RÉPUBLIQUE FRANÇAISE
Liberté
Égalité
Fraternité

ADEME
AGENCY FOR ECOLOGICAL TRANSITION

SECTORAL TRANSITION PLAN FOR THE FRENCH SUGAR INDUSTRY

EXPERTISES

SUGAR

Summary report

JULY 2024

With the contribution of the European Union LIFE programme

Finance ClimAct

I Care — Because our impact matters

This document is published by ADEME

ADEME
20, avenue du Grésillé
BP 90406 | 49004 Angers Cedex 01

Contract number: 2022MA000117
Study carried out on behalf of ADEME by: I Care by BearingPoint
(Eulalie SAISSET, Eugène PIPRAUD, Guillaume BONNENTIEN)
Reference LIFE Finance ClimACT project: LIFE 18/IPC/FR/000010 (Action C7.1. Sectoral Transition Plans)
Technical coordination - ADEME: Martin MANGEART et Adeline PILLET
Division/Department: Business and Industrial Transitions Division / Industry Department

ADEME would particularly like to thank stakeholders in the sugar sector for their participation and commitment throughout the development of this Sectoral Transition Plan:
Christian Spiegeleer, Rémi Aubry (Syndicat national des fabricants de sucre - National Union of French Sugar Manufacturers)
Patrick Roiron, Pascal Hamon (Cristal Union)
Romain Rossi, Carlota Pons (Tereos)
Romain Barella, Gaël Le Taillandier de Gabory (Saint-Louis Sucre)
Bernard Morin (Lesaffre Frères)
Fabrice Kolb, Eric Forêt (Sucrerie Ouvré & Fils)

ADEME would also like to thank all the participants in the various bilateral exchanges and workshops, in particular:
Stéphane Petit, Vincent Bartoli, Hervé Graser, Bruno Labilloy, Jérôme Bignon (Cristal Union)
Jean-Yves Delamare, Jean-François Simon, Thibault Morel-Fourrier (Tereos)
Anne Despouy (Syndicat national des fabricants de sucre - National Union of French Sugar Manufacturers)
Josh Gartland, Laëtitia Trepos (European Association of Sugar Manufacturers)
Marc Zribi, José Soares, Marie-Agnès Oberti (France AgriMer)
Raphaëlle Malot, Jean-Marc Callois, Nicolas Cordier (Ministère de l'Agriculture et de la Souveraineté Alimentaire - French Ministry of Agriculture and Food Sovereignty)
Sébastien Schellen (De Smet Engineers & Contractors)
Jean-Louis Striebig (Confédération Générale des Planteurs de Betteraves - General Confederation of Beet Growers)
Alexis Patry (Association de recherche technique betteravière - (Beet Technical Research Association))
Serge Zaka (Independent agroclimatology consultant)
Gilles Rouvière, Virginie Somon (Alliance 7)
Nicolas Philippot (Gardel)
Laurant Barau (eRcane)

Finally, for the design of this Summary Report, ADEME would like to thank:
Céline GRAVOUIL and Cécile MORANÇAIS (Sennse)

And:
Sarah MARCHAND, Quentin DURAND (I Care by BearingPoint), Eliott Rabin
Aurélie BICHOT, Grégoire DAVID, Antoine PIERART, Alba DEPARTE, Audrey TREVISIOL (ADEME)

CITATION OF THIS REPORT
Martin MANGEART, Adeline PILLET, Cyrielle BORDE, ADEME, Guillaume BONNENTIEN, Eulalie SAISSET, Eugène PIPRAUD, I Care by BearingPoint 2024. Sectoral Transition Plan for the French sugar industry: Summary. 48 pages.

This document is available online at librairie.ademe.fr librairie.ademe.fr

Photo credits: cover Shutterstock

Graphic design: sennse • 1891

Printing: Printed in France by SETIG-Abelia, certified ISO 140001 and Imprim'Vert.
This document is printed on 100% PEFC paper.

