technically and financially viable to do so, and if there is a sufficient secure supply. It is imperative that the government and industry continue to implement a clear plan for the provision of affordable, secure and low-carbon energy (electricity, gas and other fuels), and that the government delivers on its promise to decarbonise the national electricity grid. A clear long-term regulatory framework will encourage industry to invest in the UK. At the same time, incentives need to encourage energy efficiency and not just decarbonisation; currently, the balance is tipped in favour of decarbonisation (and provision of renewable electricity) which is not the most cost-effective approach – see also comments on demand-side response above.

The bigger impact on electricity by the plants also offers the possibility to have demand response activities. This implies more bi-directional traffic on the electricity grid. Both aspects (*more* traffic in *both* directions on the grid) will be demanding on the grid, which will not only transport more electricity, but will also have to cope with a more bidirectional flow of energy, taking into account distributed generation (e.g. solar PV, wind, bio-energy) and the effects of demand and response.

Example actions include:

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

5.3.2 Electrification of Heat

Electrification of heat is an important decarbonisation option for the food and drink sector. Compared to other industry sectors, the food and drink sector has a big part of its heat demand at fairly low temperatures and this enables the sector to shift towards electrification.

In control strategies, electric heating has a number of advantages over conventional gas or gas- or oil-fired steam heating:

- The heat output can be controlled very easily.
- The equipment becomes smaller and less complicated (less maintenance).
- The heat generation is local, so no need for hot piping throughout the plant; in the case of steam heating, there is no need for a boiler house nor condensate piping returning to the boiler house

A number of ideas were put forward at the sector meetings and workshops in relation to the electricity network which we consider worthy of investigation, as follows:

- Representatives of the gas and electricity grids should meet with industry to explore how the regulated utilities can better serve industrial customers – especially with regards to decarbonisation and energy efficiency projects. For example, how can grid connectivity be improved to export power? This could provide demand shifting and benefits to the industry, currently hampered by technical, commercial and regulatory issues.
- The capacity market does not encourage industry participation. One reason is the single calculation method to establish baseline load which does not take account of ‘dynamic load’. Demand and load shifting can benefit the UK electricity sector by avoiding the need for new generating assets. In order to make this a success, flexible operation would be required and this might not always be possible. The government can play a role in adapting regulation in order to facilitate demand and response activities.

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

5.3.3 Fuel and Feedstock Availability (Including Biomass)

Biomass provides an opportunity for the food and drink sector to decarbonise as illustrated by almost all pathways. Biomass is clearly an alternative fuel for the food and drink sector: with the exception of the pulp and paper industry, it is the only industry that can use a part of its own product flow to convert to green energy. The industry is already using biomass that is considered carbon neutral (e.g. wood fuel such as wood chip and pellets, or by-products, biomass waste, biogas from anaerobic digestion, sludge, algae, etc.). The question is whether there will be enough carbon-neutral biomass in the future? This is a very complex issue for this sector as the biomass it produces in-plant is often used as animal feed[22].

Using food waste as biomass source for the production of bio-energy could have a big impact on the food and drink sector supply chain. For example, when food currently classified as by-product for use in animal feed would be used as low-carbon biomass source for energy production, this would result in less food available for the production of animal feed. In turn, this animal feed would have to be sourced elsewhere, causing potential adverse impact on carbon emissions within the supply chain. Considering food waste as biomass source would hence require a full LCA (life-cycle assessment) approach to fully understand the benefits and consequences. And a more detailed study could clarify which use of biomass is the best option for the future and which has the least environmental impact.

Feedstock availability is less of a barrier than in the pulp and paper sector, as the only competition for using own food waste or by-products is the animal feed sector. **There is significant added value in using biomass for CHP compared to power generation only** and this should be considered by the government in its ambition to decarbonise the electricity grid. But compared to pulp and paper, the biomass in the food and drink industry is not always of the same quality (leading to biogas produced with a variable composition), which can pose an additional barrier on successfully implementing biomass CHPs.

