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Decarbonisation road map for the European food and drink manufacturing sector

A report for FoodDrinkEurope

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Executive summary

This roadmap has been developed by Ricardo Energy & Environment on behalf of FoodDrinkEurope. It assesses the climate impact of the European food and drink manufacturing sector, and sets out some of the available pathways for decarbonisation to net zero by 2050. The roadmap highlights the many opportunities that are available to the sector, whilst also discussing the numerous challenges and barriers that will need to be overcome.

What is the EU food and drink industry's climate impact today?

The global food value chain generates 690 Mt CO_2e each year. This is equivalent to a third of global emissions (and 30% of EU emissions).

The food value chain encompasses a wide range of processes, including farming, manufacturing and production, and transport. This study focuses specifically on the emissions associated with food and drink manufacturing in the EU. In Europe emissions from this source are estimated to be 94Mt CO_2e/year, comprising 11% of the emissions from the whole chain. For context, this only slightly less than the total emissions of Belgium.

The majority of the emissions from European food and drink manufacturing are associated with energy use. Approximately two thirds (62%) of energy use is consumed as heat and one third (38%) as power (electricity) from the grid. It is notable that a relatively high proportion of electricity is used for cooling. This is a particular feature of this sector as it is notably higher than that seen for other manufacturing industries. However, heat consumed at higher temperatures is currently the most challenging process to decarbonise (using technologies that are currently mature).

This study demonstrates that there are six energy intensive sub-sectors that account for more than 50% of European food and drink manufacturing GHG emissions. There are five countries which host 70% of large food processing sites (those covered by the Industrial Emissions Directive). These are France, Germany, Spain, Italy and the UK. In terms of the overall picture this is a representative figure only, as it does not directly account for all sites (for examples the many small plants operated by small and medium enterprises (SMEs)). There are a relatively low proportion of newer manufacturing sites in Europe, and many of these are found in rural or remote locations, adding to the decarbonisation challenge.

There is a huge variation in emissions across the sector. Some sub-sectors will have a much greater decarbonisation challenge than others because they are more energy intensive in nature, but also because of factors such as how much heat they need to use (which is difficult to decarbonise when used at high temperatures).

Why do we need to take action now?

The EU has committed to reaching net zero emissions by 2050. As part of this target, it aims to achieve a 55% reduction in emissions by 2030. To facilitate this, the EU is currently in the process of reviewing many of its regulations to drive decarbonisation e.g. the European Green Deal.

The 2030 target is challenging and, with just nine years left to reach the 2030 milestone, there is a need to act sooner rather than later. This is especially apparent given that some industrial plant energy efficiency retrofits may take 3-5 years to complete.

The roadmap has reviewed the range of opportunities that decarbonisation can offer the food and drink manufacturing sector. By taking a proactive approach the sector will stand to benefit from these advantages ahead of time, and in the meanwhile assist the EU in meeting its ambitious decarbonisation targets.

There are public funds already available for decarbonisation purposes. These are available to research and develop decarbonisation measures, as well as to support the uptake of mature proven technologies. This presents a big opportunity for food and drink manufacturing companies, who should be working to access these funds now.

What can food and drink businesses do?

Businesses will need to plan their specific decarbonisation path. They should start with setting an emissions baseline and selecting a tool that will guide them in their decision-making process when selecting decarbonisation options. For example, using a tool such as “marginal abatement cost curves” (MACCs) will help to select the most effective options with the lowest abatement costs. These options are termed “low hanging fruits” and are techniques that are less costly to implement and/or deliver lower operating costs. Companies should generally start their journey by identifying and implementing these.

Decarbonisation pathways are more targeted and effective when planned for each different process used (disaggregated). Companies will need to implement a collection of measures since, in most cases, there will be no “silver bullet” to achieving net zero.

Most plants will uptake decarbonisation measures relating to both energy demand and energy supply. This roadmap provides information on more than 90 measures some of which are generic, whilst others apply to specific process or sub-sectors. Many of these techniques have applicability restrictions, meaning that they cannot easily be applied to every installation.

The roadmap included proven mature techniques but also describes emerging technique that are not yet ready, either because of a low degree of maturity or a very high cost. Some of the key emerging techniques have uncertainties associated with them (e.g. timeline to affordability) but they will ultimately be required to ensure the required degree of emission reductions within the sector.

What are the barriers and opportunities to success?

The roadmap includes a PEST (political, economic, socio-cultural, technological) analysis that assigns barriers and opportunities to each group of decarbonisation technologies. The most common barriers identified are:

- An unstable policy environment in conflict with long company investment cycles (to depreciate assets).
- High Capex or Opex costs for some decarbonisation measures.
- The majority of plants are existing, and will require retrofit (often more complex than green field).
- Uncertainty around energy costs (e.g. EU ETS is already increasing electricity costs in countries like Spain).
- Achievement of net zero requires future contributions from immature technologies that are not currently readily available and have uncertain timelines for economic viability.
- Challenges for SMEs in accessing capital and technology information as well as attracting qualified professionals to drive decision making on energy or emission matters.
- Geographic location may limit access to modern or cleaner fuels infrastructure (natural gas or green hydrogen networks).
- Significant infrastructure development is necessary to increase availability of grid and/or green hydrogen.

The roadmap also highlights the range of opportunities that decarbonisation can offer to food and drink manufacturing companies:

- Many food processing temperatures are low enough that heat could be provided by renewable sources (there are exceptions for some energy intensive processes).
- Several emissions reduction efforts in this sector will be based on reducing energy usage in food processing installations. This is a win-win situation that will have benefits for operators (lower Opex) and society (lower emissions).
- Policy push: There are lower operating costs related to the relative maturity of renewable energy technologies.
- Market pull: Customers are becoming more environmentally conscious and appreciate indicators that demonstrate lower environmental impacts (such as GHG footprints).
- There are numerous EU financing mechanisms related to reducing industrial GHG emissions using both novel and mature techniques. These provide support to facilitate the net zero transition (although will seldom cover all costs).

This roadmap provides an overview of the pathway to net zero for the European food and drink manufacturing sector. It is important to note that within the sector there is a high degree of variability between sub-sectors and processes. This applies to the associated emissions as well as the available opportunities and challenges of implementation. As such, each sub-sector will ultimately need to develop its own detailed roadmap for reducing its emissions.

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1 Introduction

1.1 The need for a roadmap for the food and drink sector

The Paris Agreement, adopted at COP21 in December 2015, put in place a long-term goal to keep the increase in global average temperature to well below 2°C above pre-industrial levels; and to pursue efforts to limit the increase to 1.5°C to avoid the worst effects of climate change. As a result, the European Union (EU) and the UK have set targets to operate as net zero economies by 2050.In September 2020, the European Commission proposed an EU net greenhouse gas (GHG) emissions reduction target of at least 55% by 2030. This target puts the EU on a pathway of both emissions reductions and removals, to reach the EU Green Deal ambition of net zero emissions by 2050. The Commission's impact assessment on the latter ambition confirms that establishing an emissions reduction target is a realistic and feasible course of action.

In order to achieve this target, decarbonisation efforts will be needed across all sectors, including the food and drink manufacturing sector. Working on behalf of FoodDrinkEurope, Ricardo Energy & Environment has developed a roadmap for the achievement of net zero emissions by the European food and drink manufacturing sector by 2050.

Objectives of the roadmap

The sector has already made substantial efforts towards reducing its emissions, decreasing them by 14% to date compared to 1990 levels. Central to this achievement has been a shift towards improved efficiencies in the use of energy, water, transport and logistics. Also important is the increased use of renewable energy, reduction of food waste and the move towards a circular economy, including the use of more sustainable packaging[1,2]. In this context, the net zero roadmap builds on these efforts, supporting a transition to lower emissions and enabling an acceleration and step change in decarbonisation.

The roadmap sets out three possible pathways and provides direction for the sector on what its journey to net zero could look like. Furthermore, this roadmap has the intention to assist individual food and drink manufacturers with their own action plans through the identification of key decarbonisation measures, as well as supporting consistency of approach within the wider sector, allowing for greater collaboration. The roadmap will also enable the wider supply chain, policy makers and other stakeholders to understand how they can work with food and drink manufacturers to achieve the net zero goal.

Throughout the development of this roadmap, significant challenges and barriers to achieving net zero have been identified alongside decarbonisation opportunities.

Scope of the roadmap

This roadmap focusses on the decarbonisation of the European food and drink manufacturing sector towards net zero emissions by 2050. It considers food processing and manufacturing activities as defined by the Nomenclature of Economic Activities (NACE) sections C10 (Manufacture of food products) and C11 (Manufacture of beverages), with the exception of C10.2 (Processing and Preserving of fish, crustaceans and molluscs).

The roadmap considers the greenhouse gas emissions arising within production facilities (gate-to-gate). The emissions covered in the roadmap thus relate to Scope 1 and Scope 2 as defined by the Greenhouse Gas Protocol[3]. Scope 1 emissions are direct emissions from sources owned or controlled by companies in the food and drink manufacturing sector, for example fuels combusted on site. Scope 2 emissions are indirect emissions associated with the generation of electricity, heat and steam

[1] https://www.fooddrinkeurope.eu/priorities/detail/environmental-sustainability/
[2] https://www.fooddrinkeurope.eu/uploads/publications_documents/FoodDrinkEurope_position_on_a_carbon_neutral_Europe_by_2050.pdf
[3] https://ghgprotocol.org/

produced by others but consumed by the sector. The roadmap does not cover the activities upstream (e.g. crop growth) or downstream (e.g. retail) of food processing and manufacturing.

The roadmap focusses on alternative options relating to the supply and use of energy for food and drink manufacturing/processing, based on the assumption that food offer and demand remain in line with current trends and that similar manufacturing processes continue to be used.

Future emissions projections, relating to several scenarios, have been developed. All of these have been aligned with the two key time periods for which the European Commission has set emissions reduction targets: 2020 to 2030 and 2030 to 2050.

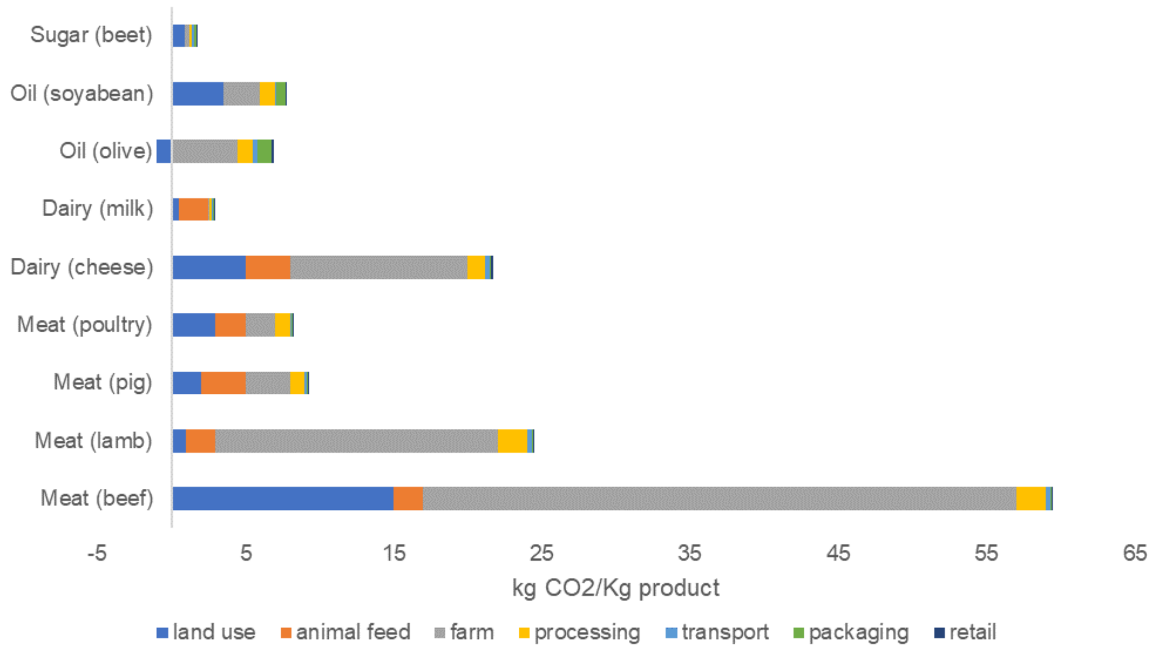
There are certain GHG emission sources from food processing installations which are not covered in this study due to the absence of accurate data. For example, this includes, data on losses of CO_2 refrigerant from cooling systems, CO_2 losses associated with the carbonisation of beverages, CO_2 losses from the creation of an atmosphere to expand the lifetime of fruits or allied for novel extraction processes (based on supercritical CO_2).

GHG emissions with the food and drink value chain

Food and drink value chains are complex, and each stage contributes to GHG generation. This is why EU climate and energy-related policies, such as "Fit for 55%" emission reduction goals are being revised to promote emission reductions and other actions across the value chain.

Food processing makes a relatively small contribution to the overall GHG emissions of the "farm to fork" path (" EDGAR-FOOD data" from DG JRC[4]). This ranges from 11% of total food change GHG emissions in the EU to 1% in India and 3% in China. For most food products, activities upstream (crop and rearing) and downstream (distribution, retail) of food processing contribute a larger share of overall GHG emissions than the industrial or manufacturing stages. This is shown in Figure 1[5]. There is, however, a high variability in total GHG emissions and emissions sources inside each food category.

Figure 1: Value chain GHG emissions for selected food and drink products (source: Poore et al.[5])



[4] Crippa, M., Solazzo, E., Guizzardi, D. et al. Food systems are responsible for a third of global anthropogenic GHG emissions. Nat Food (2021).
[5] Source: J. Poore and T. Nemececk, Reducing food's environmental impacts through producers and consumers. Science Magazine (2018).

The European Commission stated that in 2013, 17% of the EU's gross energy consumption could be attributed to the overall food and drink sector, of which 28% was used for industrial processing[6]. This translates into just under 14% of CO_2e emissions being attributed to industrial processing[6]. However, there are variabilities between regions, countries and sub-sectors. A more recent study, focussed on France, states that industrial food and drink processing accounts for roughly 5.5%[7] of total food chain emissions.

Each industrial installation generally has a limited set of tools (measures) to minimise or eliminate GHG emissions. The control of GHG emissions before or after the food processing site (scope 3) is limited as a result of being exposed to external influences. Sites can access a much wider range of tools to influence scope 1 and 2 emissions.

2 Roadmap to achieving net zero emissions by 2050

2.1 GHG emissions baseline

The first stage when developing a net zero roadmap is to identify and understand current and past emissions. This roadmap analysis has determined the baseline GHG emissions for the European food and drink manufacturing sector and its projections of future GHG emissions. It uses the 1990 to 2050 timeframe set out by the European Union's emissions reduction target.

This study provides GHG emission baseline data for two different periods:

- Recent and more accurate information sources are available for 2020 compared to earlier timeframes. This study has carried out a deep dive analysis of 2020 energy and GHG emission generation data to profit from this higher level of precision and accuracy.
- It is recognised that the majority of governments and public institutions are setting emission reduction goals using 1990 as a baseline. Therefore, this study has also presented results in 1990 terms. Nevertheless, the accuracy of GHG emissions data for the sector in 1990 is lower than for 2020.

2.1.1 Data availability for 2020

No readily available data set exists for the GHG emissions from the European food and drink manufacturing sector (scope 1 and 2 emissions). There are accurate and updated information sources to facilitate a 2020 baseline estimation. Examples of the available data sources, together with an explanation of their limitations are provided below.

Data at global level:

The most relevant inventories or data from reporting organisations, such as the Intergovernmental Panel on Climate Change (IPCC)[8], provide data for food and drink sector emissions which is combined with other sectors. Other authors (Rissman, 2020[9]) have estimated global food processing emissions combined with tobacco manufacturing as 4% of worldwide industrial emissions. Direct energy related emissions were estimated at 250 Mt CO_2e (circa 36%, scope 1) and indirect energy related emissions at 444 Mt CO_2e (circa 64 % Scope 2).

EU Emissions Trading System (EU ETS) data:

[6] https://op.europa.eu/en/publication-detail/-/publication/46e57060-e1b7-4f9d-82b3-d826c484ce77/language-en
[7] https://www.ademe.fr/sites/default/files/assets/documents/rapport-anglais-carbon-footprint-food-france-2019.pdf
[8] https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_chapter10.pdf
[9] https://www.sciencedirect.com/science/article/pii/S0306261920303603

In Europe, data from the EU ETS is summarised for different sectors and activities by the European Environment Agency (EEA) via its greenhouse gas inventory reporting("Annual European Union greenhouse gas inventory 1990–2017 and inventory report 2019", 2021[10]). This report provides food and drink sector GHG emissions associated with combustion activity covered by EU ETS. This only concerns combustion units with a total rated thermal input of more than 20MW (mainly boilers, dryers, furnaces and heating equipment)[11].

In 2017 EU ETS data showed that the total CO_2e emissions from food processing, beverages and tobacco (EU ETS category "1A2e") amounted to 39,71 kt CO_2e. This was a decrease of 23% compared to 1990 and accounted for 8% of total manufacturing emissions.

Today the food and drink sector (with tobacco) is the fifth largest GHG emitter after non-ferrous metals manufacturing[10], iron and steel, non-metallic manufacturing and chemicals.

2.1.2 Generating a baseline for 2020

The 2020 baseline data was compiled, generated and validated at sub-sector level. Twenty-seven (27) sub-sectors were used to gather data on production intensity (Million tonnes per year) and energy usage (MWh per tonne of product). These figures were then converted to GHG emissions.

Data was gathered from many sources with the most relevant ones being the Best Available Techniques Reference Document for the Food, Drink and Milk Industries (FDM BREF)[12] and reports from the European Commission's Joint Research Centre[13]. The majority of key data figures used for estimations were validated (and/or provided) by FoodDrinkEurope members' feedback. The main steps taken to generate the GHG emission baseline were:

1. Gather information on sub-sector activity, production rates (Million tonnes/year).
2. Gather information on average specific energy usage (MWh/tonne product) e.g. from FDM BREF.
3. Calculate energy consumption (MWh/year): Multiplying production rates with specific energy.
4. Gather indicative data on the percentage breakdown of energy usage, into either electricity or heat. Undertake for each sub-sector.
5. Estimate GHG emissions based on the source (electricity/combustion) and quantity used:
   a) Electricity - Calculate the CO_2e generated by grid electricity use. Multiply electricity usage by the CO_2e intensity of power generation. For example, 20MWh electricity x 0.23 tCO_2e/MWh of electricity = 4.6tCO_2e.
   b) Combustion – Undertake the same as above but substitute electricity usage and its associated carbon intensity with a combustion fuel. For example, 20MWh thermal x 0.28tCO_2/kWhth = 5.6tCO_2 (EU ETS figures).

Validations were carried out to ensure the quality of these estimates. Different sources were used to validate partial data or sub-sector data such as (but not limited to):

- EU ETS voluntary reporting information from large individual companies was reviewed to validate intensity (tCO_2e / tonne food production).
- Overall sector level energy consumption matches with energy reported by a DG JRC study ("Energy use in the EU food sector: State of play and opportunities for improvement", 2015, from Eurostat).
- Total GHG emissions for 2020 were 79 $MtCO_2e$ (EEA's 2018 GHG inventory (39 Mt/y CO_2e from heat >20 MWth)).

[10] https://www.eea.europa.eu/publications/annual-european-union-greenhouse-gas-inventory-2021
[11] Many of these combustion units belong to sugar manufacturers, dairies and breweries (more than 100 sites reporting to EU ETS) but also others (such as feed, starch or fruit and vegetables) and there are also many combustion units in food processing sites below the EU ETS threshold not covered by this EU ETS registry. https://www.i4ce.org/wp-core/wp-content/uploads/2015/10/13-03-Climate-Report-39-Agriculture-in-the-EU-ETS_CDC-Climat-Research.pdf
[12] https://eippcb.jrc.ec.europa.eu/sites/default/files/2020-01/JRC118627_FDM_Bref_2019_published.pdf
[13] https://publications.jrc.ec.europa.eu/repository/handle/JRC96121

- The 2020 baseline estimate is 93MtCO_2e for the sector using raw data (energy intensity and production rates). The UK hosts 10% of European sites and other studies[14] have reported 9 MtCO_2e/year in the UK for the food processing sector. This 9 MtCO_2e matches with 10% of the 93 MtCO_2e estimated in our baseline.
- The sub-sector GHG emissions from heat generation included in this baseline (using raw data from production rates and energy intensity) matches with other studies on ETS data for the agricultural sector[15] (at combustion plants >20 MWth).

Information sources used (and our experience from similar projects in this sector) reveal high variability in energy usage and CO_2e emissions for each process or sub-sector. This has been taken into account in the analyses (e.g. using average values). This variability depends on many factors such as product portfolio, plant size, plant age, etc.

2.1.3 Key findings from the 2020 baseline

Following the above methodological approach, we estimate that the European food and drink sector (including the U.K) generated circa 94 MtCO_2e in 2020. 62% of these emissions were generated by the use of heat as during processing.

Energy usage is the main source of GHG emissions in the European food and drink sector. This is consumed either as grid electricity or heat and power generated at combustion units on site. CO_2 (or other GHGs) is not generated in conversion or manufacturing processes (other than combustion units to deliver heat) with small exceptions on fermentation processes or CO_2 addition for soft drinks. Key data on baseline energy usage and CO_2e emissions are displayed in Table 1.

Cooling systems are used intensively in many of the food processing sub-sectors. Some of the refrigerant used in these cooling systems generates GHG emissions due to leaks and losses to the atmosphere. There are no precise estimations available on the amount of these emissions and the use of the associated refrigerant gases that are being phased out by European and worldwide regulations.

Within each sub-sector there are high levels of variability in the quantities of energy used in different food manufacturing processes[16]. For example, cheese manufacturing reports a higher specific energy usage (MJ/kg of product) than milk production (including sterilisation). The energy usage factor of an installation depends heavily on the product portfolio but also on other parameters such as plant age or plant size. For example, new equipment such as turbines, boilers or dryers, have a higher energy efficiency.

The specific energy usage of food and drink manufacturing processes ranges from 5.2 MWh/tonne of product in processes with high energy requirements to 0.1 MWh/tonne (Table 1) for less intense ones.

Sub-sectors with a higher proportion of energy consumption attributed to grid electricity (up to 100%) will more easily follow their decarbonisation pathways since most grid supplies are decarbonising at rates set by EU goals. On the contrary, some sub-sectors consuming only 5% of their energy from grid electricity will see their decarbonisation pathway driven by economic viability of heat decarbonisation measures and access to finance/capital.

The average specific GHG emissions (tonnes CO_2e per tonne of product (scope 1 and 2)) from food and drink manufacturing processes ranges from 1.27 (ethanol manufacturing) to 0.05 (e.g. beer).

Most food and drink manufacturing processes that require heat (such as drying or pasteurisation) have a low temperature requirement (below 150ºC). These low temperature heat demand processes are a good opportunity for the use of renewable energy heat sources (see Section 3.2.1).

[14] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/416672/Food_and_Drink_Report.pdf
[15] https://www.i4ce.org/wp-core/wp-content/uploads/2015/10/13-03-Climate-Report-39-Agriculture-in-the-EU-ETS_CDC-Climat-Research.pdf
[16] For example, cheese manufacturing reports higher specific energy (MJ/kg of product) than milk production (including sterilisation).