Brochure ref. 012588 – ISBN print: 979-10-297-2406-0 – ISBN web: 979-10-297-2405-3
Dépôt légal : ©ADEME Éditions, july 2024

Contents

Joint editorial

Sylvain WASERMANN
Chairman and Chief Executive Officer of ADEME

The sugar industry is an important part of French agriculture and industrial expertise, and essential at the European level through its exports. A major player in some regional economies, the industry is responsible for 3% of industrial greenhouse gas emissions, mainly linked to the natural gas used to produce the steam needed to extract sugar from sugar beet and sugar cane. Like other industries, the sugar sector will have to decarbonise if France is to meet its climate commitments by 2050.

With the help of I Care, ADEME has used its expertise and modelling capabilities to propose transition scenarios for the sugar industry. Dialogue with actors in the industry has enabled the development of three scenarios highlighting the technological and economic challenges of decarbonising the industry.

This study shows that there is no single, simple solution for decarbonising the sugar industry, but rather a combination of several complementary strategies. A reduction in energy consumption can be achieved through multiple recycling of steam within the process and would place greater demands on the electricity network. At the same time, energy recovery from washing water and beet pulp could be used to cover residual energy needs, depending on the local context and changes in demand for pulp from livestock farms. Lastly, this study encourages us to consider European market dynamics when imagining the future of the French sugar industry, which include the effects of climate change on crops, changes in dietary sugar consumption, the decline in the use of bioethanol in road transport and the development of biobased chemicals.

ADEME's Sectoral Transition Plans show that there are concrete, effective solutions for reducing industrial greenhouse gas emissions while maintaining competitiveness and the ability to meet the needs of society. They can be used to assess different technological trajectories and their costs, and also to anticipate certain market trends.

We would like to extend our warmest thanks to all those who contributed to this work, particularly the industry professionals and the National Union of French Sugar Manufacturers.

Christian SPIEGELEER
President of the National Union of French Sugar Manufacturers (SNFS)

The French sugar industry welcomes this unprecedented industrial foresight project, which has mobilised our specialists together with the ADEME teams.

The Sectoral Transition Plan has been useful in that it has helped to explain our industrial realities such as the specifically high seasonality of sugar extraction activities and our energy performance, which contributes to making France the leading sugar producer in the European Union. Closely linked to an ongoing concern with energy, decarbonisation is central to our companies' strategies. The exercise provides food for thought for discussions that have been underway for some time but does not provide ready-made solutions on a site-by-site basis. The three scenarios cannot be exhaustive: they outline a range of possibilities that do not exclude different or intermediate paths, or the impact of future innovations or variables such as markets, geopolitics, etc.

An almost complete decarbonisation of France's industrial base is possible through a combination of optimisation (partial electrification), technology and biomass. It cannot be done without the use of a significant part of the beet pulp, some being left over for other uses.

The investment effort appears to have been underestimated: it does not take into account inflation or the need to maintain ongoing investment in the modernisation and maintenance of industrial facilities not directly linked to energy. It also requires costs (capital, but also service providers, know-how and labour) to be updated in order to finance and render possible the projects envisaged, with appropriate levels of aid.

Maintaining our competitiveness is a prerequisite and a permanent condition: downstream on the sugar and ethanol markets, and equally upstream, so that sufficient remuneration enables farmers to keep sugar beet (an annual plant, but not a monocrop) in their crop rotation on a long-term basis. The SNFS also hopes that the administration will be persuaded to adopt a bolder, more confident vision of the sector's economic future: both for the biofuels that will be produced in low-carbon facilities and for the positive effects of agronomic and industrial improvements in French production based on a robust and sustainable sector.

Finally, the radical transformations associated with the transition will have many consequences that will require human resources, the availability of new technologies and above all the persistence of agricultural yields capable of saturating an efficient decarbonised industrial tool in a sector that contributes to the prosperity of our country.