Potential actions to support these conclusions are described below:

- Simplify regulations on renewable energy
- Make investments in renewables more attractive
- Allowing biogas to be injected in the natural gas grid
- Encouraging R&D in industry and academia with regard to biomass and providing support for pilot projects: not only first-generation biomass but also second- and third-generation biomass and biofuels that do not compete with other food or feed flows
- Maintain awareness – when making policy – of biomass distribution between competing users (food and drinks sector using it for energy generation, versus animal feed sector using it to produce animal feed), while maintaining stable supply and prices to permit sustainability of the food and drink sector (assuming that biomass is sufficiently available for industrial use)

[22] According to the UK waste hierarchy, top priority is given to preventing waste in the first place. When waste is created, priority is given to preparing it for re-use and recycling (using food waste as animal feed), whereas other recovery options such as incineration with energy recovery are given a lower priority.

5.3.4 Energy Efficiency and Heat Recovery Technology

Energy management is the driver for a structured approach in the evolution towards an energy-efficient and low-emissions process. Process design accounts for 13.2% emissions reduction in 2050 in the BAU pathway. Implementation of these two options on new installations and plant layout can result in significant improvement steps.

From the workshops it became clear that energy management should be given a more important role in the decision-making process in companies. Potential actions to support this conclusion are described below:

- The UK Energy Savings Opportunity Scheme (ESOS) is a mandatory energy assessment scheme for large undertakings and their corporate groups in the UK. These organisations need to carry out ESOS assessments (energy audits of buildings, industrial processes and transport) every four years, to identify cost-effective energy-saving measures. Organisations are exempted from the four-yearly energy audit obligation when they are fully covered by ISO 50001, thereby already providing an incentive for implementing ISO 50001. But the government could set up an additional subsidy system, tax breaks or other incentives to further accelerate the introduction of ISO 50001 (as in Germany or France).
- Internally, the energy manager and the team should be involved in the design of new processing lines. Investments should take into account the total cost of installation and operation (not only considering investment, but also energy consumption, maintenance and decommissioning costs).

Another point of focus to improve energy efficiency in the food and drink sector is the implementation of a state-of-the-art steam system. Steam is a utility that is used in almost all food and drink companies. In all pathways it is one of the top contributors to the emissions reduction in 2050. Also, in the CCA agreements, it is one of the main focus areas in the food and drink policy to achieve CO_2 reductions by 2020.

One of the main barriers for implementing efficient solutions in the steam production and distribution is the longevity of boilers and steam systems. Boilers are large investments and a 30-40 year lifespan is no exception. This often results in overcapacity compared to the current needs of the process.

Potential actions to support this conclusion are described below:

- Establish a subsidy scheme enabling companies to improve or replace old installations
- Promote and conduct research to check alternatives for steam heating (electric heating or direct gas firing) in food and drink plants. This would reduce the demand for steam, making it possible to install smaller boilers as a replacement for the old boilers, thus reducing energy losses.

5.4 Closing Statement

This roadmap report is intended to provide an evidence-based foundation upon which future policy can be implemented and actions delivered. The way in which the report has been compiled is designed to ensure it has credibility with industrial, academic and other stakeholders and is recognised by government as a useful contribution when considering future policy. It will be successful if, as a result, the government and the food and drink sector are able to build on the report's evidence and analysis to deliver significant reductions in carbon emissions, increased energy efficiency and a strong competitive position for the UK food and drink industry in the decades to come.

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7. GLOSSARY

Adoption

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

Applicability

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

Barrier to Decarbonisation or Energy Efficiency

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

Business as Usual (BAU)

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

Decarbonisation

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

Carbon Reduction Band or Bin

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

Carbon Reduction Curve or Profile

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

Competition Law

The UK has three main tasks:

- Prohibiting agreements or practices that restrict free trading and competition between business entities. This includes in particular the repression of cartels.
- Banning abusive behaviour by a firm dominating a market, or anti-competitive practices that tend to lead to such a dominant position. Practices controlled in this way may include predatory pricing, tying, price gouging, refusal to deal and many others.

- Supervising the mergers and acquisitions of large corporations, including some joint ventures. Transactions that are considered to threaten the competitive process can be prohibited altogether, or approved subject to 'remedies' such as an obligation to divest part of the merged business or to offer licences or access to facilities to enable other businesses to continue competing.

Deployment

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

Enabler for Decarbonisation or Energy Efficiency

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

Grid CO_2 Emission Factor

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

Maximum Technical Pathway (Max Tech)

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

Option

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

Option Register

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

Pathway

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

Projection of Production Changes

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

Reference Trend

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

Scenario

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

Scenario Assumptions

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

Sensitivity case

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

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