The products manufactured by the food and drink sector will remain after the transition to a net zero economy. Other products such as fossil fuels directly generate GHG emissions and will be expected to undergo significant production reduction after the implementation of Green Deal policies. Food and drink processing generates GHG emissions by using energy to manufacture products, rather than from the products themselves. Therefore, there is not a need to change the products or processes themselves, only the way energy is consumed.

Table 1: Baseline data for energy usage and CO_2e emissions (2020)

Sub-sector	Production	Energy		Share of energy		CO_2e emissions		
	Production	Specific	Total	Electricity	Heating	Total	Electricity	Heat
	Mt/y	MWh/t	10^6 MWh/y	%	%	Mt CO_2e /y	Mt CO_2e /y	Mt CO_2e /y
Feed	153	0.57	87.2	30	70	**21.4**	7.3	14.0
Beer	41	0.19	7.9	30	70	**1.9**	0.7	1.3
Market milk	150	0.18	26.3	30	70	**6.4**	2.2	4.2
Cheese	5.5	0.79	4.3	80	20	**1.2**	1.0	0.2
Milk powder	2.5	1.10	2.8	30	70	**0.7**	0.2	0.4
Ethanol	5	5.20	26.0	30	70	**6.4**	2.2	4.2
Fish processing	4.5	0.40	1.8	70	30	**0.5**	0.4	0.1
Frozen Fruit & Veg (non tomato/potato)	5	1.10	5.5	12	88	**1.3**	0.2	1.1
Rest/Canned F&V (non tomato/potato)	4	1.10	4.4	12	88	**1.0**	0.1	0.9
Jams F&V (non tomato/potato)	1	3.00	3.0	30	70	**0.7**	0.3	0.5
Dried fruit/veg	0.9	0.30	0.3	50	50	**0.1**	0.0	0.0
Cut potato products (frozen)	5.6	0.85	4.8	25	75	**1.2**	0.3	0.8
Potatoes - Flakes & granulates (dried)	0.5	4.20	2.1	5	95	**0.5**	0.0	0.5
Potatoes - Rest/ others (crisps snacks)	2.5	1.60	4.0	20	80	**1.0**	0.2	0.7
Tomato processing	8	1.28	10.2	20	80	**2.4**	0.6	1.9
Grain milling	35	0.65	22.6	100	0	**6.3**	6.3	0.0
Meat processing	12.5	0.95	11.9	70	30	**3.1**	2.3	0.8
Crushing & refining of rape and sunflower seeds	41	0.70	28.7	20	80	**6.9**	1.6	5.3
Crushing & refining of soya beans	17	0.90	15.3	25	75	**3.7**	1.1	2.6
Standalone refining	5	0.25	1.3	30	70	**0.3**	0.1	0.2
Olive oil	2.2	0.60	1.3	100	0	**0.4**	0.4	0.0
Soft drinks & juices	34	0.08	2.6	80	20	**0.7**	0.6	0.1
Native & modified starch	5	1.00	5.0	30	70	**1.2**	0.4	0.8
Starch-proteins and fibres	5	1.60	8.0	30	70	**2.0**	0.7	1.3
Starch derivatives (including glucose, maltodextrins, polyols)	6	1.50	9.0	30	70	**2.2**	0.8	1.4
Sugar	16.4	2.10	34.4	3	97	**8.0**	0.3	7.7
Others	40	1.24	49.5	30	70	**12.1**	4.2	8.0
Total	**608.1**	**1.24**	**380.1**	**38**	**62**	**93.6**	**34.4**	**59.2**

2.1.4 Apportionment of GHG emissions within the EU food and drink manufacturing sector in 2020

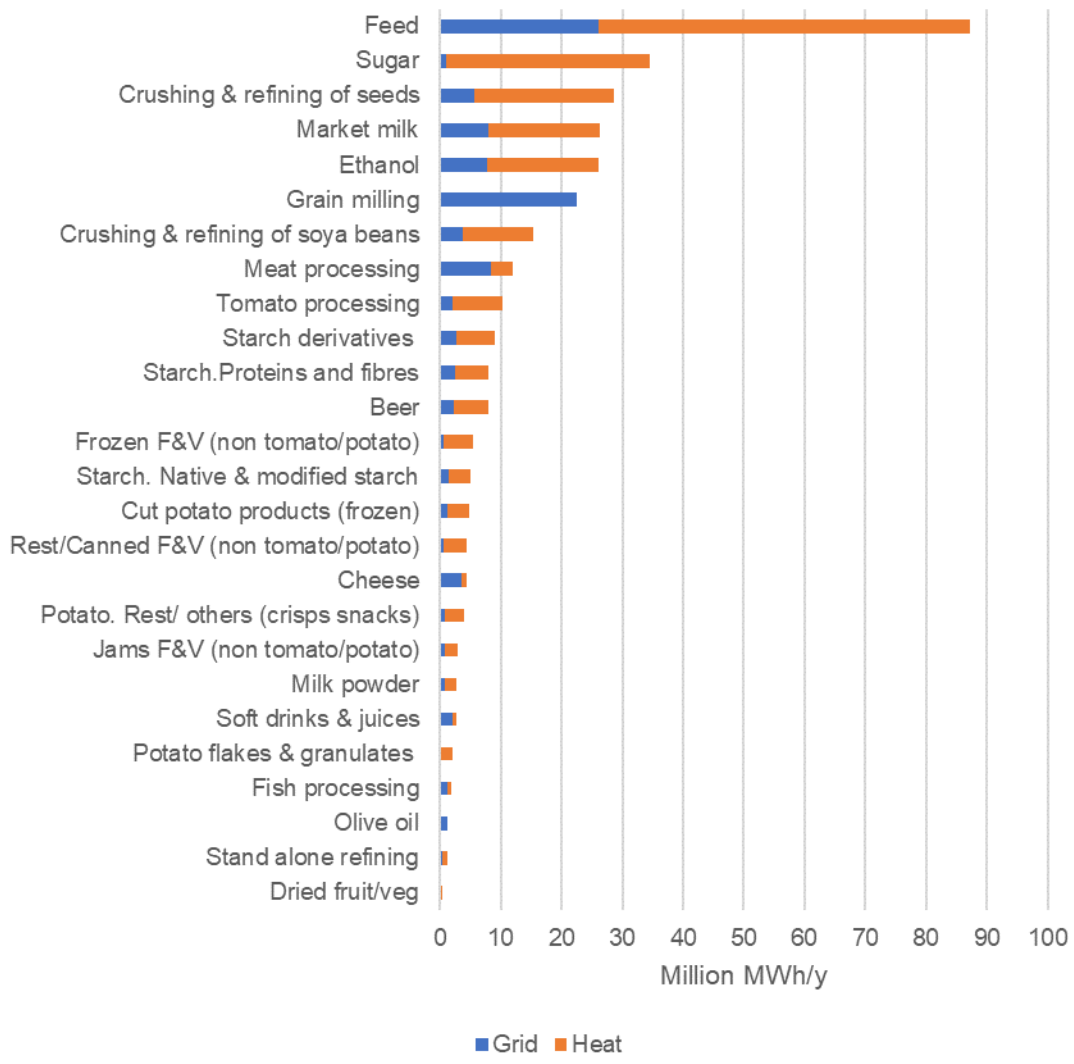
Distribution by manufacturing processes that have larger GHG generation

Our baseline data shows that GHG emissions generation is distributed across more than 20 sub-sectors, each presenting a high variability in terms of energy use and therefore also of GHG emissions. There are six sub-sectors with higher energy intensity that account for more than 50% of the GHG (so transition will be more challenging for them). The majority of sub-sectors account only for 1 to 2 % of the food and drink sector CO_2e generation. There are several sub-sectors (e.g. sugar or dried potatoes) where energy usage is almost entirely from on-site combustion, higher than 95% of energy share. These processes will have more challenging decarbonisation paths, especially if requiring high operating temperatures.

Within most sub-sectors there is a large share of small installations operated by small and medium-sized enterprises (SMEs). There are many combustion units below 20 MWth, which are not covered by official/mandatory databases, such as EU ETS.

Figure 2 shows net energy usage per sub-sector.

Figure 2: Total annual energy usage per sub-sector



Distribution between European countries with larger food and drink sector manufacturing GHG emissions

According to the EEA, based on data from the EU ETS on emissions by country in 2019, the largest GHG emitters from the EU food and drink sector were : France (18%), Spain (13%), UK(10%), Poland (10%); and Italy (9%). The countries that had achieved the greatest GHG emissions reduction in this sector since 1997 are: Sweden (16%), Latvia (10%) and Finland (1%). Other countries have reported a GHG emissions increase in this period, such as Germany, Italy and Spain.

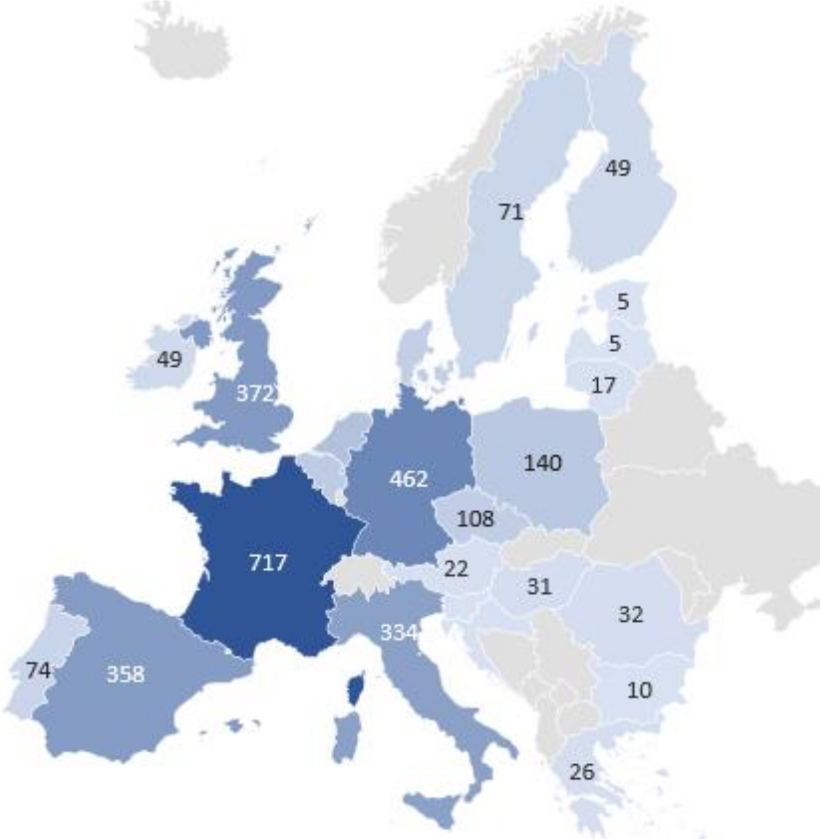
According to the European Pollutant Release and Transfer Register (E-PRTR) and, based on the number of installations covered by the Industrial Emissions Directive (IED)), France, Denmark, the United Kingdom, Spain, Poland and Italy have the largest number of installations in 2020. This is consistent with EEA (EU ETS) data on quantity of emissions. This database provides information on different IED categories. Table 2 shows the number of sites present in the countries that are most dominant in the food and drink sector.

Table 2: Number of large food and drink manufacturing installations in selected European countries

Country	IED code	Europe	France	Germany	United Kingdom	Spain	Italy
Processing Animal	6.4 b (i)	687	217	50	87	69	88
Processing Vegetable	6.4 b (ii)	1548	268	204	200	243	153
Combination of feedstocks	6.4 b (iii)	603	231	101	56		57
Dairies	6.4 c	469	1	107	29	46	36
Total		**3307**	**717**	**462**	**372**	**358**	**334**
Share %		100%	22%	14%	11%	11%	10%
Cumulative share			22%	36%	47%	58%	68%

Table 2 shows that five countries account for 68% of the food and drink manufacturing installations in Europe (EU and UK). Similar analysis could be done for emissions volume per process or sub-sector. Figure 3 provides the total number of large food and drink sector installations (those covered by IED) in each European country.

Figure 3: Food and drink large (IED covered) installations across Europe

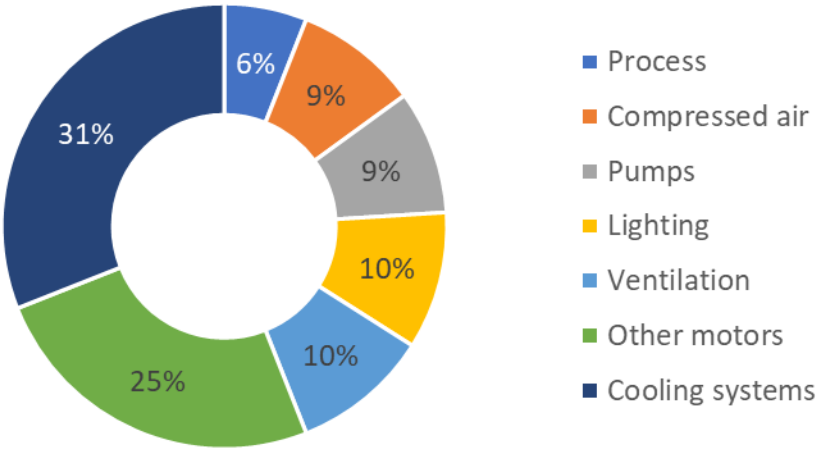


Distribution between units, equipment, and operations

Roughly two thirds of the energy used in the food and drink processing sector comes from natural gas. The second largest source is electricity, with, a minor contribution from coal and oil in third place. Processes with high heat demand are drying, evaporation, baking ovens, pasteurisation, etc. Systems that use electricity[12] include refrigeration, cooling, ventilation, lighting, pumping, air compression, etc.

Figure 4 shows how electricity consumption by the food and drink manufacturing sector can be apportioned to the use of different technologies. The significant proportion of energy used by cooling systems is a specific feature of food and drink manufacturing.

Figure 4: Share of electricity consumption (demand) of cross-cutting technologies in the food and drink manufacturing sector[17]



Conclusions derived from the 2020 baseline data

Based on the insights described (for larger sectors and countries) the study has maintained a wide scope for the analysis of measures to decarbonise the sector. It was not possible to discount any processes or countries on the basis of being insignificant.

The measures and next steps included in this report are not applicable for every country and every sub-sector. Political, Economic, Social and Technological (PEST) analysis (see Section 3.2) has been used to describe applicability restrictions of these measures taking into account the geographical and process diversity.

2.1.5 Emissions baseline for 1990

As previously explained, several policy instruments and relevant studies (e.g. IPCC) are currently expressing their emission reduction goals or ambitions using 1990 as a baseline.

Between 1990 and 2020 production by the food and drink sector grew by up to 20% in a number of sub-sectors, according to the EEA[9]. Despite this there was a reduction in the sector's net GHG footprint. This emission reduction was achieved through higher energy efficiencies and is mainly associated with the reduced use of heating energy, while electricity use has remained relatively stable. Energy efficiency measures are often not considered as a top priority to increase profitability since energy bills are typically low (2 to 10% of Opex) for a number of food and drink manufacturing processes.

In terms of heat, the energy consumed in the EU food and drink manufacturing sector has been decreasing in recent decades while production has been growing. For example, in the UK, since the 1990s, the food and drink sector has lowered its heat related carbon footprint, improving its energy efficiency by 20% between 1990 and 2010[18]. In Europe, the total GHG emissions associated with heat consumption in the food and drink sector have decreased by 23% since 1990 and by 1% between 2018 and 2019[19]. These heat related GHG emissions were equivalent to 72 $MtCO_2e$ at the 1990 baseline year.

17 https://publications.jrc.ec.europa.eu/repository/handle/JRC96121
18 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/416672/Food_and_Drink_Report.pdf
19 https://www.eea.europa.eu/publications/annual-european-union-greenhouse-gas-inventory-2021

Our study assumes that grid electricity used by the food and drink sector has remained similar to 1990 levels (mentioned in recent food industry studies[16]). This represents 34 $MtCO_2e$ in 1990 for power-related emissions.

The overall net GHG emissions for the sector in 1990 are therefore estimated to be 106 $MtCO_2e$. This is 14% higher than the estimated emissions for 2020.

2.2 Defining the pathways to net zero

2.2.1 Approach

The net zero 2050 roadmap has been developed using the approach shown in Figure 5.

Figure 5: Roadmap development flowchart

The roadmap has been developed by considering two possible futures for the EU food and drink sector in the form of pathways to net zero that involve different combinations of decarbonisation options. The pathways help the sector understand how changes in future market forces, supply chains, policies, incentives, availability of funding, among other factors, may gradually change the course of action for the sector, and what could be the alternative paths to net zero for the sector as progress is being made over time.

The pathways highlight a number of enabling actions that different stakeholders in the food and drink sector would need to follow to be able to implement each pathway to net zero. A number of actions and decarbonisation options that could be enabled more quickly have also been included in these two pathways. These are further discussed in Section 4.4.

2.2.2 Decarbonisation measures

Food and drink processing typically has a high heating and cooling demand and is uniquely placed to implement a wide range of decarbonisation measures. The majority of interventions reviewed are relevant for all food and drink sectors but some sub-sector specific actions have also been included.

Decarbonisation measures for this report have been identified by reviewing the sector's best practices and predicted technology development and selected, in consultation with FoodDrinkEurope members' feedback. There is still capacity to implement mature energy efficiency measures so the list of decarbonisation options consists of both mature and novel technologies with the potential to become more prevalent in the next 20 years. The maturity of the measures has been evaluated using the Technology Readiness Level (TRL) descriptor. Technologies of maturity Level 7, 8 and 9 have been reviewed for their decarbonisation capacity. TRL Level 7 indicates prototypes that have been used in an operational environment, TRL 8 – technology that has been proven to work under typical conditions and TRL 9 systems' operation is proven through mission operations.

The list of decarbonisation measures has been prepared with the lens of applicability in the food and drink sector, reviewing barriers, drawbacks, and additional technologies required for successful implementation. With SMEs comprising more than 90% of the sector[20], the relevance to the SME market has also been considered. There are also large installations with high energy intensity where decarbonisation will entail sector specific challenges. The list of actions was varied and covered changes to the processes and renewable energy generation options.

The long list of measures initially identified was grouped to model their decarbonisation potential. Figure 6: Categories of decarbonisation measure and technique, shows the key categories. The complete list has also been included in Appendix 3.

As shown in Figure , food and drink processing sites can introduce decarbonisation measures at both the supply and demand side of energy use. This applies to both heat and power.

An example could be a local anaerobic digestor producing biogas from process residues (e.g. to use organic content in effluent during water treatment). There is excellent potential to deploy biogas at industrial sites for both heat supply and fuel. Several plants are already using this option (European Biogas Association[21]). Due to its properties, organic stabilised form, the digestate can also be used in agriculture as a chemical fertiliser replacement. High thermal needs mean that biomethane availability can facilitate the decarbonisation of the sector.

Another example on the supply side is green hydrogen, which is a clean-burning fuel. Hydrogen is seen to have considerable potential, with a substantial part of the funding for Green Initiatives in the EU being directed towards green hydrogen research and development. Hydrogen's versatility means it has the potential to disrupt many processes, including energy storage and supply. The Hydrogen Council[22] estimate that by 2050 the hydrogen market could accommodate 18% of global energy consumption (vs 4% today). However, there are barriers on its applicability (see section 3.2 of this report).

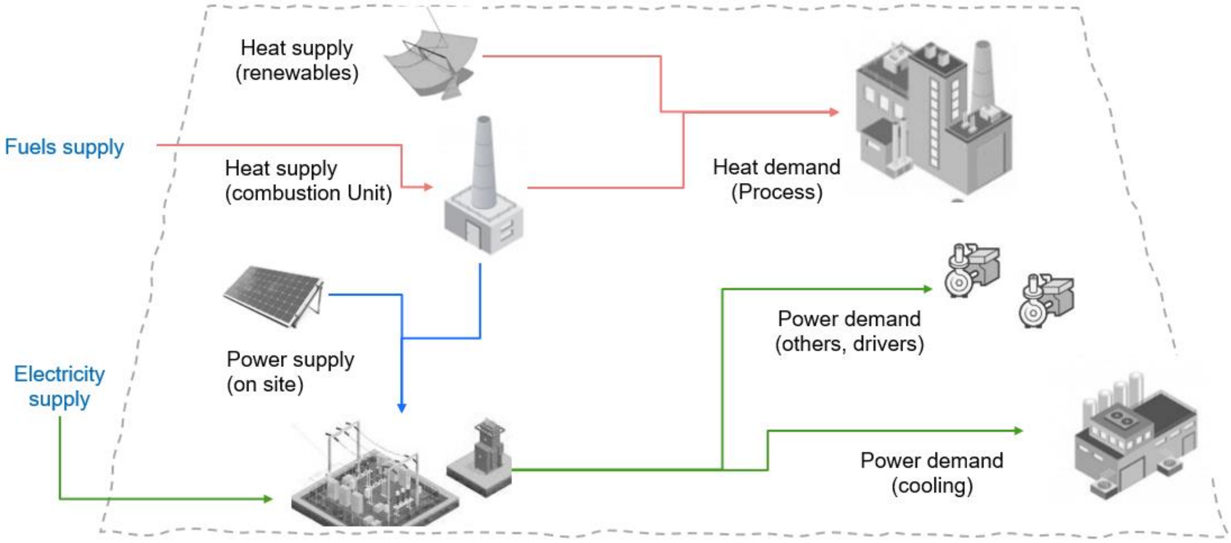
The food and drink sector can also reduce energy demand on-site by introducing proven and mature energy efficiency technologies and novel technologies, including sub-sector specific applications. More efficient equipment utilising robotics and flexible automation, more efficient motors, and removing heat requirement from processes can further decarbonise processing sites.

[20] https://eippcb.jrc.ec.europa.eu/sites/default/files/2020-01/JRC118627_FDM_Bref_2019_published.pdf

[21] https://www.europeanbiogas.eu/wp-content/uploads/2021/04/Paper-The-role-of-biogas-production-from-wastewater-in-reaching-climate-neutrality-by-2050.pdf

[22] https://hydrogencouncil.com/wp-content/uploads/2021/02/Hydrogen-Insights-2021.pdf

Figure 6: Categories of decarbonisation measure and technique



2.2.2.1 Energy management measures

The first category of energy management interventions includes process management and optimisation measures. The actions are usually low-cost, available to all sub-sectors and result in reduced energy use on-site. These measures are a starting point for other interventions. Some of the measures, although low cost, will require staff commitment and will need to be repeated on a regular or on-going basis.

The energy management measures focus on optimising processes and reducing energy intensity and there is still capacity to implement them across the sector. The following techniques can be used to achieve energy reduction:

- Regular energy auditing and energy monitoring (using Key Performance Indicators and benchmarking).
- Use of adaptive controls and sensors for measurement of core parameters.
- Decision making support systems such as energy plans (see section 2.3.2.1.8 of the FDM BREF) – energy management systems.
- Pinch analysis used to identify heat recovery opportunities or to determine minimum process heating and cooling, especially in the brewing sector and the milk powder industry.