Project background

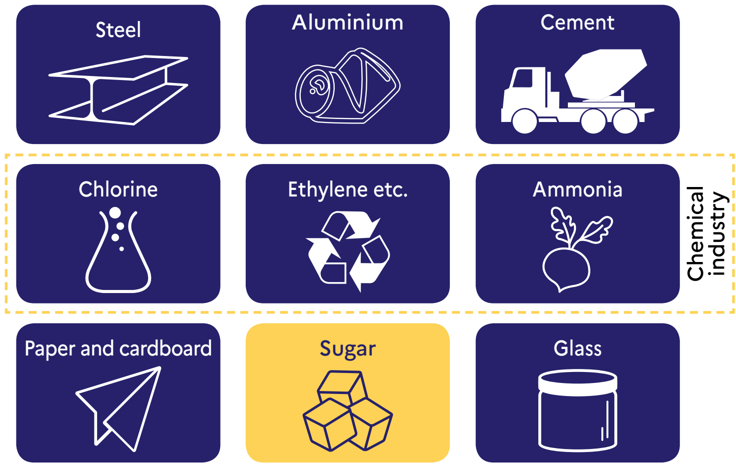
From the National Low-Carbon Strategy to the Sectoral Transition Plan

The current National Low-Carbon Strategy (SNBC2) sets out the path France intends to take to achieve carbon neutrality by 2050, a commitment it made following the 21st Conference of the Parties (COP 21) convened under the United Nations Framework Convention on Climate Change (UNFCCC). For industry, this trajectory translates into an 81% reduction in emissions compared to 2015. An intermediate target of a 35% reduction in emissions has been set for 2030. While a number of guidelines have been put forward (e.g. providing a framework to encourage management of the demand for energy and materials, giving priority to low-carbon energies and the circular economy, etc.), their temporal and sectoral variations have not been detailed. Yet the challenges of decarbonising industry vary greatly from one sector to another. Moreover, manufacturers need visibility to make investments: industrial equipment has a lifespan of several decades, so the effects of today's investments will continue until 2050. The Sectoral Transition Plans are being developed on the basis of this timeframe and this need for visibility for manufacturers. Public authorities also need to be able to propose effective policies that encourage decisions on the investments needed to achieve carbon neutrality by 2050.

By drawing up these Sectoral Transition Plans (STPs) in consultation with the key actors in the sectors concerned, ADEME aims to provide visibility for both manufacturers and investors, as well as public authorities. The project is therefore a continuation of the work carried out for the SNBC, breaking down heavy industry into 9 sectors in order to tailor decarbonisation solutions as closely as possible to the industrial issues facing each sector (Figure 1).

Part of a European LIFE programme called Finance ClimAct, the aim of these transition plans is to explore different decarbonisation scenarios in order to identify the transformations in industrial sectors required for a carbon-neutral society. This project takes a 360° view, looking not only at the technological aspects but also at markets, funding, costs and jobs. This work should lead to the formulation of proposals for «public-private» actions to accelerate transition in these key sectors.

Figure 1. The 9 sectors covered by the Sectoral Transition Plans.



This document summarises the main results of the Sugar Sectoral Transition Plan.

Encadré 1

STP method[1]

Phase I: Survey of the industry. This phase consists of mapping the market (consumption, imports-exports, production) and building a model representing the energy consumption, GHG emissions and production costs of French industry in 2015.

Phase II: Projections. Each scenario is based on (i) the projection of a transition environment, (ii) the formulation of assumptions about market trends and the implementation of decarbonisation technologies, (iii) modelling and (iv) analysis of the results.

Phase III: Development of action plans.

The method, tools and assumptions used are described in greater detail in the full report.

[1] ADEME. Methodological guide to drafting a sectoral transition plan for the decarbonisation of industry. 2023.

Project

Finance ClimAct

With the contribution of the European Union LIFE program

30 people working full time on the project

18 million euro budget

5 years

Projet partners

ACPR, AMF, Banque de France, Finance for Tomorrow, GreenFlex, Institute for Climate Economics, Ministry of Ecological Transition, 2° Investing Initiative

The main limits of the exercise

All the results presented are based on an ambitious modelling exercise of decarbonisation trajectories for the sugar industry up to 2050, using an innovative methodology that is, however, subject to limitations, particularly in terms of scope and access to data. This is the prism through which the reader should view this document, especially with regard to the conclusions that they may draw from it, in particular by considering the following elements:

• A limited objective that does not take into account all the criteria for the ecological transition.

The objective of the current National Low-Carbon Strategy (SNBC2) for the manufacturing industry focuses on direct GHG emissions (category 1) and does not therefore take into account emissions linked to electricity production (category 2), indirect emissions upstream and downstream of the value chain (category 3, 4, 5 and 6), for example, the GHG emissions associated with the upstream agricultural activities that enable sugar beet to be produced in the fields, or other ecological issues associated with the climate such as the preservation of biodiversity or land use conflicts.

• A scope of analysis of industrial sites focused on sugar beet processing in mainland France.

Although sugar can be produced from two different agricultural raw materials (sugar beet and sugar cane), it is the industrial sites in mainland France processing sugar beet that account for the bulk of production and national GHG emissions: the industrial sites producing sugar cane in the French Overseas Departments and Regions are already carbon-free thanks to energy recovery from bagasse (the fibrous material that remains after crushing sugar cane). The modelling and scenarios carried out as part of the Sugar Sectoral Transition Plan therefore relate solely to the sugar beet sector.

• A decision not to project industrial strategies that could lead to concentrations of production capacity at certain sites.

The very significant volume of investment required could encourage manufacturers to concentrate production at certain sites to generate economies of scale. However, we have chosen not to include a projection on this basis, which places our investment results at the high end of estimates.

• A broad view of the sugar sector, which is therefore heavily dependent on external factors.

The aim of this exercise is to provide an overview of the factors affecting GHG emissions from sugar production. It was therefore necessary to make assumptions about parameters outside of the sector, such as demographics and changing diets. To enable comparison, energy and CO_2 price trajectories have been set in the same way in all the scenarios. An analysis of the impact of such factors on the competitiveness of the sugar industry is, however, a different exercise, and requires an in-depth study of the future of the sugar industry in Europe.

• This sectoral approach could be further enriched by other factors determined by other economic actors.

Since the sugar industry is a node in a complex economy that interacts with upstream entities (dietary trends, agricultural production) and downstream entities (agri-food industries, chemicals and transport), which are themselves evolving, an exhaustive systemic approach to decarbonising the sector would require adopting a vision that goes well beyond the scope of this sector, and therefore numerous assumptions about other nodes in the system. This is the ambition of ADEME's broader project, entitled "Transition(s) 2050", published at the end of 2021.

• Furthermore, as in any foresight exercise, the range of assumptions and combinations of assumptions is infinite, and each scenario could be further discussed by the various actors involved.

Without being predictive in nature, the three scenarios have been developed with the participation of industry professionals and are the result of internal work by ADEME. They reflect three technically plausible outcomes, with different degrees of desirability, in which the choices made by industry and public policy would be significantly different. Other possible trajectories could very well be explored to reveal further insights.

Moreover, the full report that accompanies this summary provides additional information on the context of the scenarios and the way in which the transition could occur in terms of potential industrial strategies. It also details the assumptions made for each scenario. The aim is to broaden the scope of reflection in relation to the various results of the summary. These elements of analysis, which can be described as academic, are based on extensive bibliographical research and sources of public information, as well as interviews with actors in the sector, and are intended to be as objective as possible, given the cross-referencing of all these sources by the authors.

Key figures for the French sugar industry

20

The number of sugar factories in metropolitan France in 2024

spread across five companies, including two agricultural cooperatives, which account for around 85% of production.
In the French overseas departments and regions, four companies operate five factories.

4,5 million tonnes

Average sugar production between the 2015-2016 and 2021-2022 seasons, consisting of 95% sugar beet and 5% cane sugar[2].

France is the largest producer in Europe, with almost 30% of European production (and is the 9th largest producer in the world[3]). Worldwide, 80% of production comes from sugar cane.