Regular maintenance of manufacturing assets is key to preventing a reduction in energy efficiency due to, for example, lower compression efficiency, air leakage and pressure variability.

Table 3: Sample energy management decarbonisation measures

Examples of actions / interventions	Generic/ specific	Capex/ Opex	SMEs?	TRL	Scope 1	Scope 2
Energy Management Systems	Generic	Opex	Y	9; BAT(1)	Y	Y
Controls	Generic	Opex	Y	9; BAT	Y	Y
Maintenance	Generic	Opex	Y	9; BAT	Y	Y
Other managerial measures (training, etc)	Generic	Opex	Y	9; BAT	Y	Y

(1)Best Available Technique

2.2.2.2 Decarbonisation of combustion units and electrification of heat

There are both mature and novel solutions to decarbonise combustion units and a gradual shift towards renewable generation can be seen across all sub-sectors. Table 4 shows a selection of interventions available to the food and drink sector.

Table 4: Sample measures for decarbonisation of combustion units

Examples of actions/interventions	Generic/ specific	Capex/ Opex (2)	SMEs?	TRL	Scope 1	Scope 2
CHP	Generic	Capex	N	9; BAT	Y	Y
Combined cycle	Generic	Capex	N	9; BAT	Y	Y
Heat pump for hot water generation (sanitary, heating, water tracing, cleaning, etc)	Generic	Small Capex	Y	9; BAT	Y	Y
Replacement/New unit with higher Energy eff.	Generic	Capex	Y	9; BAT	Y	Y
Bio based fuels (biogas, e.g. from Anaerobic digestor)	Generic	Small capex	Y	9; BAT	Y	N
Novel Anaerobic digestion features for Biogas generation from wastewater	Generic	Capex	N	8; ET	Y	N
Bio based fuels (biomass)(1)	Generic	Small Capex	Y	9; BAT	Y	N
Residues/waste as fuel	Generic	Capex	Y	9; BAT	Y	N
CO_2 capture and storage (CCS)	Generic	Capex	N	9; BAT	Y	N
Gasification/pyrolysis of solid waste / residues	Generic	Capex	N	9; BAT	Y	N
Cleaner fuels (H_2)	Generic	Opex	Y	8; ET	Y	N
Cleaner fuels (Ammonia)	Generic	Capex	Y	6; ET	Y	N

(1)Certain biobased fuels (such as woody biomass) would be consumed under cascade guidance generated by EU (non-binding).(2) A number of interventions (like H_2 as fuel) will have impact on Opex and Capex but only most significant one is reported here.

There is excellent decarbonisation potential in switching from fossil fuels to renewable energy. The International Renewable Energy Agency projects that 60%[23] of existing heat demand can be provided by renewable energy, especially that requiring low to medium temperatures. The most significant potential for integrating renewable energy is seen in biomass energy, solar thermal heating, and geothermal heat pumps. Heat pumps (using electricity from renewable sources) can be used to increase the drying efficiency of conventional air dryers and perform as dehumidifiers.

The use of bioenergy or bio-feedstocks to generate heat, including options that deliver electricity, is a mature technology recognised by the food and drink sector. In certain sub-sectors, such as dairy, switching to biogas obtained from anaerobic digestion can bring significant emissions reduction.

Switching from combustion to electric heating can also provide substantial reductions but decarbonisation is dependent on the energy mix in the grid in the given location.

Low carbon hydrogen can also be used as an alternative fuel, but achieving true emissions abatement potential will rely on innovation, both in hydrogen production and infrastructure.

Carbon capture and storage (CCS) has been reviewed but due to its high cost is not deemed as applicable to the food and drink sector, in particular the SME segment.

[23] https://www.fooddrinkeurope.eu/uploads/publications_documents/SME_White_Paper.pdf

Geothermal technologies, including the use of ground source heat pumps (up to 50°C), direct geothermal energy (up to 100°C), and deep and enhanced geothermal systems (up to 190°C) have been included in this group of measures. However, it has been recognised that the technologies yielding higher temperatures in particular, are only available in certain geolocations and might require significant investment, even at the feasibility stage of the project.

Solar systems represent a significant contribution to renewable generation, both in the form of solar photovoltaics and solar heat (concentrated solar systems and non-concentrated solar heat installations). Non-concentrated solar heat options can be used to pre-heat the water in small applications and can be an affordable renewable option for the industry. Concentrated solar technologies use mirrors and lenses to focus a large area of sunlight onto a receiver which in turn can be converted to heat (solar thermal energy) or electricity can be generated using a heat engine connected to an electrical power generator.

2.2.2.3 Lower heat demand

Process heat can account for 60-70% of the total energy needs in the food and drink sector, with some processes (e.g. baking) experiencing significant heat loss[24]. Some baking and processing equipment loses over half of its energy to the atmosphere[25]. This is associated with difficulties in customising the control of the operation of some of these ovens[26]. Therefore, lowering the heat demand shows great potential for decarbonisation of the sector, as shown in Table 5.

Evaporation and pasteurisation, which operate at lower temperatures, can benefit from heat recovery from other processes. Examples of processes that can apply heat or steam recovery are baking and bread proving, steam cooking tunnels, sterilisation and drying.

Heat recovery and on-site steam, electricity, and heat production, using distributed generation, co-generation, or combined heat and power (CHP), can also lower overall heat demand and have been included in this review.

Table 5: Sample decarbonisation measures focused on lowering heat demand

Examples of actions / interventions	Generic/ specific	Capex/ Opex	SMEs?	TRL	Scope 1	Scope 2
Heat recovery	Generic	Capex	Y	9; BAT	Y	N
Identification of heat recovery option (Pinch analysis)	Generic	Small Capex	N	9; BAT	Y	N
Insulation	Generic	Small Capex	Y	9; BAT	Y	N
Optimising steam distribution systems	Generic	Capex	Y	9; BAT	Y	N
Mechanical Vapor Re-Compression (MVR)	Generic	Capex & Opex	Y	9; BAT	Y	Y
Replacement/ new cooking device/unit (more effi.)	Specific	Capex	Y	9; BAT	Y	Y
Separation with membrane (instead of heat)	Specific	Capex	Y	7; ET	Y	Y
Cleaning (CIP) without heat	Generic	Small Capex	Y	7; ET	Y	Y

[24] Alia Ladha-Sabur, et al. Mapping energy consumption in food manufacturing. Trends in Food Science & Technology, 86 (2019), pp. 270-280
[25] Sanjay Mukherjee, Abhishek Asthana, Martin Howarth, Ryan Mcneill, Ben Frisby. Achieving operational excellence for industrial baking ovens Energy Procedia, 161 (2019), pp. 395-402
[26] https://c2e2.unepdtu.org/wp-content/uploads/sites/3/2016/03/cts402-improving-efficiency-of-bakery-ovens-0.pdf

Examples of actions / interventions	Generic/ specific	Capex/ Opex	SMEs?	TRL	Scope 1	Scope 2
New drying technologies	Specific	Capex	Y	7; ET	Y	N
Solar drying for organic intermediates with renewable heat	Specific	Capex	Y	8; ET	Y	N
Advanced oven technology: water bath oven	Specific	Capex	Y	7; ET	Y	N

2.2.2.4 Decarbonisation of cooling

Decarbonisation of energy for cooling is a specific challenge for the food and drink sector. Emissions generated from providing cooling energy are significantly higher in the food and drink sector than any other industrial sector.

Energy efficient cooling can achieve substantial energy savings and includes advanced refrigeration technologies and advanced insulation on equipment and piping. Simple measures, such as installing pump controls, operating at higher temperatures and adjusting operational temperatures, can reduce cooling demand by as much as 10-30%[27] and can be applied widely across all sub-sectors. The use of mixed refrigerants (as listed in Table 6) can further reduce the energy demand for cooling.

Table 6: Sample cooling decarbonisation options

Examples of actions / interventions	Generic/ specific	Capex/ Opex	SMEs?	TRL	Scope 1	Scope 2
Cooling by Renewable sources (power)	Generic	Capex	Y	8; ET	N	Y
Avoid chillers for cooling	Generic	Small Capex	Y	9; BAT	N	Y
Refrigeration heat recovery	Generic	Small capex	Y	9; BAT	N	Y
Replacement/ new unit more efficient	Generic	Capex	Y	9; BAT	N	Y
Operational efficiency / reduced storage time	Generic	Small Capex	Y	9; BAT	N	Y
Higher temperatures	Generic	Opex	Y	9; BAT	N	Y
Alternative refrigeration (e.g. magnetic)	Generic	Capex	Y	7; ET	N	Y
Precooling of ice-water	Specific Dairy	Capex	Y	9; BAT	N	Y
Cooling fruit and vegetables before freezing	Specific F&V	Capex	Y	9; BAT	N	Y

2.2.2.5 Process power (not used for heat or cooling)

The improved energy efficiency of processing power is a crucial means of achieving net-zero. The energy efficient technologies are often sub-sector specific and include intervention across all aspects of process power. Due to the variability, this report focuses on measures with the greatest emissions abatement potential. A sample of process measures for decarbonisation is included in Table 7.

[27] Stefan Henningsson, *et al.* Minimizing material flows and utility use to increase profitability in the food and drink industry. Trends in Food Science & Technology, 12 (2001), pp. 75-82

Table 7: Sample of process power decarbonisation measures

Examples of actions / interventions	Generic/ specific	Capex/ Opex	SMEs?	TRL	Scope 1	Scope 2
Renewable sources	Generic	Capex	Y	7; ET	N	Y
Use of high-efficiency motors / drivers	Generic	Small Capex	Y	9; BAT	N	Y
Frequency converters for motors	Generic	Small Capex	Y	9; BAT	N	Y
Variable speed drives	Generic	Small Capex	Y	9; BAT	N	Y

2.2.2.6 Sub-sector specific measures

Due to the complex nature of the food and drink sector, there is a large group of sub-sector specific measures that have been reviewed with the help of FoodDrinkEurope members. The actions span across all categories and were assessed based on their uptake and carbon emissions reduction potential.

An example of a sub-sector specific measure is the use of energy efficient homogeniser. The homogeniser's working pressure is reduced through optimised design and thus the associated electrical power needed to drive the system is also reduced. Table 8 shows a sample of sub-sector specific measures analysed.

Pressing and dewatering products prior to drying is another example of measures applicable to specific sub-sectors such as Starch, Ethanol and Sugar. Solar energy can also be used for pre-treatment of sugar beet pulp. The mechanical dewatering and pre-drying can result in significant heat demand reduction.

Non-thermal pasteurisation, using UV, pulsed light or ultrasound (or a combination of thereof) also results in significant heat demand reduction. Cold pasteurisation using microporous membrane filters can also be used to retain the majority of bacteria and yeast. These actions are especially advantageous for heat sensitive products such as beer, wine (especially sparkling wine) and pulp-free fruit juices.

Table 8: Sample sub-sector specific decarbonisation measures

Examples of actions / interventions	Generic/ specific	Capex / Opex	SMEs?	TRL	Scope 1	Scope 2
Energy-efficient homogeniser	Specific Dairy	Capex	Y	9; BAT	N	Y
Larger shock freezers, with warmer evaporation temperatures	Frozen food, Ice cream	Capex	Y	9; BAT	N	Y
Application of a negative pressure for mixing purposes	Specific soft drinks	Capex	Y	9; BAT	N	Y
Use low-pressure blowers for bottle drying	Specific soft drinks	Small Capex	Y	9; BAT	N	Y
Precooling of ice-water	Specific Dairy	Capex	Y	9; BAT	N	Y
Cooling fruit and vegetables before freezing	Specific F&V	Capex	Y	9; BAT	N	Y
Cooling fruit and vegetables before freezing	Specific Fruit & Vegetable	Capex	Y	9; BAT	N	Y

2.3 Decarbonisation pathways to 2050

This study has forecasted different decarbonisation pathways. Each pathway is based on external reference scenarios (given contextual realities). The complete list of decarbonisation measures described in previous sections were included for each scenario at different uptake rates.

The study estimates different overall decarbonisation values for the European food and drink sector throughout the 2020-2050 period. The main drivers to justify the different decarbonisation outcomes in each scenario include:

- Level of uptake for those decarbonisation technologies.
- Pace of grid decarbonisation from 2020 till 2050.

2.3.1 Selection of scenarios

The study has compared three different decarbonisation pathways based on three different ‘reference scenarios’. The different scenarios described in Table 9 are used to forecast the contextual reality during the food and drink sector decarbonisation route maps.

These different versions of future reality can be summarised as follows:

- **S1-Baseline, business as usual (BAU)**: This describes a scenario without the Green Deal. It shows the outcome of environmental policies in place in 2020. There were already strong EU commitments with a certain degree of ambition for GHG reduction and renewable energy sources penetration. This can be considered as our worst-case scenario.
- **S2-Faster decarbonisation**: This scenario shows a future with full implementation of the Green Deal delivering successful results (e.g. achieving goals). This assumes that the majority of worldwide regions (China, India, USA, etc.) apply similarly ambitious policies to their GHG emissions sources. These parallel worldwide transformations deliver, in the mid or long term, that cleaner technologies (such as electric boilers of green Hydrogen fuel) become economically viable due to economy of scale. This can be considered as the best-case scenario.
- **S3-Slower decarbonisation:** This scenario shows a future with full implementation of the Green Deal and mixed results. This assumes that relevant worldwide regions (such as China, India, USA, etc.) do not apply similarly ambitious policies to their GHG emissions sources or do it at slower pace than the EU. Cleaner technologies do not become economically viable in the mid-term.

Table 9: Description of the three decarbonisation scenarios used in the analysis

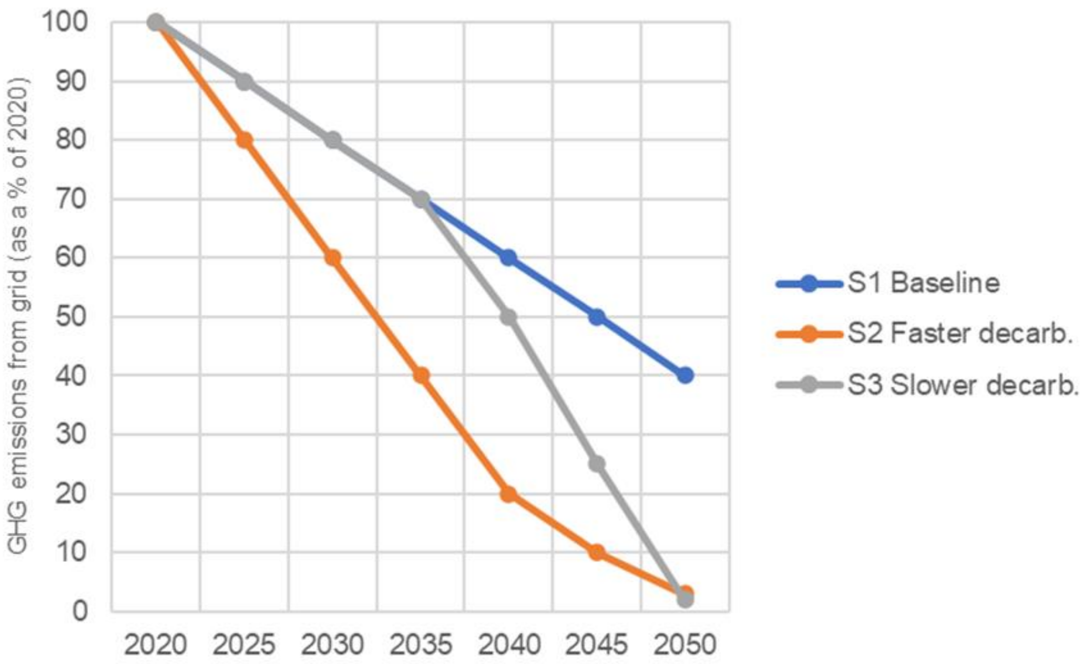
Features	S1-Baseline (3ºC)	S2-Faster decarbonisation (1.5ºC)	S3- Slower decarbonisation (2ºC)
(External) Reference scenario	Clean Planet for all (2018) “Baseline”	Impact assessment 2020 “ALLBNK”	
EU policies	Environmental policies in place in 2020 before the Green Deal	Complete reform delivered by full implementation of Green Deal	
Worldwide policies	Slower and/ or less ambitious implementation of decarbonisation policies	Large industrial regions implement policies similar to green deal	Slower and/ or less ambitious implementation of decarbonisation policies
Climate change model (scenario)	RCP 6 (likely to exceed 2ºC)	RCP 2.6 (not likely to exceed 2ºC)	RCP 4.5 (more likely than not to exceed 2ºC)
Economic feasibility of key decarbonisation technologies	Slow penetration of cleaner technologies, that remain economically unaffordable	Cleaner technologies become economically viable (2030-2040) facilitating % uptake	Slow penetration of cleaner technologies, that remain economically unfordable
Penetration of renewable in 2050 (%)	35%	>60%	>60%
Share of electricity in the total energy mix (%)	35%	50 %	50 %

This study does not review the negative impacts of climate change, physical risks for the industrial installations, nor wider impacts on the European populations. Scenarios such as S1, that include a softer set of policies, will end up with larger physical impacts (related to climate change and weather events). These physical impacts, for example, may affect raw material buying for the food and drink sector (e.g. different conditions to cultivate crops or different spread of pests). In the long term those scenarios (such as S1) might include large population movements moving away from hotter European regions. Sales and marketing units in food companies would need to react to those changes.

Our projections also consider the food and drink sector market growth from 2020 until 2050 and an average European rate of decarbonisation for electricity grid GHG emissions.

- Regarding **sales (production) in the food and drink sector** until 2050 the same path has been assumed for the three scenarios: an increase of 1% production rate per year for the sector as a whole in Europe.
- Figure shows the different **grid decarbonisation** paths assumed for each scenario in the study. The starting point for each case study (so called 100%) in 2020 is the average value of 0.28 tCO_2e. generated per MWh. The S2 scenario predicts a faster grid decarbonisation (e.g. reaching 50% (0.14 tCO_2e/ MWh) between 2030 and 2035.

Figure 7: Average European grid decarbonisation assumed in the study



2.3.2 Approach and assumptions

The analysis assigns emission reduction contributions for each group of decarbonisation techniques for the whole food and drink sector. The reality is far more complicated since these reductions will vary from one process to another. For example, certain processes with a very high share of energy consumption from the grid would mainly rely on the decarbonisation of the power supply by their power supplier. Nevertheless, those sites might also explore alternatives to accelerate decarbonisation such as power consumption from power purchase agreements (PPA) or renewable power generation at site.

This study is based on a different set of technology uptake trends for each scenario. These levels of uptake increase in every decade and are higher in the faster decarbonisation scenario (S2) assuming that some of the barriers described later in this report are overcome or resolved.

Energy management. This group of measures includes techniques such as management systems, maintenance, training and monitoring consumption. This study has assigned a maximum level of energy reduction of 10% (from 2020 to 2050) to be achieved when successfully implementing these measures.

It was assumed that circa 50% of the plants have already (2020) put in place these options for GHG emission reduction based on managerial energy reduction measures.

2.3.2.1 Heat

Lower heat demand: this group covers generic or specific measures that would reduce the amount of heat energy required by the process (e.g. insulation, recovering energy from steam condensate, cleaning in place (CIP) without heat or specific such as partial milk homogenisation). The study assumes that successful implementation of these measures would deliver 10% maximum heat reduction. The study assigns 40% uptake in 2020 for generic measures and 5% for specific ones (since a number of those specific measures are novel, not commercialised in 2020).

Electrification of heat: this group describes the impact of incorporating electric boilers and/or heat pumps to reduce the amount of heat provided by combustion units. These are techniques that apply to one or a few processes only (such as pasteurisation using high pressure). The model assigns a maximum heat reduction by 2050 of 25% of heat usage in the sector when successfully implementing all these measures. We have assumed that in 2020 only 5% of sites have already implemented these options. The IEA, in its latest Net Zero report[28], suggests no new sales of fossil fuel boilers will take place beyond 2025.

Decarbonisation of combustion units: this group includes a large set of measures such as using cleaner fuels (Green Hydrogen or ammonia or bio-based residues), using proven available technologies (CHP, cogeneration or higher efficiency units). The study assigns a maximum heat related GHG emission reduction of 52% when fully implementing all these measures by 2050. A 5% level of uptake is considered in 2020 since many of these techniques (e.g. green Hydrogen) are not available nor commercialised yet.

Heat from renewables: concentrated solar heat (CSH) is the most relevant option in this group. The study has assigned a maximum heat usage reduction by 2050 of 12% if these group of measures are successfully implemented (e.g. recognising that some processes may require higher temperatures not feasible for CSH). The estimation assumes that only 5% of sites have implemented this solution in 2020.

2.3.2.2 Power

The analysis assumes coherency between heat and power calculations: technologies that electrify heat consumption (described above) will increase the energy usage from the grid (in the same proportion or amount) during the transition. In 2050, since the European grid will be decarbonised (for most scenarios), these grid electrification projects will generate negligible (or no) GHG emissions.

The decarbonisation forecasted assumes that in the three scenarios food and drink manufacturing plants take up measures to decarbonise power regardless of the power supply (grid) being decarbonised in parallel. The drivers for companies engaging in these investments might be different, such as aiming to reduce the operating costs (lower energy usage) or to position products as cleaner (lower GHG footprint) showing smaller values in any of these footprint indicators. Security is another argument to decarbonise power, establishing your own supply will be more secure than grid-based renewables (especially with energy storage added).

Power supply switch to renewable energy: this entails reduction of grid-based power consumption achieved through the self-production of power with renewables (e.g. solar PV) or power purchase agreements (PPA) with certified renewable suppliers. The study assumes that 20% of total power related GHG emissions can be eliminated with this group by 2050 and that currently only 5% of plants have implemented this option.

Lower power demand: A large set of options were identified including more efficient heating, ventilation and air-conditioning (HVAC), reducing compressed air system leaks, LED lighting, energy-efficient homogenisers for nectar/juice production. The study assumes that 10% of total power related GHG

[28] https://www.iea.org/reports/net-zero-by-2050

emissions could be reduced with this group by 2050 and that currently 30% of plants have implemented this option.

Decarbonisation of cooling: This group contains a large set of options such as indirect adiabat air conditioning (AC) cooling systems or reduced storage time (volume). The study assumes that 5% of total power related GHG emissions could be reduced with this group by 2050 and that currently only 1% of plants have implemented this option.

Process power (not used for heat or cooling): examples for this group are well known such as the use of high-efficiency motors/drivers or variable speed drives. The study assumes that 10% of total power related GHG emissions could be eliminated with this group by 2050 and that currently only 5% of plants have implemented this option.

2.3.3 Technology uptake levels assumed for each scenario

There are many drivers that will have an impact on the level of uptake of these cleaner technologies. The main drivers were taken into account when formulating the different scenarios. They include:

- **Mandatory legally binding requirements** enforced directly or indirectly with policy tools (such as EU ETS or environmental permits, IED and BREFs): the S1 scenario assumes a future reality with lower amount of policy requirements for food and drink processing plants than the Green Deal (S2 and S3).
- **Economic drivers** such as total cost (Totex as sum of Capex and Opex) of implementing cleaner technologies: scenario 2 assumes that beyond 2035 several options will become affordable and **economically viable**. Scenario 1 (baseline) is the only one that does not assume the support of Green Deal funding schemes to accelerate the transition.