8 million hectolitres

Average sugar beet alcohol production between the 2015-2016 and 2021-2022 seasons. This represents around 23% of processed sugar beet[5].

40 %

Proportion of sugar production exported

(including French Overseas Departments and Regions), 90% of which goes to the European Union and the United Kingdom[6].

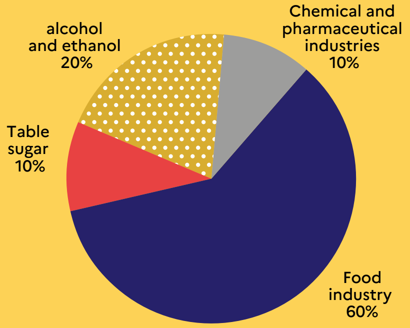
6 TWh LHV

Average fossil gas consumption by sugar beet production between 2015 and 2019. This represents 5% of national industrial consumption[7].

2 MtCO2e

Emissions linked to the operation of sugar factories in metropolitan France between 2015 and 2019[8] (around 3% of French industrial GHG emissions)[8].

Figure 2. Main outlets for the French sugar industry in 2017-2018[4].



77 %

Proportion of GHG emissions from sugar factories linked to steam and electricity production

in cogeneration plants in 2015[9].

5 400

Direct jobs during the 2022-2023 sugar beet season, 4,200 jobs outside the season, and 23,000 sugar beet growers[10].

90 to 120 days

Length of a sugar beet season[11].

Sugar production is a seasonal process that takes place from September to January (excluding alcohol distillation and crystallisation of stored syrup).

[2] France AgriMer / [3] Cultures Sucre, « Mémo Statistique Sucre et autres débouchés - Campagne 2022-2023 », 2023.
[4] Xerfi / [5] France AgriMer and CGB / [6] France AgriMer / [7] SDES and GEREP[8] GEREP / [9] GEREP / [10] CEFS and CGB / [11] SNFS

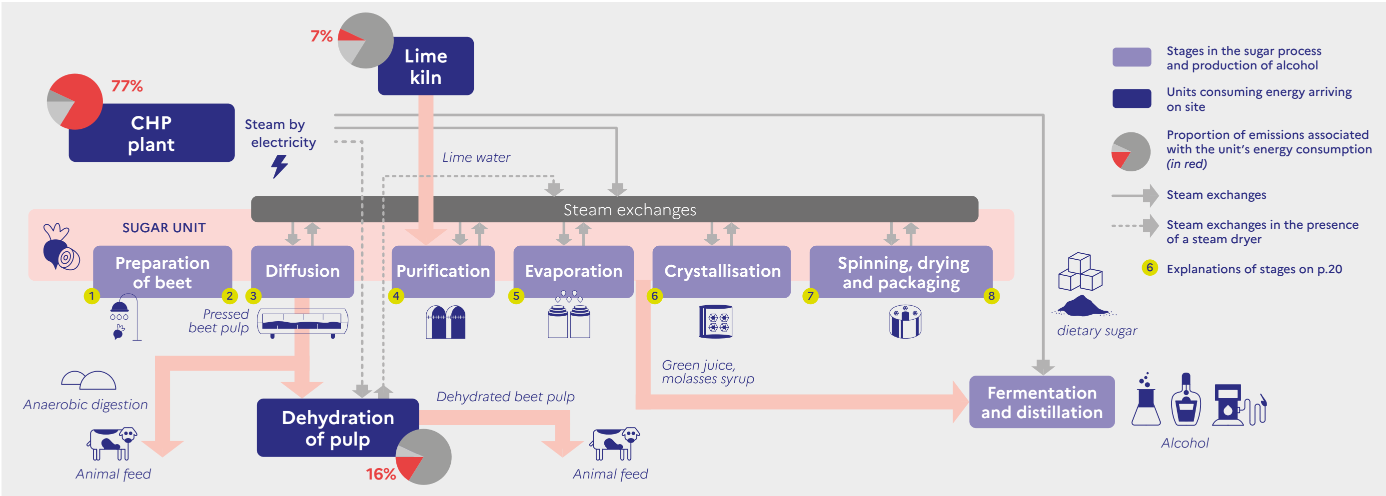
Summary for policymakers

The sugar industry: a local and seasonal sector

Sugar is produced from sugar cane (80% of world production) or sugar beet (20% of world production), depending on local biogeographical conditions (climate, soil, etc.), at industrial sites located less than 50 km from the crops. On average, France produces more than 4 million tonnes of beet sugar a year in mainland France and less than 0.5 million tonnes of cane sugar a year in the French overseas departments and regions. Around 40% of sugar production is exported, mainly to the European Union.
The processing of the agricultural raw material follows the harvest, for a period of four months, between September and January in mainland France. For the rest of the year, the sugar factories are shut down or in partial operation to crystallise stored sugar syrup or to distil alcohol, which is sometimes produced in sugar factories. Sugar and alcohol production also generates other co-products that are already recycled: beet pulp and bagasse (sugar cane fibre), molasses and vinasse, skimmings and soil from washing basins (growing media). The French sugar industry is local and seasonal in its role as a processor of an agricultural raw material.
National production is carried out at 20 sugar factories in mainland France, with two agricultural cooperatives accounting for around 85% of production (Cristal Union and Tereos) and three companies accounting for 10% of production (Saint-Louis Sucre, Lesaffre Frères and Ouvré et Fils). The five sugar factories located in the French overseas departments and regions, which are already largely carbon-free thanks to the use of bagasse as an energy source, account for a further 5% of national production.
The sugar production process is similar for the sugar cane and sugar beet sectors. It consists of extracting the 18% sugar from the other components of the plant, after washing and cutting or crushing the sugar beet and cane in several stages: diffusion in hot water to extract the sugar from the plant; purification of the raw juice by adding quicklime; evaporation to eliminate the water and obtain a dense syrup; crystallisation and separation of the molasses crystals by washing and turbining.
The French sugar industry emitted around 2 MtCO2e per year between 2015 and 2021, or 3% of industrial GHG emissions, concentrated in the sugar beet sector. 77% of GHG emissions come from combined heat and power plants (which run on gas to produce all the steam and almost all the electricity needed for the industrial process). Pulp dehydration in ovens, which are generally coal-fired, accounts for 16% of emissions. Lastly, the lime kilns on each sugar site, fuelled by coke or anthracite, generate the remaining 7% of greenhouse gases.

As national production and GHG emissions are essentially concentrated in sugar beet processing plants, the scope of analysis for this Sectoral Transition Plan has focused on the 20 sugar factories in mainland France that process sugar beet.

Figure 3. Sugar manufacturing process using sugar beet.
Source : I Care



A production outlook guided by trends in the consumption of sugar by households, of ethanol in the chemical industry and European agriculture

Trends in beet sugar production in France are determined by four main factors:

• Domestic sugar consumption and international trade, which determine the price of sugar.

• The consumption and price of energy in factories, which determines the cost of sugar production, and therefore the cost price of beet for farmers.

• Agricultural yields, which determine farmers' earning potential per hectare.

• The competitiveness of sugar beet and its agronomic value, which determine the area under cultivation.

This chain of decisions raises three major issues for the future of national production:

The first issue concerns **changes in the way sugar is used in food**, for example, incorporated into preparations (cakes, pastries, soda) or in its raw form in our coffee: these are known as free sugars, which also include honey and fruit juices. In France, in 2019, these sugars accounted for 15% of the calorie intake of children and 10.5% of the calorie intake of adults. These levels are higher than those recommended by the World Health Organisation, which recommends keeping any intake of free sugars to less than 10% of daily calorie intake (equivalent to 8 sugar cubes) and reducing it to less than 5% for additional health benefits. In this context, public policies based on fiscal leverage (soda tax, 2012) and informational leverage (Nutri-Score, 2017) have emerged in recent years to try to reduce sugar consumption among the French population, and such policies may be strengthened.