The outcome of these assumptions has an impact on the expected level of uptake forecasted for each technology group in each scenario. These levels of uptake refer to those sites where the corresponding technique is applicable. For example, many sites do not operate a combustion unit (and thus do not use fossil fuels): when the level of uptake of cleaner fuels shows a value of 100% this refers to those units where that technology is applicable. Figure , and Figure show an example of the different degree of uptake for each scenario.

Figure 8: Potential level of uptake trend for cleaner fuels in different scenarios

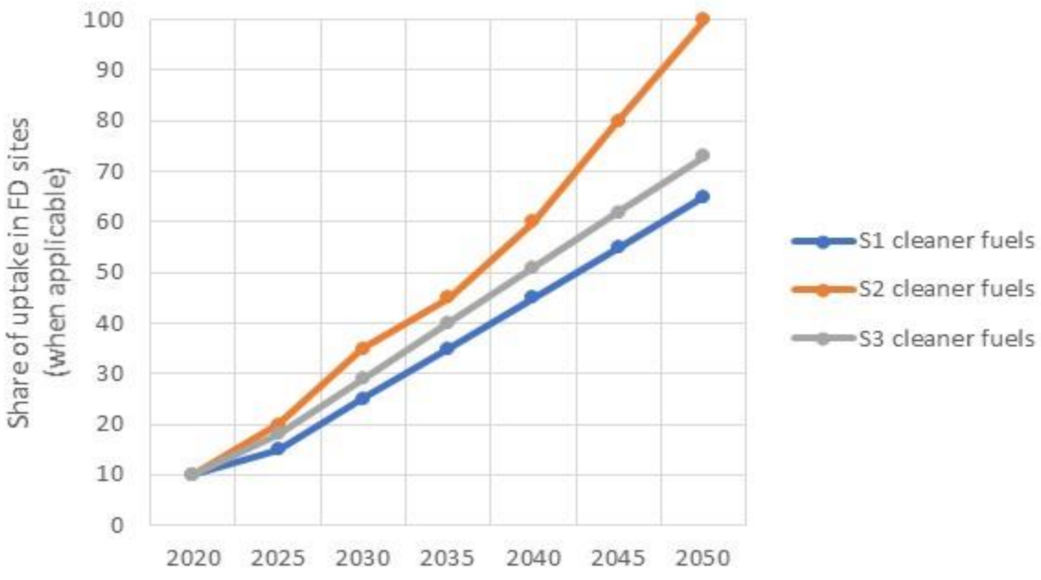
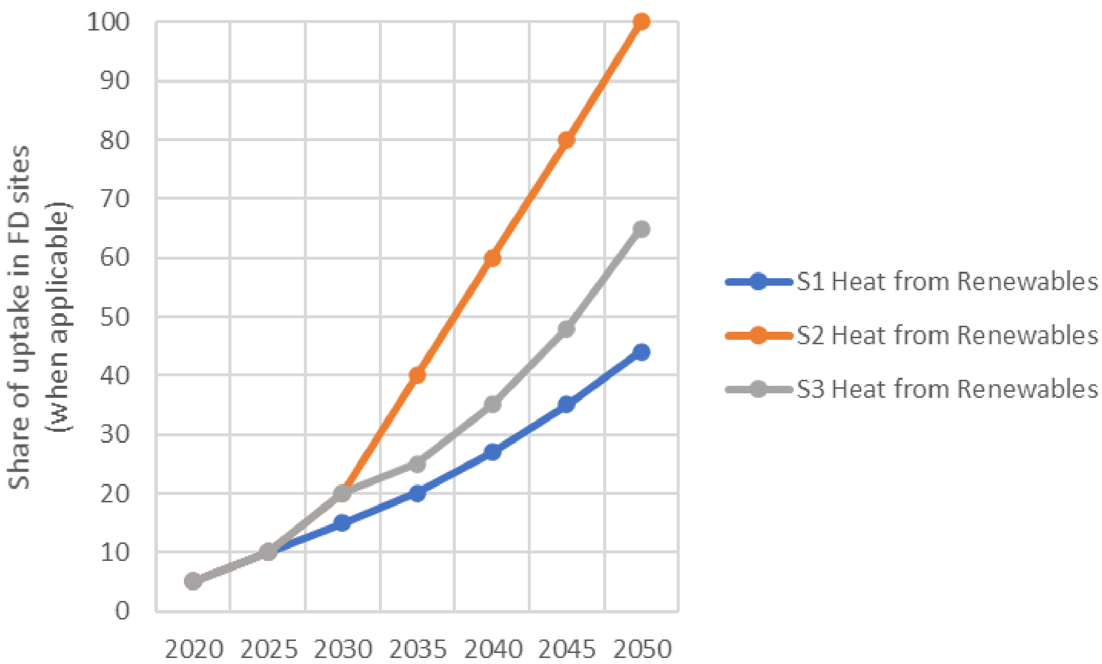


Figure 9: Potential level of uptake trend for renewable heat in different scenarios



2.3.4 Comparing the outcome for each decarbonisation scenario

This study estimates projections of different emission reduction scenarios, taking into account the assumptions and approach described in the previous sections.

Figure summarises the GHG emission reduction for every path with a similar baseline starting point of 93 $MtCO_2e$ in 2020. As described in previous sections, the main driver for these decarbonisation forecasts is the assumed level of technology uptake.

The faster decarbonisation scenario (S2) would achieve almost full decarbonisation for food and drink processing activities in Europe with a small quantity of residual emissions to be potentially manged using offsetting mechanisms. The future scenario associated with S2 assumes that every large industrial region (including China and the USA) implements ambitious policies and those lead to viable cleaner technologies such as cheap electric boilers applicable at low temperature heat demand.

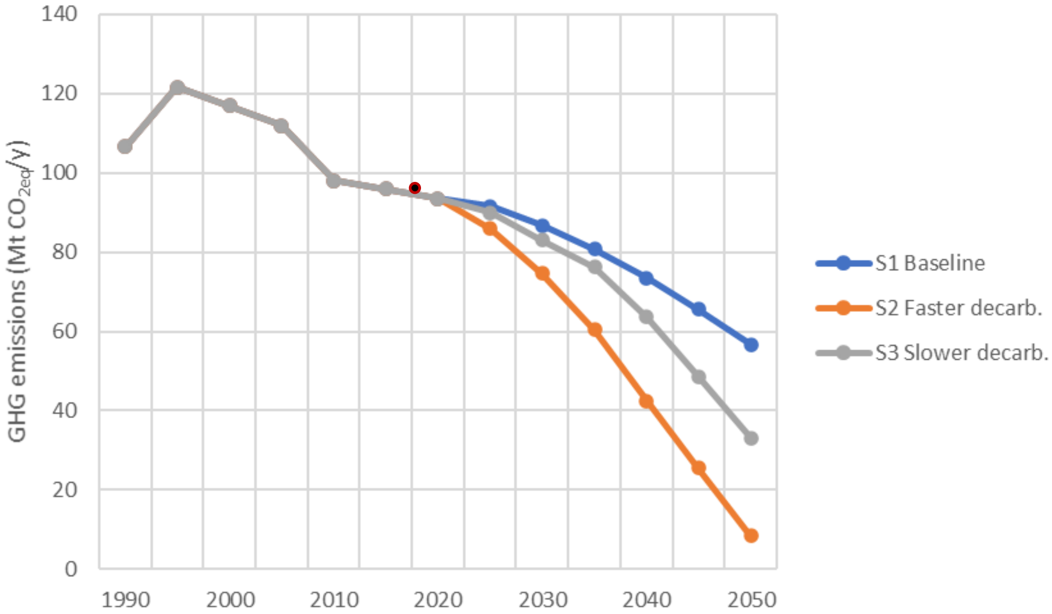
Other scenarios (such as S3) described in this study would show the outcome of a lower level of uptake of the key decarbonisation technologies. This is assumed to be the result of the numerous barriers described in Section 3.2.

For scenario S1 the decarbonisation in 2050 is even lower due to the fact that electricity decarbonisation is not fully achieved and thus scope 2 emissions remain significant.

The analysis assumes that the sector may end up in 2050 with some remaining GHG emissions. The most challenging decarbonisation measures are high temperature heat demand at remote locations (far from industrial clusters or seaports) where green hydrogen might not be affordable by 2050.

These estimations reveal that, for the best-case scenario (S2), the food and drink sector would be able to reduce GHG emissions by 92% compared to 1990 levels. For the worst-case scenario (S1) the emission reduction achievable by European food and drink sector processing stage (scope 1 and 2) would be only 47% compared to 1990 levels.

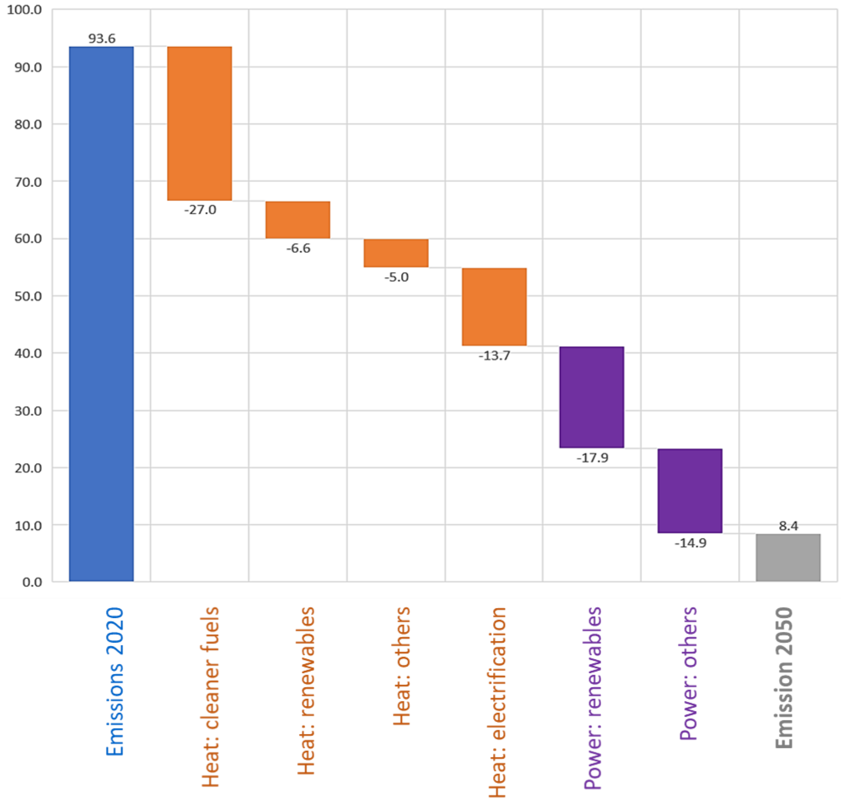
Figure 10: GHG emission reduction for the European food and drink sector for selected pathways



The contribution of each technology group will change significantly from one subprocess to another. For example, those processes that consume process heat at higher temperatures (e.g. sugar manufacturing) will have limited (smaller) contributions to decarbonisation from the electrification of heat.

Indicative values of these contributions for the European sector as a whole, for the S2 scenario are shown in Figure . The largest share of GHG reduction would be delivered by cleaner fuels, electrification of heat and the use of renewable energy.

Figure 11: Contributions to GHG reduction by technology groups (S2) ($MtCO_2e/y$)



3 The way forward

3.1 The impact of legislation

3.1.1 Introduction to policy

The European Union has set ambitious commitments to transition to a net zero economy by 2050 and has recently approved intermediate goals (2030) for decarbonisation. The Green Deal will have a relevant impact on European economic activities until 2050 and the largest set of regulatory reforms linked to climate and energy will be disclosed in summer 2021.

These Green Deal initiatives cover a wide set of topics ranging from new legally binding requirements (e.g. on new EU ETS or environmental permit rules) to new funding mechanisms or clearer rules for finance institutions' products on operations on green sustainable finance. When drafting this report some future EU initiatives such as the Carbon Border Adjustment Mechanism (CBAM) proposal were not launched. Therefore, forecasting the potential policy impacts on the food and drink sector remains challenging.

Some policy incentives might end up having heterogenous implementation across the EU. For example, national or regional regulations (or implementation features) might not support the level playing field approach that is commonly used by EU policy. Grid decarbonisation speed is another example of the uneven context for food processing installations that companies will experience across Europe.

There is a need for food and drink sector companies to monitor these reforms closely. The information on all those actions or impacts should be analysed per topic.

3.1.2 EU funds to support decarbonisation efforts

The transition to lower emission intensity activities will require significant public and private investments. The EU has developed new finance mechanisms to support industrial sectors on their decarbonisation journey. New EU funding schemes have been put in place to widen the financial support for existing installation retrofits and/or investing in new food processing plants that operate with lower energy intensity or lower GHG emissions generation.

Table 10 provides an overview and set of examples of these funding schemes.

Table 10: Examples of funding mechanisms in Europe

Name	Focus	Description	Instrument	Budget (M Euro) and TRL
The European Fund for Strategic Investments (EFSI)	Cross-cutting research and innovation scheme: maximising the energy efficiency of cross-sector industrial components in a cost-efficient manner	EFSI is an initiative launched jointly by the EIB Group - the European Investment Bank and European Investment Fund - and by the European Commission to help overcome the current investment gap in the EU. EFSI is one of the three pillars of the Investment Plan for Europe that aims to revive investment in strategic projects around the continent to ensure that money reaches the local economy.	Equity finance, Guarantees, debt financing	26,000 TRL 6,7,8
Programme for Competitiveness of Enterprises and Small and Medium-sized Enterprises (COSME)	Electricity efficiency, Heat efficiency and recovery, Carbon capture and storage, Sustainable infrastructure, Renewable energy	The Equity Facility for Growth (EFG) is a window of the Single EU Equity Financial Instrument which supports EU enterprises' growth and research and innovation (R&I) from the early stage, including seed, up to expansion and growth stage. EFG – managed by EIF – is part of COSME (Programme for the Competitiveness of Enterprises and Small and Medium-sized Enterprises), an initiative launched by the European Commission. Through COSME EFG, EIF invests in selected funds – acting as EIF's financial intermediaries – that provide venture capital and mezzanine finance to expansion and growth stage SMEs, in particular those operating across borders. The fund managers will operate on a commercial basis, to ensure that investments are focused on SMEs with the greatest growth potential."	Equity finance	2,300 TRL 1-9
		Purpose is to facilitate access to debt finance for SMEs by providing guarantees and counter-guarantees, including securitisation of SME debt finance portfolios, to selected financial intermediaries	Guarantees	
Horizon 2020	Cross-cutting R&I: improving system integration, optimal design, intelligent and flexible operation, including industrial symbiosis to increase energy and resource efficiency	2021-2027 EU Research Framework Programme. Several relevant areas of intervention (e.g. 3.2.7. Circular Industries; 3.2.8. Low-Carbon and Clean Industries, 4.2.4. Buildings and Industrial Facilities in Energy Transition)	Grant/ subsidies	100,000 TRL1-9
H2020: INEA Grants for energy and transport		Provides grants to innovative projects in the field of transport and energy. Support technology research and development in line with the EC priorities.		5,300 TRL 6,7,8
Just Transition Fund	Reduce emerging regional disparities caused by the transition towards a climate neutral	Reskilling people, providing cleaner transport and energy efficient homes in regions at risk of socio-economic difficulties as a consequence of the closure of fossil fuel-related mining and quarrying as well as	Various	7,500

	economy. Investments in SMEs, R&I, Deployment of technology and infrastructure, digitalisation, circular economy and job-search assistance and consultation	sectors requiring major transformation, such as the steel, cement, chemicals and car manufacturing sectors		
Innovation Fund	Sector-specific R&I: increasing the cost effectiveness of not yet economically viable technologies	The Innovation fund will support low-carbon innovative demonstration projects in energy intensive industries, innovative renewables, energy storage, carbon capture, use and storage (CCUS). The Fund provides predominantly grants, covering up to 60% of relevant costs, out of which 40% up-front financing based on pre-defined milestones before the whole project is up and running. Can provide funding of about €10 billion depending on the carbon price for the period 2020-2030. Funded by allowances from the EU Emissions Trading System.	Grant/ subsidies	10,000 TRL 7,8,9
Recovery and Resilience Facility	Electricity efficiency, Heat efficiency and recovery, Carbon capture and storage, Renewable energy, Sustainable infrastructure	The Recovery and Resilience Facility (the Facility) will make €672.5 billion in loans and grants available to support reforms and investments undertaken by Member States. The aim is to mitigate the economic and social impact of the coronavirus pandemic and make European economies and societies more sustainable, resilient and better prepared for the challenges and opportunities of the green and digital transitions.	Debt financing, Grant/ subsidies	672,500
Connecting Europe Facility (CEF) Energy	Cross-cutting R&I: improving system integration, optimal design, intelligent and flexible operation, including industrial symbiosis to increase energy and resource efficiency	The Connecting Europe Facility (CEF) is a key EU funding instrument developed specifically to direct investment into European transport, energy and digital infrastructures to address identified missing links and bottlenecks. Under the Connecting Europe Facility (CEF) is a funding framework to support key EU investments in transport (Trans-European Transport Networks, TEN-T), energy (Trans-European Energy Networks, TEN-E) and Broadband and Information and Communication Technologies (ICT).	Grant/ subsidies, Guarantees, Debt financing	5,300 TRL 9

The global COVID-19 pandemic has severely hit economies all over the world. In the EU, public authorities are deploying large recovery packages to bring their economies back on track. These recovery programmes can be powerful tools for simultaneously addressing two of the most pressing issues of our time: the socio-economic consequences of the pandemic and the climate crisis.

In this context, EU funds so far have not been implemented homogeneously across European countries. For example, some countries such as Finland, Belgium, Germany and Spain have used/intend to use a higher share of this recovery fund to support decarbonisation transition.

The overall cost of the decarbonisation transition for the European food and drink sector is hard to estimate in 2020 since there are still many uncertainties such as: (1) how many companies will decide to build a new cleaner site rather than carrying out many retrofits on existing units or (2) when will green hydrogen become affordable as a fuel. Nevertheless, the costs to decarbonise the sector is expected to be large and only a small share of the transition costs will be covered with the public financial support described in this section.

3.2 Barriers, challenges and opportunities

3.2.1 Opportunities

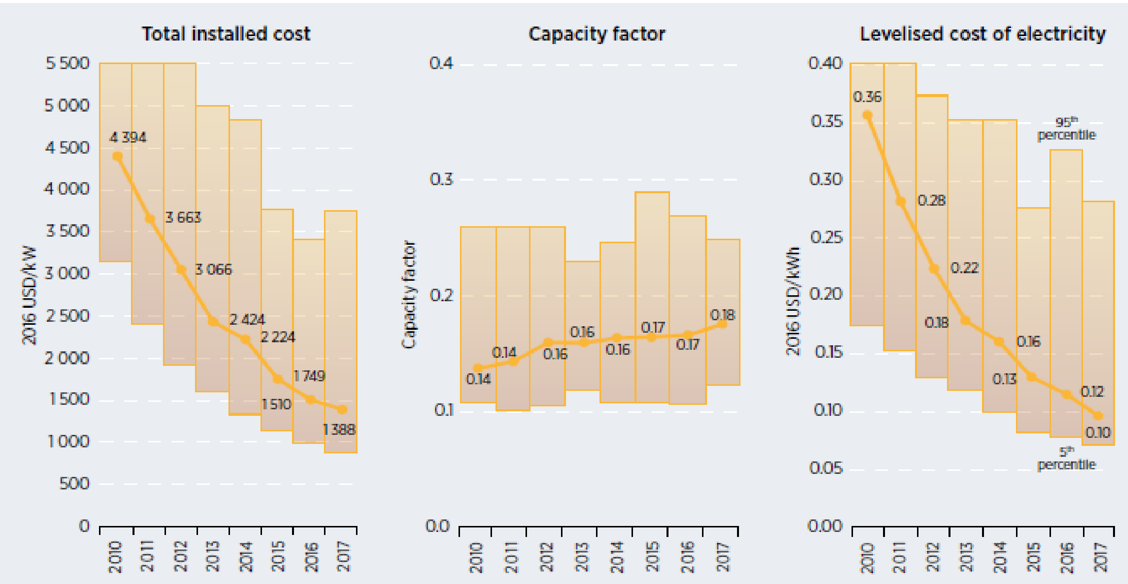
The transition to net zero will unlock a number of opportunities for industrial companies in the food and drink sector such as:

Lower operating costs: The reduction of GHG emissions in this sector will predominantly come about as a result of reducing energy usage in food and drink processing installations (i.e. energy efficiency measures). This is a win-win situation that will have benefits for operators (lower Opex) and society (lower GHG emissions). Energy costs can be small for some companies but significant in others. However, reduction in energy costs will certainly underpin an argument to justify investment in energy efficiency measures with fast returns. A number of studies (such as "Decarbonizing the food and beverages industry: A critical and systematic review of developments, sociotechnical systems and policy options"[29]) state payback times for decarbonisation measures ranges from 0.5 to 6.5 years for several processes[31].

Lower operating cost related to the maturity of renewable energy technology: Policy initiatives will ultimately decrease the cost of renewable energy supply. A number of key renewable technologies (such as concentrated solar heat (CSH)[30], solar PV and wind power[31]) have demonstrated a proven record of significantly reduced costs in the past decade. It should be noted that solar energy has barriers to implementation such as lower irradiation factors in Northern countries (see Section 3.2). The IEA operates a database on industrial sites that have incorporated CSH.

Figure 12 shows how the cost of renewable energy decreased between 2010 and 2017.

Figure 12: Example of decreasing renewable energy source costs (source: Irena[32], 2017)



Higher margins for cleaner sustainable products: The market for more sustainable food and drink products is growing. Consumers are becoming more environmentally aware and appreciate seeing indicators on the environmental performance of products (such as GHG footprints). The EU Farm to Fork strategy will harmonise these initiatives to ensure clear and reliable reporting schemes. It is recommended that food and drink companies should start using environmental impact indicators to

[29] https://www.sciencedirect.com/science/article/pii/S1364032121001507
[30] https://www.evwind.es/2020/07/29/the-cost-of-concentrated-solar-power-fell-by-47-between-2010-and-2019/76120
[31] https://www.irena.org/costs/Power-Generation-Costs/Wind-Power
[32] https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2018/Jan/IRENA_2017_Power_Costs_2018.pdf

support their decision making around decarbonisation. Although this remains less important than other purchasing criteria [33].

Funding scheme to address part of the investment needs: There are numerous financing mechanisms related to reducing GHG emissions in industry for both novel and mature techniques (see Section 3.1.2). In addition to reducing GHG emissions this investment can help modernise part of the industrial installation and achieve wider goals (such as launching new products). Transition costs may be significant for certain energy intensive processes and thus such funding may only cover only a small share of the costs.

COVID recovery funds to accelerate transition decisions: Governments across Europe are launching stimulus packages to revive their economies and to restart economic development. This is an opportunity to accelerate investments in decarbonisation. In certain countries food industries might have not been selected as a decarbonisation priority.

Profit from intense bio-based resources demand: A number of industrial sectors like petrochemicals and oil and gas refining companies will seek very large volumes of bio-based fuels and bio-based feedstocks to unlock their challenging decarbonisation pathways. Second generation biofuels provide the opportunity for food installations to dispose organic residues at lower costs. Industrial companies from the food and drink sector could become key partners both to share knowledge and, in some cases, supply organic bio-based residues. However, this may lead to increased competition to secure access to scarce agricultural materials, waste oils or other bio-based feedstocks.

Higher share of heat demand at low temperature can be provided by renewables: Many food processes use low operating temperatures. This enables heat to be provided by renewable sources (e.g. solar heat delivers 50 to 400°C)[34] Processes like scalding, cleaning and blanching use operating temperatures ranging from 60 to 80°C. Others like evaporating, pasteurizing or cooking use temperatures from 40 to 120°C. Global data confirms that the food and drink sector currently has low renewable energy usage - around 30% of its total consumption[35]. Biomass heat has been used extensively. There are worldwide examples for this sector such as the use of a geothermal energy dehydrator in a food processing plant in Mexico[36] for a 9 Mt/day unit. There are also other examples in China, Hungary, Russia, and Turkey[37].

3.2.2 Overview of barriers and challenges

In general, investment in low-carbon technology alternatives faces barriers such as:

- Higher capital and or operational costs.
- Fuel costs.
- 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.

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[33] https://www.mdpi.com/2071-1050/11/22/6279/pdf

[34] Source: EREK, "Integrating solar heat into food-production process", *Resource Efficient,* Accessed: February 23, 2021, https://www.resourceefficient.eu/cs/node/825

[35] Source: R. Sims et al, *Opportunities For Agri-Food Chains To Become Energy-Smart*, November 2015, http://www.fao.org/3/a-i5125e.pdf

[36] Source: Alexander Richter, "First industrial-grade geothermal food dehydrator of Latin America installed in Nayarit, Mexico", *Think Geoenergy,* September 25, 2020, https://www.thinkgeoenergy.com/first-industrial-grade-geothermal-food-dehydrator-of-latin-america-installed-in-nayarit-mexico/

[37] Source: IRENA, *Accelerating geothermal heat adoption in the agri-food sector*, January 2019, https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Jan/IRENA_Geothermal_agri-food_2019.pdf

- Lack of reliable and complete information for investment decision making.
- Business and policy uncertainty.
- Access to mature energy efficiency technologies and, separately, research and development (R&D).

Due to an historic reliance on fossil fuels, and the relative novelty of low-carbon technologies and strategies, there are no simple substitutions and each decarbonisation option will have challenges[38]. In addition, only some decarbonisation options will have economic benefits (e.g. lower energy costs).

The cost of implementation of some decarbonisation measures is often increased due to the existing infrastructure not being suitable for these strategies and technologies[38] (e.g. the hydrogen gas network). See Table 12.

Financial motivation to adopt certain low carbon technologies may not be imminent in the short term. However, what could help stimulate the adoption of low-carbon fuel sources in the short to mid-term, is the assessment of cost effectiveness in adopting low-carbon technologies with a view to appeasing shareholders and attracting potential investors[48]. This is already being witnessed in multiple markets and could help to kickstart wider-market adoption.

Table 12: Barriers to the commercialisation of fuel switching technologies[48]

Fuel Type	Main challenges to be addressed before commercialisation
Electricity	• Reliability • Impact on product quality for direct heating applications
Hydrogen	• Technology availability • Flame temperature and control • Impact on product quality for direct heating applications • Supply of hydrogen • Management of NOx emissions
Biomass/Waste	• Reliability of supply • Impact on product quality for direct heating applications

Technology development can be slow, often taking a decade to scale up from pilot plant (e.g. TRL 7) to commercial scale. Depreciation periods for an industrial asset can range from 15 to 30 years.

It is likely that the technologies that will be used to achieve carbon reductions by 2050 will include technologies and fuels which are known and commercially viable in the present day; or at the latest, commercialised by 2030[39]. It has been suggested that increasing energy efficiency by increasing the use of sustainable biomass and (carbon-free) electrification of processes are the most-ready solutions to achieve the necessary reductions; however developments could still be made[39].

When a new technology is integrated into commercial premises, other barriers can be incurred. These include process down-time, the high expense of hiring the limited skilled labour to install the technology, training or specialist external contracting to monitor and maintain the technology and potentially higher energy costs (with biomass, electricity and hydrogen all costing more than fossil fuels in the EU[40])[38,41,42]. All of this will affect the profit and loss accounts of a company in the short term.

This report mentions the importance of electrification of processes in multiple instances. However, barriers to achieving this can be found in the high cost of electricity, relative to other fuel sources, and constraints on the grid which may not be able to handle higher electricity throughflow.

[38] ttps://www.europarl.europa.eu/RegData/etudes/STUD/2020/652717/IPOL_STU(2020)652717_EN.pdf
[39] https://ec.europa.eu/clima/sites/clima/files/docs/pages/com_2018_733_analysis_in_support_en_0.pdf
[40] https://ec.europa.eu/clima/sites/default/files/strategies/2050/docs/industrial_innovation_part_2_en.pdf
[41] https://iea.blob.core.windows.net/assets/7f8aed40-89af-4348-be19-c8a67df0b9ea/Energy_Technology_Perspectives_2020_PDF.pdf
[42] https://www.fdf.org.uk/globalassets/resources/publications/fdf-slr-report-decarbonising-heat-to-net-zero.pdf

In Belgium, low gas prices, coupled with electricity prices being the sixth highest in the EU (as of 2017)[43], have created an economic disincentive to electrify processes and have made it even more difficult for industrial plants to adopt electrification measures. Similarly, a study by PRIMES (Price-Induced Market Equilibrium System [44]) found that electrification of processes alone would generate an 11% energy saving. This is due to the focus of this study being the electrification of high industrial heat processes, which are less efficient than thermal processes in high-temperature applications. Electrification reduces the potential to achieve energy savings through heat recovery[39].

Even in the most ambitious of decarbonisation scenarios, process emissions present a great challenge to decarbonising further. Due to half of food and drink sector emissions coming from a collection of small contributors, it is unlikely that these can be reduced and carbon capture and storage (CCS) is not likely to be a feasible solution[39].

No matter the scenario, considerable investment will be needed to achieve net-zero emissions and this needs to be carefully planned to mitigate risk[39].

There is a need for policy framework to facilitate and regulate investments, support innovation and give incentive to all necessary changes without jeopardising the competitiveness of European industry[39]. Furthermore, if unplanned, then there is a risk of companies being left with stranded assets (equipment that is bought and commissioned but only used for a few years) from wide-scale discontinuity of the more carbon intensive technologies.[39]

3.2.3 Price forecast challenges

Economic viability of decarbonisation technologies will be one of the main drivers of investment decision making processes. .

Generic and mature decarbonisation measures (such a solar photovoltaic (PV) to generate electricity) will have a more reliable price forecast and it will be easier for food and drink processing companies to assess their feasibility. Novel techniques (such as use of green hydrogen as fuel in boilers), or very specific techniques, will not have easy price forecasts and food and drink processing companies may suffer from high uncertainties which compromise investment decision making.

Support from industrial federations, national governments or the EC should also be provided to help SMEs to access reliable price forecasts (Capex and Opex). Currently, numerous information sources on decarbonisation techniques show a wide range of prices for novel technologies included in food and drink sector pathways. Innovation observatories could play a useful role for these SMEs as this would reduce the time needed to gather this information (and applicability restrictions). There are also novel fuels based on the use of CO_2 (captured from industrial emissions) with uncertain regulatory support.

An illustrative set of costs and prices for these techniques are provided below., For most of the assumptions the basis for estimations (e.g. depreciation periods) differs from one source to another. This makes it difficult to compare the data.

Biomass is very heterogeneous and prices depend on the geography and end use (e.g. taxes affecting application).

- Biomass already in use as fuel in Europe when locally available can be cheap (4 EUR/GJ assumed).
- Additional biomass resources in Europe (related with higher effort of production) might be available at higher price circa 7.5 EUR/GJ.
- Additional demand could be satisfied by imports (e.g. from Canada, USA, Russia incurring in larger transport costs), might have a higher price circa 15 EUR/GJ .

[43] https://www.sciencedirect.com/science/article/pii/S0957178715300552?casa_token=pqN6DsTWKbcAAAAA:mD6PmJQYCNFB1mJHRgmJ8Pq-S2D3iqJ_iZfFlxKSSsqd3nJGGjdAJJwYNN145lNdzOnMdqPvLRk

[44] https://ec.europa.eu/clima/policies/strategies/analysis/models_en#PRIMES

The future price of hydrogen depends on a number of factors including Capex, electricity prices, annual full load hours, transportation costs, etc. The information sources on this topic reveal a wide range of prices. For hydrogen, this results in 160 euros/MWh in 2030 and 140 euros/MWh in 2050.

To generate hydrogen, there are currently three common electrolytic methods: alkaline (ALK), polymer electrolyte membrane (PEM) and solid oxide (SOEC) electrolysis. These are termed as green hydrogen (green H_2)[52]. There are also two fossil-based hydrogen production methods which are commonly used: Steam Methane Reforming (SMR) and Autothermal Reforming (ATR). These methods are environmentally damaging on their own but can be made more sustainable by incorporating carbon capture, storage and use (CCUS) technologies into the production methods[52].

As of 2019, 95% of hydrogen in Europe is produced via SMR without CCUS[52]. Most of the remaining 5% is produced as a by-product of the chlor-alkali process in the chemical industry. Green hydrogen is currently very expensive to produce and, in most cases, there is no adequate transmission, storage and distribution infrastructure. This means that this fuel source is thus not cost competitive with SMR. Therefore, a substantial investment throughout Europe is required before it can become commercially accessible[52].

Presently, it is estimated that the consumer cost of green hydrogen in Europe is somewhere between US$2.24/kg$H_2$ and US$7.84/kg$H_2$[45]. Meanwhile, hydrogen procured by means of SMR and ATR without CCS can be obtained for between US$0.67/kg$H_2$ and US$1.35/kg$H_2$; with CCS, the same processes can produce hydrogen for between US$0.99/kg$H_2$ and US$2.05/kg$H_2$ (both examples of non-green hydrogen are from Canada)[45].

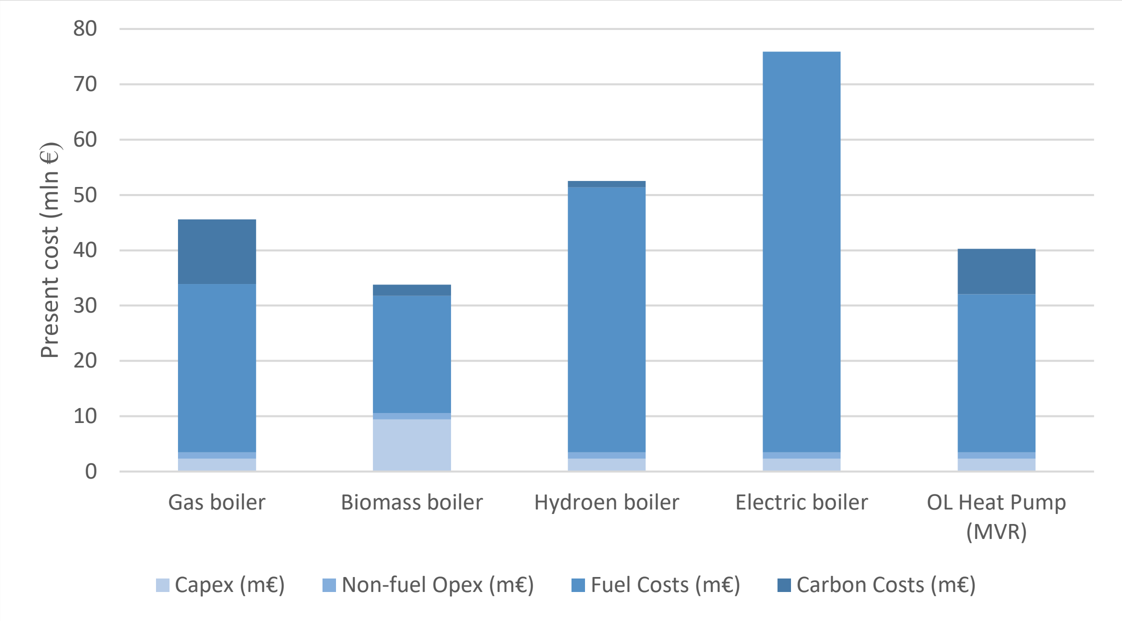
Since hydrogen's use in Europe is limited, information on the expected landed cost to end-use sectors such as food and drink production is very limited. In order to reach wide-spread commercial adoption in Europe, massive investment is going to be required and for this reason, hydrogen is not likely to be a cost-effective fuel source in the short to medium-term. As economies of scale can be taken advantage of, it is likely that hydrogen may become more commercially attractive between 2035 and 2050[46,47]. This could in part be due to hydrogen having the greatest potential (when compared to biomass/waste and electricity as green fuel sources) for replacing current fossil fuel consumption[48].

Regarding steam generation as a heat energy carrier: The techno-economic data considered for steam generation technologies includes Capex, Opex, efficiency (thermal and electric), and lifetime. The specific efficiency and costs vary by technology size, country and year. Electrode boilers, electrical resistance heating, heat pumps, steam recompression. The cost in EUR of adopting these steam techniques can be found in Figure 13 (the top graph depicts technologies generating 45GWh per year with 6MW capacity whilst the bottom shows costs for technologies generating 2GWh per year with 300kW capacity).

[45] https://www.sciencedirect.com/science/article/pii/S0360319921012684?casa_token=k4jY8JfNd-gAAAAA:XN4fjr9JHTj77fh48dLcIVpAyFP7iDfMnl1GtpzDAT0XNEYu_YwqMnny2ke5Qp_WGdK_1vzjP2I
[46] https://www.theccc.org.uk/wp-content/uploads/2018/11/H2-report-draft-20181119-FINALV3.pdf
[47] https://ec.europa.eu/energy/sites/ener/files/hydrogen_strategy.pdf

[48] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/824592/industrial-fuel-switching.pdf

Figure 43: The net present costs of technologies providing low pressure steam[49]



CO_2 price: The CO_2 price has a high impact on decision making for heat decarbonisation measures (e.g. speed of fuel switching). In many cases this tax or fee cost will drive the adoption of combustion unit decarbonisation measures. There are numerous forecasts available but companies will need to review best and worst-case scenarios (e.g. 60-100 Euro/tonne in 2040 and up to 200 in 2050) as part of their decision-making process.

3.2.4 PEST analysis for most relevant decarbonisation options

Modern technologies face multiple internal and external barriers which can affect their entry and widespread adoption into current markets. Internal barriers can often be overcome by changing how a company chooses to operate. However, external barriers, especially when they hinder the uptake of technologies which are beyond the control of any one organisation, are more difficult to overcome. These barriers can be multi-faceted and involve factors such as policy, geographic situation and economics. For this reason, Appendix A1 includes a PEST analysis where all external factors are weighed up against each other. This analysis provides a clearer picture on how difficult it may be implementing one energy efficiency technology/strategy compared to another.

Appendix A1 includes a number of brief statements, explaining the barriers and challenges for each technology's implementation. Some of these statements are very brief and for the purpose of clarity, the below paragraphs describe key aspects of the PEST analysis in more detail. For the provision of greater context when reading these paragraphs, the technology-specific information detailed in Appendix A1 has been provided in smaller PEST tables in each section.

Sustainable finance/financial support from banks. The EU has undertaken significant work on sustainable finance, including the development of the EU taxonomy for sustainable activities to prevent greenwashing. The EU has also developed an explicit standard of activities and criteria which help identify which projects will reduce GHG emissions and therefore could be focal points for investment. For example, the use of solar or wind energy to generate sustainable energy.

The taxonomy has highlighted the manufacturing sectors which have the highest emissions and has prioritised these sectors for decarbonisation by way of investment in cleaner options. It is important to

[49] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/824592/industrial-fuel-switching.pdf

note that food processing was not included in this high priority group. The taxonomy has included cleaner options to generate heat or power and these have been included in the European food and drink sector decarbonisation pathways.

Within the tables below, the “Taxon” column can be used to inform on whether the EU taxonomy considers a technology as a green investment.

1-Heat supply - decarbonisation of combustion units

1.1 Proven generic measures – Policy

There are many well-known (proven) measures and techniques to increase the energy efficiency of combustion units in industrial sites such as the use of combined cycles. There are also a number of EU policy reports and studies that state explicitly how these measures are not applicable for small units (in food and drink sectors many plants are small, below 20 MWth)[50].

1.2 Cleaner Fuels – Geographic

The availability of each different bio-based fuel varies a lot within the EU. For instance:

- Biomass from forestry is mainly used in Central-Western Europe and Northern Europe. This is likely to be due to these areas having wetter and cooler climates which promote tree growth.
- As of 2015, cereal-based biomass is produced all throughout the EU member states. France and Germany are the two main producers, both producing over 40 million tons of dry matter each year, whilst the third largest producer is Poland which produced around 25 million tons of dry matter[51].

This mixed rate of production, alongside the location based inequalities in production, creates a barrier to the use of biomass for heating since not every food processing plant in the EU will have the same availability of resource, nor will they be able to collect the same price for the biomass.

1.3 Novel generic measures – Economic

The EU and EC have explicitly included the development of green hydrogen as a pillar to achieve a net zero economy. The EU is a vocal supporter of developing this energy carrier and energy storage solution into a commercial practice norm. An example of the support for hydrogen roll-out can be seen in other industrial sectors such as the steel industry as a replacement fuel source in electric arc furnaces and basic oxygen furnaces. This would dramatically reduce the emission footprint in direct replacement iron as fossil fuels will be removed from the lifecycle[52].

Green hydrogen (H_2) is a carbon-free energy carrier that can be used as an alternative energy source. Hydrogen can be fed to fossil fuel fired furnaces (and to turbines) with only minimal adaptations to the burner and fuel system. This is why technologies using hydrogen are attractive for decarbonisation of high-temperature heat demand.

Table 13 presents the barriers and challenges identified for the decarbonisation of combustion unit heat supply.

50 https://circabc.europa.eu/ui/group/06f33a94-9829-4eee-b187-21bb783a0fbf/library/9a99a632-9ba8-4cc0-9679-08d929afda59/details see Table 5.10 (page 101-102)
51 https://op.europa.eu/en/publication-detail/-/publication/358c6d4b-1783-11e8-9253-01aa75ed71a1/language-en
52 https://www.mckinsey.com/industries/metals-and-mining/our-insights/decarbonization-challenge-for-steel

Table 13: Barriers and challenges related to decarbonisation of combustion unit heat supply

Group	Subgroup	Examples	Economic	Technical	Social	Geographic	Policy	Taxon.	Energy demand	Energy supply	Sectors
1- Combustion unit heat supply decarbonisation	Proven generic	CHP Co-generation	In large (combustion) units these measures are justified/ driven by higher efficiencies	Available mature technologies (will work also for H_2 of biogas)	No issues	(Worldwide) Suppliers that can reach any EU location	Policy assumes that some of these measures are not viable for small combustion units (SMEs)	YES		X	Most
	Cleaner fuels	Bio-based fuels	These options are seldom the better (cheapest) option. Transportation and storage cost can be relevant	Available mature technologies. Some combustion units cannot be retrofitted to use biobased fuels (e.g. natural gas units)	Still seen as threat, competing with food crops for arable land	Cheaper biofuels only in certain regions. Uneven availability of biomass or biofuels (per region).	Still seen as threat, competing with food crops for arable land	YES		X	Most
	Novel generic	H_2 as fuel	Green H_2 remains significantly more expensive than commercial fuels	Proven as fuel in Boilers (e.g. refineries) and in Turbines	No issues or positive recognition	In the future, only certain locations will have grid access to green H_2	Intense and diverse support to date to green H_2 in EU	YES		X	Most

Legend for PEST analysis tables:

No Barrier	(green)
Moderate Barrier	(yellow)
Large Barrier	(orange)

2-Heat supply switch to renewable generation

2.1 Proven Generic measures – Economic

Direct Normal Irradiation (DNI) describes the amount of direct solar radiation that a solar panel is subjected to as a result of the panel being perpendicular to the sun's rays[53]. The DNI is often greater when closer to a zero-degree latitude where the array of panels get more exposure to sunlight (the sun being situated higher in the sky for longer). The closer to 90 degrees of latitude the arrays are, the less sunlight they receive in a day - the sun is lower in the sky, and therefore DNI is lower. For this reason, arrays within southern European countries will often receive a faster return on investment (ROI) than more northern European countries due to generating more electricity from this extended exposure to sunlight[53].

Similarly, the size of the surface area available will have an effect on the ROI. Where solar arrays can be situated is often dictated by the land on which they can be placed. Areas with a high DNI will be prime locations for installing a solar array system. However, if the land available is only small, then fewer arrays

[53] https://www.ifc.org/wps/wcm/connect/a1b3dbd3-983e-4ee3-a67b-cdc29ef900cb/IFC+Solar+Report_Web+_08+05.pdf?MOD=AJPERES&CVID=kZePDPG

will be able to be situated in this location, leading to less purchasing power and therefore, paying a proportionally higher rate for the goods and services acquired to install the solar array[53]. When installing ground-mounted solar PVs, costs to be mindful of include[53]:

- Land (lease)
- PV modules
- Mounting structures
- Power conditioning units/inverters
- Grid connection
- Preliminary and operating expenses
- Civil and general work
- Developer fee

With the exception of land lease payments, on a larger scale project, the above costs could be recaptured with economies of scale. The same sort of costs will be present for a roof mounted solar array.

2.2 Proven generic measures – Geographic

As discussed, the DNI is often greater the closer that one gets to zero degree of latitude. For this reason, arrays within southern European countries, notably Portugal, Spain, Italy and Greece will have more than 1500 kWh/m^2 DNI whilst many northern regions will have less than 1000 kWh/m^2. This makes solar energy generation more attractive and reliable in southern European countries than in northern European countries.

Table 14 presents the barriers and challenges identified for switching heat supply to renewable energy sources.

Table 14: Identification and description of barriers and challenges related to heat supply switching to renewable generation

Group	Subgroup	Examples	Economic	Technical	Social	Geographic	Policy	Taxon.	Energy		Sectors
									demand	supply	
2-Heat supply Switch to renewable generation	Proven generic	Solar concentrated heat	ROI does vary with DNI and available surface	Mature and proven in a large list of sites worldwide but restrictions for small plants (e.g. space in site)	Positive recognition	Northern EU countries with lower DNI (irradiation)	No specific support in the past to promote its capabilities	YES		X	Most

	Novel generic	Geothermal	Larger investments than other alternatives	Proven and wide pool of options but not applicable to small plants (SMEs)	Certain concerns related with unknown risks	Only available in limited regions or provinces	Support on R&D and demonstration stages (Green Deal packages)	YES		X	Most

3-Electrification of heat

Proven measures – Economic

Electrification technologies are generally associated with electric heat pumps. These heat pumps are already used at industrial sites where there is a low to medium temperature heat demand[54]. Either used on its own or in conjunction with electric-powered mechanical vapor recompression (MVR) equipment for evaporation, this group of technologies can be up to three times more efficient than an industrial boiler or conventional evaporation equipment[54]. Therefore, it could be economically justifiable to replace fossil fuelled boilers with this technology. The caveat for this increased efficiency is the higher capital expenditure in relation to the conventional, fossil fuelled technologies. However, the emissions and energy cost saving could make this technology group economically viable[54].

Table 15 presents the barriers and challenges identified for the electrification of heat.

Table 15: Identification and description of barriers and challenges related to the electrification of heat

Group	Subgroup	Examples	Economic	Technical	Social	Geographic	Policy	Taxon.	Energy demand	Energy supply	Sector
3-Electrification of heat	Proven generic	Electric steam generators	Currently higher cost than (fossil) fuels but CO_2 cost will make it comparable	Proven and applicable in small plants (SMEs)	No relevant social issues	Not (significantly) affected by geographic location	Support on R&D and demonstration stages (Green Deal packages)	YES		X	Most
	Proven specific	High pressure pasteurisation/ sterilisation						NO			

54 https://www.mckinsey.com/~/media/McKinsey/Industries/Electric%20Power%20and%20Natural%20Gas/Our%20Insights/Plugging%20in%20What%20electrification%20can%20do%20for%20industry/Plugging-in-What-electrification-can-do-for-industry-vF.ashx P4 - 5

Group	Subgroup	Examples	Economic	Technical	Social	Geographic	Policy	Taxon.	Energy demand	Energy supply	Sector
	Novel generic	Heating with microwaves, etc	Many with low TRLs, so inaccurate forecast of Opex and Capex	Immature and lower TRLs	Potential concerns if human health at stake (e.g. rate of E.coli elimination)			NO			Few (limited)
	Novel specific	Ultrasound pasteurisation/ sterilisation									

4- Decarbonisation of cooling (power demand)

Novel measures – Economic

A basic magnetic cooling system consists of a magnet for the magnetisation/demagnetisation processes, magnetocaloric material, hot and cold side heat exchangers, heat transfer fluid (HTF) and control/auxiliary system equipment[55]. During the magnetisation stage, increasing the magnetic field results in an increase in temperature of the magnetocaloric material. On the other hand, during the demagnetisation stage, decreasing the magnetic field results in a reduction in temperature of the magnetocaloric material because of a physical effect known as the magnetocaloric effect (MCE)[55].

Commercial magnetic cooling systems are currently very limited due to several issues that relate to the design of the heat transfer mechanism between the magnetocaloric bed and the heat transfer fluid[55].

Table 16: Identification and description of barriers and challenges related to decarbonisation of cooling (power demand)

Group	Subgroup	Examples	Economic	Technical	Social	Geographic	Policy	Taxon.	Energy demand	Energy supply	Sectors
4- Decarbonisation of cooling (power demand)	Proven	Replacement with more efficient units	Proven small savings (ROI)	Proven and applicable in small plants (SMEs)	No relevant social issues	Not (significantly) affected by geographic location	Support on R&D and demonstration stages (Green	NO	X		Many

[55] Ezan, M.A., Ekren, O., Metin, C., Yilanci, A., Biyik, E. and Kara, S.M., 2017. Numerical analysis of a near-room-temperature magnetic cooling system. *international journal of refrigeration*, *75*, pp.262-275.

	Novel	Magnetic cooling	Far from commercialisation maturity to forecast cost accurately	Far from demonstration stages to forecast applicability restrictions			Deal packages)	NO	X		Many

5-Power supply on site switch to renewable generation

<u>Proven – Economic</u>

A major part of achieving a net zero economy within the EU is the decarbonisation of the national grid infrastructure. There are many methods being considered for helping to achieve this, but the key take-away message is that the main focus for decarbonising the grid is by having a zero-emission power supply. In terms of cost, it is expected that in the short-term, electricity prices will be higher than the baseline (which is based on projections from the IEA WEO 2009 and Oxford Economics) but in the medium to long-term, the cost of energy will reduce back to the baseline level[56].

Owning renewable energy technologies may immediately help a company to decarbonise its emissions profile but there are caveats to their adoption. The lifespan of such renewable technologies is often around 25 to 30 years. Using solar power as an example, when factoring in the large up-front costs, this technology often does not payback within 10 years; leaving another 15 to 20 years' worth of cost savings before the panels will need to be replaced[57]. This varies depending on the location of the installation since some locations in Europe may provide incentives to export any un-used electricity back to the grid, and some areas in Europe may be more suitable for a certain type of renewable energy technology; therefore generating more electricity and making it more lucrative. However, with the grid set to decarbonise by 2050, the cost-benefits may not be significant.

Table 17: Identification and description of barriers and challenges related to power supply on site switch to renewable generation

Group	Subgroup	Examples	Economic	Technical	Social	Geographic	Policy	Taxon.	Energy		Sectors
									demand	supply	
5-Power supply on site switch to renewable generation	Proven	Solar PV, Wind	In many EU countries the grid might soon be a better cost option (at same/ lower CO_2)	Proven but might be limited by available surface (space)	Small concerns remain on wind in rural (protected) areas	Northern EU countries with lower DNI (irradiation)	Support on R&D and demonstration stages (Green Deal packages)	YES		X	Most

[56] https://www.roadmap2050.eu/attachments/files/Volume1_fullreport_PressPack.pdf

[57] https://www.solarpowereurope.org/campaigns/solar-for-eu-buildings/

4 Conclusions and recommendations

4.1 Conclusions

The food and drink manufacturing sector characteristics that have an impact on the decarbonisation paths are listed below.

- Food and drink manufacturing plants are geographically spread and, unlike other industries, not concentrated in clusters. This helps the sector to play a positive role in generating jobs and economic value in rural areas or small cities, however it may limit access to modern or cleaner fuels infrastructure (natural gas or green hydrogen networks).
- The majority of manufacturing plants are small or medium sized and are operated by SMEs. (more than 99% of food and drink companies are SMEs[58]). This may have an impact on attracting a qualified workforce that can keep track of emerging technique developments and/or facilitate decarbonisation investment decision making.
- The sector is made up of a large number of processes with a very high diversity of products, and consequently different supply and value chains. This leads to a specific decarbonisation recipe for each plant or company unlike in other sectors (such as cement or iron and steel) where there are a small set of processes and relatively few decarbonisation options to assess.
- The products being produced by food and drink installations are likely to continue to be produced after the net zero transition, or at least to not be dramatically different. This sector will need to focus mainly on selecting techniques that deliver or consume energy with lower GHG emissions. There is no need for a deep transition to other markets, no need to manufacture new/different products.
- The six energy-intensive sub-sectors (that account for more than 50% of GHG) will determine the achievable level of decarbonisation for the European food and drink sector. Some of these processes demand high temperature heat that cannot currently be provided by proven technologies and will rely on the potential availability and higher energy prices of techniques that are not currently available at reasonable prices (e.g. green hydrogen). For these sectors, in the future, further reduction of GHG emissions will predominantly happen by switching to less GHG intensive energy sources (natural gas, electricity, renewable fuels) which require high investments and which will generate higher production costs.

A number of conclusions can be drawn on the emissions reduction work and options for food and processing companies:

- Many food and drink sub-sectors have been reducing energy usage and GHG emissions in recent decades. High energy intensity sectors (i.e. sugar) have already delivered important parts of the requested CO_2e emission reductions This is well captured by EU ETS data, which reflects the fact that some of the decarbonisation options mentioned in this report may have been incorporated already in a number of European plants.
- A number of decarbonisation measures can be implemented while maintaining profitability or added value. Companies will initially select those profitable measures that reduce GHG emissions, while the last part of the decarbonisation path might end up being achieved at higher operating costs.
- Most decarbonisation interventions in Europe will be related with retrofitting existing plants. High share of capacity reaching the end of investment cycle: most of the food processing plants in Europe are old, (e.g. the number of IED plants reported in 2020 is similar to those reported in 2012 included in the FDM BREF[59]).
- The majority of GHG emissions generated are derived from energy usage (scope 1 and 2) but there are also other CO_2 emissions that are not related to energy use: carbon can be used (1) as a refrigerant; (2) directly to carbonise beverages; (3) to produce deoxygenated water; (4) for

[58] https://www.fooddrinkeurope.eu/wp-content/uploads/2021/02/FoodDrinkEurope-Data-Trends-2020-digital.pdf
[59] https://eippcb.jrc.ec.europa.eu/sites/default/files/2020-01/JRC118627_FDM_Bref_2019_published.pdf

casein precipitation; (5) to increase the shelf life of some fruits and vegetables; or (6) in novel extraction processes based on supercritical CO_2. Companies with larger shares of these GHG emission sources would need to select a specific set of measures to minimise emissions.

- Companies seek to maintain profitability when making investment decisions. This criterion is also kept when investing in regulatory compliance. The selection of technologies will be an economic decision and often less risky options will have higher chances of being selected. To establish their specific route to net zero, companies will need to identify and rank decarbonisation measures that are applicable to their plant (see section 4.2 of this report). They need to rank them in ascending order of cost per tonne of abated carbon. The most common (visual) tools are abatement curves, which provide decision makers with a top-down view of the potential capital investments (often large) in techniques that can reduce plant emissions. Each plant will need more than one solution. Holistic decision making is required, and this can support building a cleaner new plant rather than carrying out many retrofits on an old plant that is almost depreciated.
- Energy and carbon prices are an important input as they influence investment decisions and respective technology selection. Some of the key resources (biomass, access to green hydrogen) are very heterogeneous and prices depend on the geography and end use (e.g. taxes affecting application).
- The future price of hydrogen depends on a number of factors including Capex, electricity prices, annual full load hours, transportation costs, etc. There are high uncertainties on dates for affordable green hydrogen.
- Decision making on investments and marketing will need to consider how the environmental footprint of products is affected by each change. Food and drink sales companies will need to use and update GHG footprint indicators for their key products. This should include every stage of the process (regardless of scope 3 estimates being less accurate).
- There will be more information in one year’s time (end 2021) to better understand externalities and EU regulations and funding schemes. Few industrial companies will be making decisions on large investments until they foresee a longer period of stable regulations. An accurate commitment can be derived at sector level, and it will be more likely to be derived at sub-sector level.

4.2 Recommendations

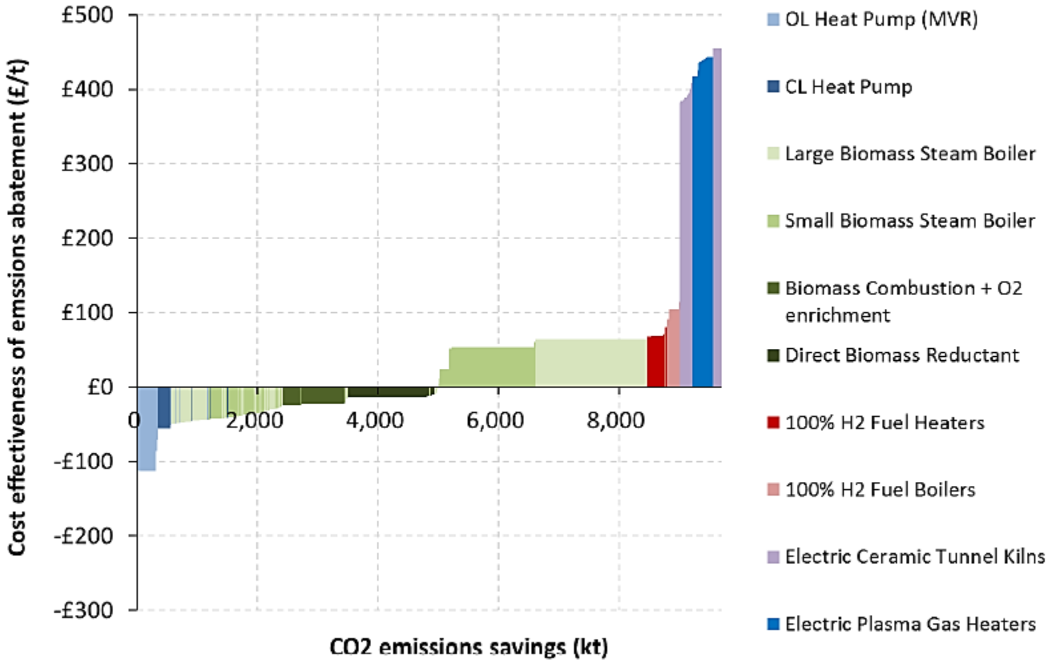
The recommendations below are linked to the barriers and conclusions identified in this study.

4.2.1 Recommendations for industrial operators

Recommendations to food and drink manufacturers:

- In the short term, there is a need to review and analyse the impact of new EU regulations. The information on all relevant actions or impacts will need to be collated, clustered and digested per topic e.g. there will be a large pool of impacts on combustions units, raw material acquisitions, etc.
- In this context, there is a risk of not meeting required product quality when using alternative production processes with lower GHG emissions. For example, this can happen with alternative pasteurisation techniques (e.g. based on ultra-high pressures) that may prove to ensure pasteurisation but could also deliver a different taste to what the customer expects. This can be solved with demonstration projects (at pilot or semi-work scale). Operators will need to identify references for technologies tested at commercial scale and ensure reference data is not coming from pilot plants (or lower TRLs).
- The CO_2 price is an externality with a high impact on decision making for heat decarbonisation measures (e.g. speed of fuel switching). In many cases this will drive the combustion unit decarbonisation measures. Companies covered by EU ETS (i.e. combustion units > 20 MWth) will need to estimate their cost of GHG emissions as an input for investment decision making. Since this price is difficult to forecast (e.g. 60-100 Euro/tonne in 2040 and up to 200 in 2050)., companies will need to include worst case scenarios in their decision-making analyses.
- Companies with high energy intensity need to select a precise or accurate decision-making tool to prioritise technology selection. Examples of these tools are provided in Figure 1 below.

Figure 14: Example of decarbonisation selection tool[60]



[60] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/824592/industrial-fuel-switching.pdf

- When food and drink companies innovate, many companies focus on product innovation rather than process. Energy efficiency is perceived by industry as important, and this might be top priority for energy intensive processes. For companies with very low energy usage, reputation and stakeholder interest might be a key driver to prioritise decarbonisation efforts.
- Ensure there is a coordinated effort. Marketing, strategy, and finance need to be directly involved. The impact of transition risks (such as policy requirements) and climate change risk cannot be abated solely by the environmental protection department. There are short, mid and longer-term actions that need contributions from many experts inside each food and drink processing company or installation.
- Ensure climate impacts on the market are considered when selecting investments: EU citizens driven by changes in climate, in the long term, may move from hotter arid regions to cooler ones[61]. Consumer habits may also change as a result of new weather conditions. For example, it might not be wise to retrofit an existing plant in a region where the population is projected to decrease in the coming decades.
- Ensure other mega trends that impact on markets are considered: For example, the share of people working from home is increasing and this will certainly impact food consumption habits.

4.2.2 Recommendations to national governments

National governments and competent authorities can also provide support on these decarbonisation challenges by doing the following:

- Ensure the grid is decarbonised at the relevant pace to meet EU decarbonisation goals. Countries/regions with cleaner grids may attract companies wanting to report lower GHG footprints to sell low emission products.
- Provide support on electrification of heat: there is a need for grid networks to hold larger electricity transport (not only for industry). There is also a need for developing grid prices policies/markets which promote the transition from fossil fuel (combustion units) to higher shares of energy from grid.
- Ensure there are grid expansions to facilitate electrification, including rural areas where many food and drink plants are located.
- Assign budgets for Funds and/or investment in infrastructure: certain decarbonisation technologies require substantial investments in infrastructure for electricity or hydrogen networks by government (or public agencies and companies), if possible, in collaboration with regional industrial federations.
- Facilitate easier access to technical information for manufacturing and engineers teams (from national governments or public institutions) to facilitate generation of decision-making tools (comparing CO_2e abatement costs): webinars, guidelines, reference reports for each different process.
- Promote decarbonisation success stories: Risk of production disruption energy saving may have low priority in an organisation and the proposed projects might focus on low risk, projects that minimise impact/changes to the existing process. Such a focus on “business as usual” operations with minimal changes drives up the perceived risk and hence cost of new. Disseminating successful projects on decarbonisation will help to reduce perceived risk.
- Promote policy implementation stability and clarify uncertainties: Stable carbon accounting rules including waste, biobased fuels and every circular economy aspect. Minimise changes beyond 2021 to facilitate a realistic forecast on cost of carbon (e.g. to understand ETS scope extension impact on price and volatility).

[61] https://www.ipcc.ch/srccl/chapter/chapter-5/

Appendices

A1 Identification and description of barriers and challenges during the PEST analysis

Key		
Key	No Barrier	
	Moderate Barrier	
	Large Barrier	

Identification and description of barriers and challenges

Group	Subgroup	Examples	Economic	Technical	Social	Geographic	Policy	Taxon.	Energy demand	Energy supply	Sectors
Heat supply Decarbonisation of combustion units	Proven generic	CHP Co-generation	In large (combustion) units these measures are justified/ driven by higher efficiencies	Available mature technologies (will work also for H_2 of biogas)	No issues	(Worldwide) Suppliers that can reach any EU location	Policy assumes that some of these measures are not viable for small combustion units (SMEs)	YES		X	Most
	Cleaner fuels	Biobased fuels	These options are seldom the better (cheapest) option. Transportation and storage cost can be relevant	Available mature technologies. Some combustion units cannot be retrofitted to use biobased fuels (e.g. natural gas units)	Still seen as threat, competing with food crops for arable land	Cheaper biofuels only in certain regions. Uneven availability of biomass or biofuels (per region).	Still seen as threat, competing with food crops for arable land	YES		X	Most
	Novel generic	H_2 as fuel	Green H_2 remains significantly more expensive than commercial fuels	Proven as fuel in Boilers (e.g. refineries) and in turbines	No issues or positive recognition	In the future, only certain locations will have grid access to green H_2	Intense and diverse support to date to green H_2 in EU	YES		X	Most
Heat supply Switch to renewable generation	Proven generic	Solar concentrated heat	ROI does vary with DNI and available surface	Mature and proven in a large list of sites worldwide but restrictions for small plants (e.g. space in site)	Positive recognition	Northern EU countries with lower DNI (irradiation)	No specific support in the past to promote its capabilities	YES		X	Most

	Novel generic	Geothermal	Larger investments than other alternatives	Proven and wide pool of options but not applicable to small plants (SMEs)	Certain concerns related with unknown risks	Only available in limited regions or provinces	Support on R&D and demonstration stages (Green Deal packages)	YES		x	Most
Lower heat demand (All sectors)	Proven generic	Heat recovery	Most of these measures have proven ROI, economically viable	Proven with no/ limited technical risks (or uncertainties)	No relevant social issues	Not (significantly) affected by geographic location	No need to have policy support (and also profitable for SMEs)	NO	X		Most
		Optimising steam distribution systems									
		Insulation									
		Cleaning (CIP) without heat									
Lower heat demand (Sub-sector specific specific)	Proven specific	Replacement/ new cooking device/unit (more effi.)	Many may have limited ROI	Proven with no/ limited technical risks (or uncertainties)	No relevant social issues	Not (significantly) affected by geographic location	Many of these have low ROI and would benefit from support policies	NO	X		Few (limited)
		Industrial heat pump dryers									
		Solar drying for organic intermediates with renewable heat									
		Decrease evaporation rate of wort boiling									
	Novel specific	Advanced oven technology: water bath oven						NO	X		Few (limited)
		Separation with membrane (instead of heat)									
Electrification of heat	Proven generic	Electric steam generators	Currently higher cost than (fossil) fuels but CO_2 cost will make it comparable	Proven and applicable in small plants (SMEs)	No relevant social issues	Not (significantly) affected by geographic location	Support on R&D and demonstration stages (Green Deal packages)	YES		X	Most
	Proven specific	High pressure pasteurisation/sterilisation						NO			
	Novel generic	Heating with microwaves, etc	Many with low TRLs, so inaccurate forecast of Opex and Capex	Immature and lower TRLs	Potential concerns if human health at stake (e.g. rate of E.coli elimination)			NO			Few (limited)
	Novel specific	Ultrasound pasteurisation/sterilisation									

Lower power demand	Proven	Frequency converters, LEDs lighting	Proven small savings (ROI)	Proven and applicable in small plants (SMEs)	No relevant social issues			NO	X		Most
Decarbonisation of cooling (power demand)	Proven	Replacement with more efficient units						NO	X		Many
	Novel	Magnetic cooling	Far from commercialisation maturity to forecast cost accurately	Far from demonstration stages to forecast applicability restrictions				NO	X		Many
Power supply on site Switch to renewable generation	Proven	Solar PV, Wind	In many EU countries the grid might soon be a better cost option (at same/ lower CO_2)	Proven but might be limited by available surface (space)	Small concerns remain on wind in rural (protected) areas	Northern EU countries with lower DNI (irradiation)		YES		X	Most

A2 Full list of decarbonisation measures

Category	Name	Description	Maturity (TRL/date)	Applicable in	Restrictions	Requirements for implementation	Drawbacks	Economics	Emissions reduction potential	
Energy Management	**Energy Management Systems**	Computer aided systems collecting and monitoring data on energy use. The systems provide analysis of energy use and identify opportunities for increased energy efficiency.	TRL 9	All	Applicable to new and existing plants, Applicable to large and small plants	No specific (additional) requirements	No drawbacks	Small investment (<50 k EUR); Expert judgement	Energy management software	15%
Energy Management	**Controls**	Use of controls to achieve energy saving.	TRL 9	All	Applicable to new and existing plants, Applicable to large and small plants	No specific (additional) requirements	No drawbacks	Small investment (<50 k EUR); Expert judgement	Lighting, heating, cooling	10%
Energy Management	**Maintenance**	Energy saving through maintenance; can be obtained by housekeeping and simple maintenance, condition-based maintenance and advanced condition monitoring. Proper housekeeping and simple maintenance can reduce energy losses at low cost with relatively short payback period.	TRL 9	All	Applicable to new and existing plants, Applicable to large and small plants	No specific (additional) requirements	No drawbacks	Small investment (<50 k EUR); Expert judgement	Maintenance of lighting, heating and cooling equipment as well as process equipment.	Medium reduction of power (5-10%)
Energy Management	**Other managerial measures (training, etc)**	Training	TRL 9	All	Applicable to new and existing plants, Applicable to large and small plants	No specific (additional) requirements	No drawbacks	Small investment (<50 k EUR); Expert judgement	N.A.	Medium reduction of power (5-10%)
Lower heat demand	**Heat recovery**	Use of heat exchangers and heat pumps to recover heat.	TRL 9	All; proven in: Breweries, Oilseed processing and vegetable oil refining & Starch production	Heat recovery is not applicable where there is no demand that matches the production curve	No specific (additional) requirements	No drawbacks	100,000 - 1,600,000 Eur Investment (875,000 EUR average) with 20,000 - 30,000 EUR annual operating costs. Can have up to 200,000 EUR annual savings and 8-year payback for some technologies. The investment costs can vary. The	Wort boiling, ammonia-based heat pump, air-compressed systems, general recycling of waste heat to provide required heat to earlier lifecycle processes	Medium reductions of heat (5-10%)

Category	Name	Description	Maturity (TRL/date)	Applicable in	Restrictions	Requirements for implementation	Drawbacks	Economics	Emissions reduction potential	
								heat recovery consists of a complete system of heat exchangers, storage tanks and pipes that must also be integrated into the automation which can incur a substantial capital investment.		
Lower heat demand	**Identification of heat recovery option (Pinch analysis)**	Pinch analysis is a methodology to reduce energy usage and carbon footprint by setting rigorous scientifically based energy targets. Pinch analysis is used to determine minimum process heating and cooling, especially in the brewing sector the milk powder industry	TRL 9	All using heat and steam	For more complex situations, an experienced team will be needed to cover the pinch analysis, process simulation, cost estimation and plant operation.	No specific (additional) requirements	No drawbacks	Projects can start from about EUR 5000. Operating and capital cost savings.	N.A.	Medium reductions of heat (5-10%)
Lower heat demand	**Insulation**	Insulation of pipes, vessels and equipment by selecting effective coating materials	TRL 9	All	No technical restrictions	No specific (additional) requirements	No drawbacks	Investment cost was about EUR 1 408 000 with a payback period of 7.6 years.	Coating materials with low conductivity values and high thickness. Pre-insulation	Reduce the heat/cold loss by 82–86 %. Additionally, 25–30 %. Potential emission reductions between 44.4 % and 70.7 % heat can be saved by using pre-insulated pipes
Lower heat demand	**Optimising steam distribution systems**	Optimizing steam systems leading to minimizing operating costs. (e.g. Improving condensate recovery, steam trap management program, changing steam generation conditions)	TRL 9	Food canning processes, Brewing, Steam peeling, Steam blanching, Steam drying	Applicable to new and existing plants, Applicable to large and small plants	No specific (additional) requirements	No drawbacks	Medium Investment (50-200 k EUR)Expert Judgement	N.A.	Medium reductions of heat (5-10%)

Category	Name	Description	Maturity (TRL/date)	Applicable in	Restrictions	Requirements for implementation	Drawbacks	Economics	Emissions reduction potential	
Lower heat demand	**Mechanical Vapor Re-Compression (MVR)**	Vapour is compressed by a mechanical compressor and then reused as a heat source. Most new evaporators are fitted with an MVR system	TRL 9	Sugar manufacturing; starch processing; tomato, apple and citrus juice concentration; brewing; and in the evaporation of milk and whey	No technical restrictions	MVR generates noise, so sound insulation is required.	No drawbacks	New = EUR 1.5 million. Annual operating cost of EUR 175 000... A saving of 75% compared to TVR	MVR evaporator (2 types, fan and a high-speed turbine), steam-heated finisher	Medium reductions of heat (5-10%)
Lower heat demand	**Replacement/ new cooking device/unit (more effi.)**	Upgrades to processing equipment resulting in reduction in energy use.	TRL 9	All but in particular meat processing, bakery and confectionery, food canning.	Applicable to new and existing plants, Applicable to large and small plants	No specific (additional) requirements	No drawbacks	Small investment (<50 k EUR); Expert judgement	N.A.	Medium reductions of heat (5-10%)
Lower heat demand	**Separation with membrane (instead of heat)**	Polymeric Membranes and Ceramic Membranes used for separation in food and drink processing, which contributes to lower operation temperatures.	TRL 9	Beverages, Dairy, Starch, Egg products	No technical restrictions	No specific (additional) requirements	No drawbacks	Medium Investment (50-200 k EUR)Expert Judgement	Most often combined with -successive filtrations with different molecular weight cut-off membranes or with other types of separation (pre-treatment by enzyme, depectinization or occulation; concentration by evaporation; ion exchange for demineralization, de-acidification, discolouring, etc.)	Medium reductions of heat (5-10%)
Lower heat demand	**Cleaning (CIP) without heat**	Cleaning of product contact surfaces such as process pipes, vessels and equipment, without disassembly and without use of heat. This process uses highly concentrated alkaline, chlorinated liquid detergent.	TRL 9	All but in particular Dairy, Bakery	Applicable to new and existing plants, Applicable to large and small plants	No specific (additional) requirements	No drawbacks	Small investment (<50 k EUR); Expert judgement	N.A.	Medium reductions of heat (5-10%)

Category	Name	Description	Maturity (TRL/date)	Applicable in	Restrictions	Requirements for implementation	Drawbacks	Economics	Emissions reduction potential	
Lower heat demand	**New drying technologies**	New drying technologies using less water in the initial product mixture, using starch hybrids, special drying techniques for dairy production, spent yeast.	TRL 7	Starch, Sugar, Fruit and Vegetable	Applicable to new and existing plants, Applicable to large and small plants	No specific (additional) requirements	No drawbacks	Small investment (<50 k EUR); Expert judgement	Superheated steam drying, refractance window drying systems, High electrical field drying or electrohydrodynamic drying, ohmic drying	Medium reductions of heat (5-10%)
Lower heat demand	**Solar drying for organic intermediates with renewable heat**	Tunnel dryer using solar thermal energy.	TRL 9	Grain, Fruit and vegetable processing	Limited drying capacity Optimum air flow must be provided in the dryer across the drying process to control temperature and moisture in wide ranges independent of the weather conditions.	– High labour input for loading, turning and unloading – Electricity is required to operate the fan – Requires UV-resistant transparent cover material	– Dryer cannot be operated during adverse weather or low solar radiation	Small investment (<50 k EUR); Expert judgement	Passive or active drying structures	Medium reductions of heat (5-10%)
Lower heat demand	**Advanced oven technology**	Advanced oven technology: water bath oven or shower ovens	TRL 9	Bakery	No technical restrictions	No specific (additional) requirements	No drawbacks	Small investment (<50 k EUR); Expert judgement	N.A.	Medium reductions of heat (5-10%)
Lower heat demand	**Use of pre-dried fodder**	Use of fodder that has been pre-dried (e.g. By flat pre-wilting).	TRL9	Fodder and alfalfa harvest	No technical restrictions	Extra resources are required for spreading the fodder flat (staff, specific machinery and fuel).	The variability of weather conditions has an impact on the continuity of the harvesting sites. As the raking stage is carried out after mowing, the most reliable weather forecasts are required in order to adapt the work in the event of rainy periods. It is sensitive to moisture so should avoid being used in mornings (avoiding dew)	Raking machine purchase: about EUR 85 000, excl taxes; tractor purchase: about EUR 78 000, excl taxes; installation modifications: EUR 10 000–50 000, excl taxes. Operational costs between 2,000 - 20,000 EUR excl taxes	Flat pre-wilting	Energy savings of about 30% - reduction in fuel consumption in the dryers of about 20–30 % - reduction in NMVOC emissions of about 30 %

Category	Name	Description	Maturity (TRL/date)	Applicable in	Restrictions	Requirements for implementation	Drawbacks	Economics	Emissions reduction potential	
Lower heat demand	**Recycling of waste gas from dryer**	Injection of the waste gas from the cyclone into the burner of the dryer.	TRL9	Any process that requires the drying of plants and grains	No technical restrictions	Pipes must be made of stainless steel instead of grey steel	Recycling of waste gas increases dust emission levels expressed in concentrations. However, the pollution load remains the same. Increased electricity consumption to feed the dedicated ventilator of the system. For safety reasons, special attention must be paid to the minimum circulation speed of the recycled waste gas to avoid the accumulation of dust and the risk of fire	Recycling system is about EUR 300 000	Drying drum	Energy saving of 7 % with ideal conditions
Lower heat demand	**Use of waste heat from pre-dryer**	The heat of the outlet steam from the high-temperature dryers is used for pre-drying part or all of the green fodder	TRL9	All fodder	No technical restrictions	No specific (additional) requirements	The wet scrubber generates acid washing water, which may require storage before discharge (e.g. landspreading).	The investment in a pre-dryer is about EUR 5 million for a line evaporating 30 000 litres per hour	Pre-dryer,	Reduces energy consumption in the high-temperature dryer. Greenhouse gas and other emissions to air are also reduced.

Category	Name	Description	Maturity (TRL/date)	Applicable in	Restrictions	Requirements for implementation	Drawbacks	Economics	Emissions reduction potential	
Lower heat demand	**Mash infusion process**	Mash infusion process carried out instead of mash decoction process, in which part of the mash is separated and cooked, the mash is only heated up to a maximum of 78 ° C with several temperature increments	TRL9	Brewing	No technical restrictions	Requires high-quality malt, though the malt grades available permit the use of a mash infusion process for many beer types	The type of mashing process has an effect on beer taste and aroma, and is part of the beer recipe, which could limit changeover. For beers with a higher alcohol content or special taste profiles, the decoction process is often used, as it produces more fermentable sugars and is associated with other benefits.	No additional costs compared with the mash decoction process.	Mash tun	Energy savings of between 20 % and 50 %.
Lower heat demand	**Highly efficient electric ovens (bread, cookies, wafers)**	Electric ovens replacing direct gas fired ovens with the key difference being the use of electric elements as the heating source. Tubular electric heaters are used instead of direct gas burners.	TRL 9	Baking	No technical restrictions	No specific (additional) requirements	No drawbacks	Small investment (<50 k EUR); Expert judgement	Electric oven	Medium reduction of power (5-10%)
Lower heat demand	**Highly efficient electric fryers**	Upgrading plant equipment to efficient electric fryers	TRL 9	Baking	No technical restrictions	No specific (additional) requirements	No drawbacks	Small investment (<50 k EUR); Expert judgement	Electric oven	Medium reduction of power (5-10%)
Lower heat demand	**Mash-in at higher temperatures**	The mashing-in of the grain is carried out at temperatures of approximately 60 °C, which reduces the use of cold water.	TRL9	Brewing	No technical restrictions	No specific (additional) requirements	The technique may not be applicable due to the product specifications, e.g. Wheat beers need to be mashed in at lower temperatures (45 °C to 55 °C). Brewers monitor	No specific Economical benefit	N.A.	Medium reduction of power (5-10%)

Category	Name	Description	Maturity (TRL/date)	Applicable in	Restrictions	Requirements for implementation	Drawbacks	Economics	Emissions reduction potential	
							the potential risks at increased mashing-in temperatures. Insufficient degrading of protein- and beta-glucan during mashing-in is the most important risk, but it is possible to overcome this by supply of malt of a consistently high quality, i.e. With sufficient amounts of natural enzymes. The adjuncts used also play a role in the choice of mashing-in temperature.			
Lower heat demand	**Heat recovery from wort kettle vapour**	Recovery of the heat from the boiling wort vapour (e.g. By plate heat exchangers).	TRL9	Brewing	No technical restrictions	No specific (additional) requirements	Approximately 75 % of the condensation heat is recovered. The remaining 25 % gets lost in transfers	The energy saving in the brewhouse is approximately 26 %, or approximately 13 % of the total heat consumption	N.A.	Less heat will be used which means that less fuel has to be burnt to produce steam or hot water. This reduces CO_2 and other combustion-associated emissions.
Lower heat demand	**Increase the degree of high gravity brewing**	Production of concentrated wort which reduces its volume and thereby saves energy. This creates a stronger beer, which is then diluted back to the desired original wort and alcohol content towards the end.	TRL9	Brewing	No technical restrictions	No specific (additional) requirements	The process has its limits, as the yeasts perform worse during fermentation with increasing original gravity and alcohol content. In addition, the aroma profile can change.	Savings will be achieved due to the smaller wort volume to boil and due to the smaller fermenting beer volume to cool.	N.A.	25 % heat energy savings in the wort kettle and 25 % cooling energy savings at fermentation

Category	Name	Description	Maturity (TRL/date)	Applicable in	Restrictions	Requirements for implementation	Drawbacks	Economics	Emissions reduction potential	
Lower heat demand	**Integrated energy system in the CO_2 recovery**	Area-wide use in larger breweries. CO_2 is reused in the production process.	TRL9	Brewing	The CO_2 recovery plant needs considerable re-engineering and investment to realise the modification to energy optimisation. It may not be applicable to breweries that do not liquefy CO_2 prior to use in the brewery. Also, the cooling energy produced from the vaporised CO_2 must be able to be utilised elsewhere in the brewery (first option). The technology is applicable to breweries able to process approximately 500 kg CO_2/h and run continuously, i.e. > 5 000 h/year	No specific (additional) requirements	CO_2 recovery prevents the release of CO_2 and vocs into the atmosphere, but has nothing to do with cooling or reducing electricity consumption. On the contrary, the system requires more electricity.	The electrical energy and maintenance costs are relatively low. An installation cost of EUR 30 000 and a payback period of 11 months have been reported	Heat exchanger, evaporator	The amount of total energy saved is approximately 85 kwh per 1 000 kg of CO_2 evaporated.
Lower heat demand	**Decrease evaporation rate of wort boiling**	The evaporation rate can be reduced from 10 % down to approximately 4 % per hour (e.g. By two-phase boiling systems, dynamic low-pressure boiling). The breweries strive to keep the evaporation rate as low as possible, as this correlates directly with energy consumption.	TRL9	Brewing	The technique may not be applicable due to the product specifications. Evaporation of the wort is, among other things, meant to strip out unwanted flavours like DMS which may limit the lower evaporation rate.	No specific (additional) requirements	Unwanted sulphur components in the wort and cloudy finished beer are two well-known risks. The boiling of the wort and the associated evaporation also expel unwanted aromas. This is why there are sensory limits to the reduction in evaporation.	No specific Economical benefit	N.A.	A reduced evaporation rate will lead to proportional savings of heat energy. If the evaporation rate is reduced from 10 % to 6 %, a 40 % heat energy saving is expected.

Category	Name	Description	Maturity (TRL/date)	Applicable in	Restrictions	Requirements for implementation	Drawbacks	Economics	Emissions reduction potential	
Lower heat demand	**Sterile water use in homogeniser**	Flushing the aseptic barriers with sterilised water instead of steam.	TRL9	All	No technical restrictions	No specific (additional) requirements	No drawbacks	An investment cost of EUR 30 000 has been reported (for a homogeniser of 17 m 3). The payback period is less than a year and a half.	N.A.	Reduction of steam and water consumption. Water that was previously used in the heat exchanger for the condensation is now mixed with the steam.
Lower heat demand	**Use of continuous pasteurisers**	Flow-through heat exchangers are used (e.g. Tubular, plate and frame). The pasteurisation time is much shorter than that of batch systems.	TRL9	Dairies	No technical restrictions	No specific (additional) requirements	No drawbacks	No specific Economical benefit	N.A.	Reduced energy consumption and wastewater production, compared to batch pasteurisers
Lower heat demand	**Regenerative heat exchange in pasteurisation**	The incoming milk in the counter current flow is preheated by the hot milk leaving the pasteurisation section.	TRL9	Dairies	No technical restrictions	In older dairies, heating and cooling energy can be further reduced by replacing the old plate exchangers with more effective ones.	No drawbacks	Reduction in energy costs. In an example installation, investment costs of around EUR 145 000 (with low operating costs)	Heat exchanger	Reduced energy consumption.
Lower heat demand	**Hibernation for pasteurisers and sterilisers**	The pasteuriser/steriliser unit is in hibernation mode during water circulation (for aseptic lines without losing the aseptic status).	TRL9	Dairies	Generally, there are no technical restrictions to the applicability of this technique in dairies.	No specific (additional) requirements	No drawbacks	Reduced operating costs	N.A.	A reduction in energy consumption of between 60 % and 85 % can be achieved during hibernation mode.
Lower heat demand	**Ultra-high temperature process of milk without immediate pasteurisation**	UHT milk is produced in one step from raw milk, thus avoiding the energy needed for pasteurisation.	TRL9	Dairies	Generally, there are no technical restrictions to the applicability of this technique in dairies (within the constraints imposed by product availability and production mix). It is also applicable for flavoured milk processes.	No specific (additional) requirements	No drawbacks	This technique results in a 30 % reduction in the investment cost and a 50 % reduction in the operating cost compared to a traditional line.	N.A.	Reduction in electricity consumption can be up to 38 %, steam consumption up to 45 %, freshwater consumption up to 60 %, and product losses up to 33 %.

Category	Name	Description	Maturity (TRL/date)	Applicable in	Restrictions	Requirements for implementation	Drawbacks	Economics	Emissions reduction potential	
Lower heat demand	**Multistage drying in powder production**	A spray-drying process is used in combination with a downstream dryer, e.g. Fluidised bed dryer.	TRL9	Dairies	Most modern configurations are with three stages of drying. The multistep concept should be considered when building new installations and taking into account the economics. Product specifications should also be taken into account.	No specific (additional) requirements	Spray dryers produce noise emissions and explosive dust/air mixtures can occur.	Investment involves additional capital and operational costs.	A mix of the following: evaporator, Spray dryers, roller dryers, integrated fluidised bed dryers, rotary atomiser, CIP filter (which consists of a tubular filter without a cyclone).	Reduced energy and water consumption. Reduced dust emissions. It is reported that if an integrated FBD is used, the energy consumption for drying can be reduced by approximately 20 %
Lower heat demand	**Partial milk homogenisation**	The homogeniser's working pressure is reduced through optimised design and thus the associated electrical energy needed to drive the system is also reduced.	TRL9	Applicable to high-pressure homogenisation of emulsions and suspensions, aseptic or non-aseptic high- or low-viscous products, including pasteurised milk, UHT milk, cream, yoghurt, condensed milk, ice cream mix, fruit juices, concentrates, etc.	No technical restrictions	No specific (additional) requirements	No drawbacks	Reduced operational cost. A lower pressure also means less load on the homogeniser, so maintenance and worn parts' replacement intervals will be less frequent, which means reduced downtime.	Homogeniser	Electricity consumption can be reduced by 15 - 33%
Lower heat demand	**Sequential air ventilation for cheese ripening**	Temperature based Sequential Ventilation (TSV) in the ripening room.	TRL 8	Dairy, specifically cheese	No technical restrictions	No specific (additional) requirements	No drawbacks	Reduced operational costs due to reduction in energy consumption and energy used for ventilation.	Ventilation systems	40% - 60% TSV reduced energy consumption (42%) and ventilation time (48%) of the ripening room.

Category	Name	Description	Maturity (TRL/date)	Applicable in	Restrictions	Requirements for implementation	Drawbacks	Economics	Emissions reduction potential	
Lower heat demand	**High temperature cheese ripening with later humidification and ionisation of the ventilation air**	The temperature of the air is increased to shorten ripening times. The ventilation air is humidified and cleaned by a discharge tube which ionises the air which is passed through ventilation ducts.	TRL 9	Dairy, specifically cheese	No technical restrictions	No specific (additional) requirements	No drawbacks	A shortening of the ripening time by 50 %, an improvement of the product quality and a reduction of the consumption of plastics and fungicidal agents have also been reported. Considerable savings have been achieved in labour costs and maintenance and in the use of materials for cleaning the ventilation system. The payback period is around two years.	Ventilation systems	Reduced energy consumption.
Lower heat demand	**Use of ultrafiltration for protein standardisation of cheese milk**	The milk flows under pressure over a membrane that withholds the protein molecules, thus increasing the cheese yield per processed milk unit	TRL 9	Dairies, mostly cheese and milk	No technical restrictions	No specific (additional) requirements	No drawbacks	Reduced energy and water consumption, whey and wastewater in comparison with traditional standardisation. The investment cost in the example Danish dairy is EUR 430 000 and the payback period is 5.9 years.	N.A.	Energy savings seen in a Danish example: . Electrical energy 473 MWh/yr - 19 kWh/t cheese . Thermal energy 1,235 MWh/yr - 49 kwh/t cheese . Water 7 500 m³/yr - 300 l/t cheese
Lower heat demand	**Single pasteuriser for nectar/juice production**	Use of one pasteuriser for both the juice and the pulp instead of using two separate pasteurisers.	TRL 9	Soft drinks	Applicability may be restricted due to the pulp particle size.	No specific (additional) requirements	No drawbacks	No specific Economical benefit	Pasteuriser	Single-line solution consumes 25 % less heating and cooling energy

Category	Name	Description	Maturity (TRL/date)	Applicable in	Restrictions	Requirements for implementation	Drawbacks	Economics	Emissions reduction potential	
Lower heat demand	**Hydraulic sugar transportation**	Sugar is transported to the production process with water. As some of the sugar is already dissolved during the transportation, less energy is needed in the process for dissolving sugar.	TRL 9	Sugar treatment, producers of sugar solution and beverage producers	No technical restrictions	No specific (additional) requirements	No drawbacks	Reduced energy costs. Safe working environment due to the powder being placed outside the factory	Pasteuriser added to the sugar dissolver	Reduction of dissolution temperature which leads to a lower energy consumption
Lower heat demand	**Generation of an auxiliary vacuum**	The auxiliary vacuum used for oil drying, oil degassing or minimisation of oil oxidation is generated by pumps, steam injectors, etc. The vacuum reduces the amount of thermal energy needed for these process steps.	TRL 9	Animal and vegetable oil	The technique is applicable when a vacuum range of 40–120 mbar is required. It is readily available and its operating reliability is very good, allowing series production. Completely different vacuum conditions are required for distillative neutralisation/deodorisation.	No specific (additional) requirements	No drawbacks	Reduced costs due to appropriate vacuum conditions.	Vacuum, reactor/evacuating reactor	The reported volume of wastewater is up to 1.7 m 3 /t of unrefined oil and the COD level is up to 75 mg/l.
Lower heat demand	**Pressing of corn fibre or wheat fibre before drying**	Mechanical dewatering is the use of mechanical force to remove the water from the product.	TRL 9	Starch, Ethanol	No technical restrictions	No specific (additional) requirements	No drawbacks	Reduced costs due to shorter drying times	N.A.	High reductions of heat (>10%); Expert judgement
Lower heat demand	**Pressing of corn germs before drying**	Mechanical dewatering is the use of mechanical force to remove the water from the product.	TRL 9	Starch, Ethanol	No technical restrictions	No specific (additional) requirements	No drawbacks	Reduced costs due to shorter drying times	N.A.	High reductions of heat (>10%); Expert judgement

Category	Name	Description	Maturity (TRL/date)	Applicable in	Restrictions	Requirements for implementation	Drawbacks	Economics	Emissions reduction potential	
Lower heat demand	**Dewatering of corn gluten before drying**	Dewatering process using decanter centrifuge together with a pH and temperature control system. Corn gluten dewatered using decanters is dryer than that from rotary vacuum drum filters (rvdfs). The lower water content means less energy is needed for drying.	TRL 9	Starch	No technical restrictions	No specific (additional) requirements	No drawbacks	Reduced costs due to shorter drying times	Decanter centrifuge	High reductions of heat (>10%); Expert judgement
Lower heat demand	**Heat recovery for preheating the potato juice**	Potato juice is heated up using the heat from the potato water during the protein separation stage.	TRL 9	Potato starch plants	No technical restrictions	No specific (additional) requirements	No drawbacks	An investment cost of EUR 1 300 000 (capacity about 100 m 3 /h in terms of potato juice) and annual savings of EUR 200 000. Reduced energy costs	N.A.	Reduction of energy consumption for potato juice heating of around 50%
Lower heat demand	**Pressing of sugar beet pulp**	The beet pulp is pressed to a dry matter content of typically 25–32 %.	TRL 9	Various sugar plants	Pressed pulps can only be stored for a few days, unless made into silage.	No specific (additional) requirements	No drawbacks	Drying the pulp produces animal feed that can be stored for a longer time.	N.A.	Reduced energy consumption for beet pulp drying
Lower heat demand	**Indirect (steam drying) of beet pulp**	Drying of beet pulp by the use of superheated steam.	TRL 9	Various sugar plants	The technique may not be applicable to existing plants due to the need for a complete reconstruction of the energy facilities. Retrofitting can involve the reconstruction of the steam generation and electricity production sections including, for example, revising the entire heat transfer arrangements within the installation.	No specific (additional) requirements	No drawbacks	Costs are site-specific and differ for new and existing plants. High-temperature drying is typically 6% cheaper than fluidised bed dryers. Drying the pulp produces animal feed that can be stored for longer than moist feed.	Fluidised bed dryers (fbds). Juice evaporator/concentrator. Diffuser	Reduced dust and odour emissions to air. As hot gas is not used, NOx is not released.

Category	Name	Description	Maturity (TRL/date)	Applicable in	Restrictions	Requirements for implementation	Drawbacks	Economics	Emissions reduction potential	
Lower heat demand	**Solar drying of sugar beet pulp**	Use of solar energy to dry the beet pulp.	TRL 9	Sugar beet	May not be applicable due to local climatic conditions and/or lack of space.	It requires extra resources for spreading the pulp (staff, specific machinery and fuel).	No drawbacks	Costs of around EUR 2 million (mainly construction cost of concrete area) for a drying area of 14 ha.	N.A.	Stopping the conventional pulp dryer results in a significant decrease in gas and electricity consumption and CO_2, particles and odour emissions. A reduction of about 15–25 % of the total fuel consumption (natural gas) can be achieved, resulting in about 10 000–15 000 tonnes less of CO_2 being emitted
Lower heat demand	**Low temperature drying of sugar beet pulp**	Direct (pre)drying of beet pulp using drying gas, e.g. Air or hot gas.	TRL 9	Sugar beet	If there is no market for the dried pulp, or if the pressed pulp is used for biogas production or directly distributed as feed, or if some other technology for pulp drying is chosen, this technique would not be economically viable	No specific (additional) requirements	Dust and odour are emitted. NOX, CO and organic compounds are emitted when hot gas is used. Wastewater is produced.	About 30 % energy can be saved by using the vapours of the High Temperature Drying step for the first step, Low Temperature Drying.	Belt dryers	The energy consumption and air pollution are reduced
Electrification of heat	**Industrial heat pump dryers**	New types of heat pump technology that use waste heat to produce high temperatures suitable for industrial drying processes.	TRL 7	Sugar and starch	Temperatures produced can only reach 160 degrees Celsius. If higher temperatures are a requirement, this technology may not be suitable	No specific (additional) requirements	No drawbacks	Medium Investment (50-200 k EUR)Expert Judgement	Closed or open loop heat pump	Medium reductions of heat (5-10%)
Electrification of heat	**Cleaning (CIP with electric heat or ultrasound)**	CIP with ultrasound. High frequency, low displacement vibrations stop mineral scale and fouling build-up from settling. CIP with ultrasound improves heat transfer efficiency, reducing energy use.	TRL 9	All	No technical restrictions	No specific (additional) requirements	No drawbacks	Costs are site-specific and differ for new and existing plants.	N.A.	High reductions of heat (>10%); Expert judgement

Category	Name	Description	Maturity (TRL/date)	Applicable in	Restrictions	Requirements for implementation	Drawbacks	Economics	Emissions reduction potential	
Electrification of heat	**Electric steam generators**	Electric steam generators for food and drink processing	TRL 9	All	No technical restrictions	No specific (additional) requirements	No drawbacks	Costs are site-specific and differ for new and existing plants.	N.A.	High reductions of heat (>10%); Expert judgement
Electrification of heat	**Heating with microwaves**	Heating with microwaves	TRL 9	All	No technical restrictions	No specific (additional) requirements	No drawbacks	Costs are site-specific and differ for new and existing plants.	N.A.	High reductions of heat (>10%); Expert judgement
Electrification of heat	**Electrification of pasteurisation/ sterilisation processes**	Electrification of pasteurisation/ sterilisation processes	TRL 9	All	No technical restrictions	No specific (additional) requirements	No drawbacks	Costs are site-specific and differ for new and existing plants.	N.A.	High reductions of heat (>10%); Expert judgement
Electrification of heat	**High pressure pasteurisation/sterilisation**	High pressure pasteurisation/sterilisation	TRL 9	All	No technical restrictions	No specific (additional) requirements	No drawbacks	Costs are site-specific and differ for new and existing plants.	N.A.	High reductions of heat (>10%); Expert judgement
Electrification of heat	**Non-thermal pasteurisation technologies: Ultrasound pasteurisation/sterilisation**	Use of ultrasound for pasteurisation and sterilisation instead of thermal treatment. Ultrasonic waves propagating in a liquid medium causes cavitation, which has been attributed as the main mechanism responsible for cell disruption.	TRL 10	Fruit juice, Dairy	Regulatory approval Ultrasound does not inactivate alkaline phosphatase or lactoperoxidase enzymes.	No specific (additional) requirements	The free radicals formed during cavitation may cause harmful effect on the consumer, Ultrasound may cause physicochemical effect which may be responsible for off-flavour, discoloration and degradation of components,	Costs are site-specific and differ for new and existing plants.	N.A.	High reductions of heat (>10%); Expert judgement
Electrification of heat	**Non-thermal pasteurisation technologies: UV pasteurisation/sterilisation**	Use of ultraviolet light to sterilise and pasteurise milk without heat. Cold sterilisation.	TRL 9	Fruit Juice, Dairy	Regulatory approval	No specific (additional) requirements	UV light is not effective against spores as a single alternative treatment	Costs are site-specific and differ for new and existing plants.	N.A.	High reductions of heat (>10%); Expert judgement

Category	Name	Description	Maturity (TRL/date)	Applicable in	Restrictions	Requirements for implementation	Drawbacks	Economics	Emissions reduction potential	
Electrification of heat	**Non-thermal pasteurisation technologies: Pulsed light pasteurisation/sterilisation**	Use of pulsed light to sterilise and pasteurise milk without heat. Cold sterilisation.	TRL 9	Fruit Juice, Dairy	Regulatory approval	No specific (additional) requirements		Costs are site-specific and differ for new and existing plants.	Combined application of pectin coating and UV sterilization technology	High reductions of heat (>10%); Expert judgement
Heat supply-decarbonisation of combustion units	**CHP**	Combined heat and power (CHP) generation, also known as cogeneration, is a technique through which heat and electricity are produced in one single process.	TRL 9	All	No technical restrictions	Heat and power loads need to be balanced.	No drawbacks	Medium Investment (50-200 k EUR)Expert Judgement	N.A.	High reductions of heat (>10%); Expert judgement
Heat supply-decarbonisation of combustion units	**Combined cycle**		TRL 9	All	No technical restrictions		No drawbacks	Medium Investment (50-200 k EUR)Expert Judgement		High reductions of heat (>10%); Expert judgement
Heat supply-decarbonisation of combustion units	**Heat pump for hot water generation (sanitary, heating, water tracing, cleaning, etc)**	Heat pump technologies for hot water provision	TRL 9	All	No technical restrictions	No specific (additional) requirements	No drawbacks	Medium Investment (50-200 k EUR)Expert Judgement	Heat pumps	High reductions of heat (>10%); Expert judgement
Heat supply-decarbonisation of combustion units	**Replacement/New unit with higher Energy eff.**	Upgrades to existing equipment with more efficient units	TRL 9	All	No technical restrictions	No specific (additional) requirements	No drawbacks	Medium Investment (50-200 k EUR)Expert Judgement	N.A.	High reductions of heat (>10%); Expert judgement

Category	Name	Description	Maturity (TRL/date)	Applicable in	Restrictions	Requirements for implementation	Drawbacks	Economics	Emissions reduction potential	
Heat supply-decarbonisation of combustion units	**Bio based fuels (biogas, e.g. From AD)**	The biogas generated by anaerobic digestion or anaerobic treatment of wastewater is used as a fuel, e.g. In a gas engine or in a boiler. It may be previously treated (e.g. To remove hydrogen sulphide).	TRL 9	All	No technical restrictions	The engine is sensitive to hydrogen sulphide gas and therefore a scrubber system is provided upstream to remove this compound.	No drawbacks	A total cost of around EUR 1 million has been reported (for a CHP plant that generates 600 kwh of electrical and 600 kwh of thermal energy). Reduction of fuel consumption	Anaerobic digester, biogas holder, gas analyser, gas engine, generator. Or alternatively: a boiler producing process heat or a DDGS dryer, without treatment. Dryer and recuperator.	The CHP plant enables the methane gas generated by the anaerobic digester to be converted to a valuable renewable source of energy. Additionally, the CHP plant enables the anaerobic digester to divert waste and instead convert it to a valuable product.
Heat supply-decarbonisation of combustion units	**Novel Anaerobic digestion features for Biogas generation from wastewater**	E.g. Novel anaerobic digestion system coupling biogas recirculation with mgcl2 addition	TRL 6-8?	To be determined	To be determined	To be determined	To be determined	To be determined	To be determined	High reductions of heat (>10%); Expert judgement
Heat supply-decarbonisation of combustion units	**Bio based fuels (biomass)**	Use of biofuels or biomass to provide heat.	TRL 9	All	Space requirements for feedstock storage			Medium Investment (50-200 k EUR)Expert Judgement	N.A.	High reductions of heat (>10%); Expert judgement
Heat supply-decarbonisation of combustion units	**Residues/waste as fuel**	Use of residues or solid waste to produce heat.	TRL 9	All	Space requirements for feedstock storage		This process requires working closely with the regulator to ensure compliance with emissions and waste regulations	Medium Investment (50-200 k EUR)Expert Judgement	N.A.	High reductions of heat (>10%); Expert judgement
Heat supply-decarbonisation of combustion units	**CO_2 capture and storage (CCS)**	Capturing waste CO_2 for use on site	TRL 9	All (larger sites)			High capital cost	Large Investment (>200 k EUR); Expert Judgement	N.A.	High reductions of heat (>10%); Expert judgement

Category	Name	Description	Maturity (TRL/date)	Applicable in	Restrictions	Requirements for implementation	Drawbacks	Economics	Emissions reduction potential	
Heat supply-decarbonisation of combustion units	**Gasification/pyrolysis of solid waste / residues**	Thermal treatment of solid waste through partial oxidation of the feedstock. Oxygen is added, but not in sufficient quantities to allow the substance to be completely oxidised and full combustion to occur. The partial combustion results in the production of 'Syngas' which can be used to substitute natural gas, chemicals, fertilisers, transportation fuels and hydrogen.	TRL 9	All (larger sites with access to feedstock)			High capital cost	Large Investment (>200 k EUR); Expert Judgement	N.A.	High reductions of heat (>10%); Expert judgement
Heat supply-decarbonisation of combustion units	**Cleaner fuels (H_2)**	Use of hydrogen and fuel cell technology to provide electricity.	TRL 9	All (larger sites)		Competitive green H_2 at affordable cost, infrastructure	High capital cost	Large Investment (>200 k EUR); Expert Judgement	N.A.	High reductions of heat (>10%); Expert judgement
Heat supply-decarbonisation of combustion units	**Cleaner fuels (Ammonia)**	Use of ammonia to provide electricity supply	TRL 9	All	Health and safety considerations	Competitive green ammonia supply	Engineers are still working to control polluting nitrogen oxide (NOx) emissions Supply of clean ammonia- most existing ammonia is produced from methane.	Large Investment (>200 k EUR); Expert Judgement	N.A.	High reductions of heat (>10%); Expert judgement
Heat supply-generated by renewables (not combustion)	**Concentrated solar heat and power (CSH, CSP)**	CSP technology using mirrors to concentrate and collect heat. Can be used in direct application or further used to produce electricity	TRL 9	All: Canning, Drying. Brewing, Dairy (for warming up liquids)	Lack of small scale CSP for rural/off grid applications		High upfront investment costs, Maintenance of the systems: mirrors have to be cleaned every three to four weeks, Low awareness levels	Large Investment (>200 k EUR); Expert Judgement	N.A.	Medium reductions of heat (5-10%); Expert judgement
Heat supply-generated by renewables (not combustion)	**Geothermal heat supply**	Geothermal energy used in primary form (heat) for food processing	TRL 9	Drying, Milk pasteurisation, Evaporation and distilling, Sterilisation	Location specific	Policy and regulatory frameworks . Access to qualified suppliers/installers	Resource risks associated with initial stages of the project. High upfront investment.	Large Investment (>200 k EUR); Expert Judgement	N.A.	Medium reductions of heat (5-10%); Expert judgement

Category	Name	Description	Maturity (TRL/date)	Applicable in	Restrictions	Requirements for implementation	Drawbacks	Economics	Emissions reduction potential	
Heat supply-generated by renewables (not combustion)	**Other renewable heat supply**	Other renewable heat supply	TRL 9	All	No technical restrictions			Small investment (<50 k euro); Expert judgement	N.A.	High reduction of power (>10%); Expert judgement
Power supply-decarb. Of on-site generation	**Solar PV supply**	Use of Solar Photovoltaics to generate electricity on site	TRL 9	All	Location specific	No specific (additional) requirements	Intermittent output - might require additional investment in battery storage	Small investment (<50 k EUR); Expert judgement	N.A.	High reduction of power (>10%); Expert judgement
Power supply-decarb. Of on-site generation	**Voltage optimisation**	Fixed or Electronic-dynamic voltage optimisation for equipment on site.	TRL 9	All	No technical restrictions	Analysis of electricity characteristics (e.g., voltage, current, active power, and power factor) and power quality (harmonic distortion and under- and overvoltage events)	Set up costs and disruption to the process	Small investment (<50 k EUR); Expert judgement	N.A.	10%
Power supply-decarb. Of on-site generation	**Other renewable power supply (batteries, etc)**	Other renewable power supply (batteries, etc)	TRL 9	All	No technical restrictions			Small investment (<50 k EUR); Expert judgement	N.A.	High reduction of power (>10%); Expert judgement
Lower power demand	**Power demand monitoring/control systems**	Monitoring systems to provide accurate energy data and implement controls	TRL 9	All	No technical restrictions	No specific (additional) requirements	No drawbacks	Small investment (<50 k EUR); Expert judgement	N.A.	
Lower power demand	**More efficient HVAC**	More efficient heating and ventilation systems	TRL 9	All	No technical restrictions	No specific (additional) requirements	No drawbacks	Small investment (<50 k EUR); Expert judgement	N.A.	30%
Lower power demand	**Reducing compressed air system leaks**		TRL 9	All	No technical restrictions	No specific (additional) requirements	No drawbacks	Small investment (<50 k EUR); Expert judgement	N.A.	
Lower power demand	**LED Lighting**	LED lighting installed throughout the site	TRL 9	All	No technical restrictions	No specific (additional) requirements	No drawbacks	Small investment (<50 k EUR); Expert judgement	N.A.	

Category	Name	Description	Maturity (TRL/date)	Applicable in	Restrictions	Requirements for implementation	Drawbacks	Economics	Emissions reduction potential	
Lower power demand	**Energy-efficient homogeniser**	The homogeniser's working pressure is reduced through optimised design and thus the associated electrical energy needed to drive the system is also reduced	TRL 9	Pasteurised milk, UHT milk, cream, yoghurt, condensed milk, ice cream mix, fruit juices, concentrates, etc.	No technical restrictions	No specific (additional) requirements	No drawbacks	Reduced operational cost.	Homogeniser	Electricity consumption can be reduced by about 30 %. In some cases where there is a higher capacity, additional savings of between 15 and 33% can be achieved.
Increased Frosting temperatures	**Larger shock freezers, with warmer evaporation temperatures**	Blast/ shock freezer operating with higher evaporation temperatures	TRL 9		No technical restrictions	No specific (additional) requirements	No drawbacks	Reduced operational cost.	N.A.	N.A.
Lower power demand	**Application of a negative pressure for mixing purposes**	A negative pressure is created which forces fluids to be emptied from containers or powder to be added into the mixer.	TRL 9	Beverages	Powder mixing does not work well. For viscous powders like stabilisers, there is a need to add another technique, such as high-shear mixing. With excessively viscous powders like stabilisers	No specific (additional) requirements	No drawbacks	No specific Economical benefit	N.A.	N.A.
Lower power demand	**Energy-efficient homogeniser for nectar/juice production**	The homogeniser's working pressure is reduced through optimised design and thus the associated electrical energy needed to drive the system is also reduced.	TRL 9	Pasteurised milk, UHT milk, cream, yoghurt, condensed milk, ice cream mix, fruit juices, concentrates, etc.	No technical restrictions	No specific (additional) requirements	No drawbacks	Reduced operational cost.	Homogeniser	Electricity consumption can be reduced by about 30 %. In some cases where there is a higher capacity, additional savings of between 15 and 33% can be achieved.

Category	Name	Description	Maturity (TRL/date)	Applicable in	Restrictions	Requirements for implementation	Drawbacks	Economics	Emissions reduction potential	
Lower power demand	**Use low-pressure blowers for bottle drying**	Low-pressure air blowers are installed for bottle drying application. Elimination of air knives usually installed for drying applications in bottling lines and substitution by blowers is a good practice for energy efficiency.	TRL 9	Soft drinks	No technical restrictions	Typically, the blower assembly is mounted on the floor or platform with distribution hoses that supply air to multiple nozzle assemblies. A knowledgeable vendor should be consulted to ensure that the systems are properly sized.	The bottle drying operation may take longer (than air knives) in some plants.	Blower equipment is far less expensive to maintain. Can save EUR 9 000/year assuming 5 000 h/year of operation and an electricity cost of EUR 0.10/kwh. The average payback time is 2 years or less.	Blowers that use motor-driven fans	N.A.
Decarbonisation of cooling	**Cooling by Renewable sources (power)**	Cooling provided by heat pumps	TRL 9	All	No technical restrictions	No specific (additional) requirements	No drawbacks	Small investment (<50 k EUR); Expert judgement	Heat pumps	High reduction of power (>10%); Expert judgement
Indirect adiabat AC cooling systems	**Avoid chillers for cooling**	Cooling process where air flowing through a closed loop is pre-cooled to the desired temperature	TRL 9	All	No technical restrictions	No specific (additional) requirements	No drawbacks	Small investment (<50 k EUR); Expert judgement		High reduction of power (>10%); Expert judgement
Decarbonisation of cooling	**Refrigeration heat recovery**	Recovery and re-use of waste heat which can be deployed in a different process	TRL 9	All	Air quality considerations	Heat recovery opportunities must meet demand	No drawbacks	Small investment (<50 k EUR); Expert judgement	Heat pumps	High reduction of power (>10%); Expert judgement
Decarbonisation of cooling	**Replacement/ new unit more efficient**	Upgrades to existing cooling system resulting in energy saving	TRL 9	All	No technical restrictions	No specific (additional) requirements	No drawbacks	Small investment (<50 k EUR); Expert judgement		High reduction of power (>10%); Expert judgement
Decarbonisation of cooling	**Operational efficiency / reduced storage time**	Operational efficiency / reduced storage time	TRL 9	All	No technical restrictions	No specific (additional) requirements	No drawbacks	Reduced energy cost. Very low/no cost investment	N.A.	High reduction of power (>10%); Expert judgement
Decarbonisation of cooling	**Higher temperatures**	Operating cooling at higher temperatures	TRL 9	All	No technical restrictions	No specific (additional) requirements	No drawbacks	Reduced energy cost. Very low/no cost investment	N.A.	High reduction of power (>10%); Expert judgement

Category	Name	Description	Maturity (TRL/date)	Applicable in	Restrictions	Requirements for implementation	Drawbacks	Economics	Emissions reduction potential	
Decarbonisation of cooling	**Alternative refrigeration (e.g. Magnetic)**	Magnetic refrigeration uses the magnetocaloric effect in magnetic solids, where certain types of metal (such as Gadolinium) will heat up when magnetized and cool down when demagnetized. A heat-transfer liquid is used to remove the heat as the metal is magnetized and is then replaced by more liquid for the demagnetization stage which then absorbs the cooling and is applied for the refrigeration. Barocaloric & electrocaloric refrigeration	TRL9?	All	No technical restrictions	No specific (additional) requirements	No drawbacks	Reduced energy cost.	Magnetic, Barocaloric and Electrocaloric refrigeration	High reduction of power (>10%); Expert judgement Magnetic refrigeration is 30% 30% more energy efficient than conventional refrigeration technology.
Decarbonisation of cooling	**Precooling of ice-water**	When ice-water is used, the returning ice-water is precooled (e.g. With a plate heat exchanger), prior to final cooling in an accumulating ice-water tank with a coil evaporator.	TRL 9	Cooling milk and vegetables	No technical restrictions	No specific (additional) requirements	Using ammonia involves safety risks. Leakages can be prevented by proper design, operation and maintenance.	Dairy implemented example: the precooling system saved almost 20 % electricity when installed in an existing ice-water system. Investment cost of EUR 50 000 and installation cost of EUR 135 000	Plate heat exchanger, coil evaporator, a pump, valves, regulators, pipework	High reduction of power (>10%); Expert judgement
Decarbonisation of cooling	**Cooling fruit and vegetables before freezing**	Cooling fruit and vegetables before freezing	TRL 9	Fruit and vegetables	No technical restrictions	No specific (additional) requirements	No drawbacks	Reduced freezing times	N.A.	High reduction of power (>10%); Expert judgement
Process power (rest, not used for heat or cooling)	**Renewable sources**	Renewable generation for process power	TRL 9	All	No technical restrictions	No specific (additional) requirements	No drawbacks	Medium Investment (50-200 k EUR)Expert Judgement	N.A.	High reduction of power (>10%); Expert judgement
Process power (rest, not used for heat or cooling)	**Use of high-efficiency motors / drivers**	Use of high-efficiency motors to minimise motor losses.	TRL 9	All; where motors are used.	No technical restrictions	No specific (additional) requirements	No drawbacks	Reduced energy costs	High efficiency motors	High reduction of power (>10%); Expert judgement

Category	Name	Description	Maturity (TRL/date)	Applicable in	Restrictions	Requirements for implementation	Drawbacks	Economics	Emissions reduction potential	
Process power (rest, not used for heat or cooling)	**Mash-in at higher temperatures**	The so-called "high-short mashing process" often starts at 60 ° C. Energy is saved through higher mashing temperatures and shorter mashing times	TRL 9	Brewing	Not applicable to all sites	No specific (additional) requirements	This process is feasible for standard beers. However, this inactivates various enzymes that break down viscous substances and proteins. As a result, poorer filtration performance and poorer fermentation are accepted. Fluctuating qualities of the brewing grain lead to a restricted application of the "high-short mashing process"	Reduced energy costs	N.A.	High reduction of power (>10%); Expert judgement
Process power (rest, not used for heat or cooling)	**Frequency converters for motors**	Conversion of standard power to adjustable voltage and frequency	TRL 9	All	No technical restrictions	No specific (additional) requirements	No drawbacks	Reduced energy costs	N.A.	High reduction of power (>10%); Expert judgement
Process power (rest, not used for heat or cooling)	**Variable speed drives**	Installation of devices that can vary the speed of a normally fixed speed motor	TRL 9	All	No technical restrictions	No specific (additional) requirements	No drawbacks	Reduced energy costs	N.A.	High reduction of power (>10%); Expert judgement

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