The second issue concerns the **development of uses for ethanol produced from sugar**. In France, in 2022, 50% of ethanol was produced from sugar beet and 70% of ethanol was used as a supplementary fuel to petrol in cars. However, this market is expected to shrink as a result of the gradual electrification of vehicles, the pace of which will be accentuated by the end of sales of combustion-powered vehicles in 2035 in the European Union. Other sectors could be interested in this molecule, which could be used in the still limited development of biobased chemicals Various projects are currently emerging to produce biobased ethylene or butadiene from ethanol, or isobutene from sugar. At the same time, demand for beet ethanol will also be impacted by the production of ethanol from wheat and maize and the production of ethanol from resources that do not compete with food.

Finally, the third issue concerns the **development of agriculture in Europe in relation to external competitors (Brazil, India, Thailand). As Europe's leading producer** France is a major player in the continental sugar market, which has a structural deficit: domestic production only covers 90 to 95% of European consumption each year. However, since the end of sugar quotas in 2017, the European market has been more open to foreign competition on the price of sugar, a factor accentuated by free trade agreements allowing certain volumes to enter the European market with reduced customs duties, but with greater environmental impacts than French production[12].

Alongside these economic aspects, domestic production is facing the consequences of climate change and the loss of biodiversity, which means that farming practices need to evolve. These consequences are already visible in crops and the changes in practices required represent major risks for farmers and involve uncertainty about the impacts on yields depending on the varietal alternatives and new management techniques that will be proposed. In this respect, as with any agricultural raw material, the relevance of producing sugar beet in a given area depends on the soil and climate conditions. With climate change, the biogeography of sugar beet is likely to evolve and move northwards as farmers make technical and economic choices between different crops. From this perspective, maintaining French beet production could help offset the fall in production in southern European countries, which would be more affected than the eastern and northern regions of France.

The future of sugar production is therefore linked to a number of uncertainties regarding the development of traditional outlets (dietary sugar, fuel ethanol), new markets (sugar and ethanol for biobased chemicals) and European agricultural production. It is against this backdrop of poor visibility on market opportunities that major technological choices need to be made quickly to achieve in-depth decarbonisation of this industrial sector.

[12] Deloitte. Study of the impact of deindustrialisation on France's carbon footprint. 2022.

Ambitious decarbonisation made possible by two major levers: energy efficiency through electrification and energy recovery from pulp

Two main decarbonisation strategies stand out among sugar manufacturers:

• Reducing energy consumption as much as possible by **a major deployment of the levers of energy efficiency through electrification**, which implies a sharp increase in electricity consumption from the national grid and greater dependence on fluctuations in the price and availability of electricity.

• Ensuring that sugar factories become self-sufficient as soon as possible by **recovering energy from sugar beet pulp**, which will involve a change in the supply of feed for farmers, who currently use this resource to feed their livestock.

These two trends reflect local realities in terms of the location of sugar sites and the demand for pulp from nearby farmers, which varies greatly from region to region.

The first strategy is to reduce the sector's dependence on fossil fuels by implementing complementary passive and active energy efficiency solutions, including electrification. These energy efficiency initiatives can be deployed more or less intensively in sugar factories, with the dual advantage of reducing GHG emissions and sugar and alcohol production costs. It should be noted, however, that the seasonal nature of production, which is specific to the sugar industry, has a major impact on its energy supply, and in particular on its capacity for mass electrification. There are a number of pitfalls to using more electricity from the grid: the need to develop electricity transmission infrastructure on sites in rural areas with little scope for increasing power; the potential increase and variability of electricity prices, particularly in winter; and the constraints of possible load shedding operations on the grid when factories need to operate continuously for four months. While mass electrification of sugar factories appears to be a promising solution, its implementation must be carefully planned so as not to disrupt the smooth running of sugar factories and the electricity network.

➜ Pressed beet pulp © Adeline Pillet

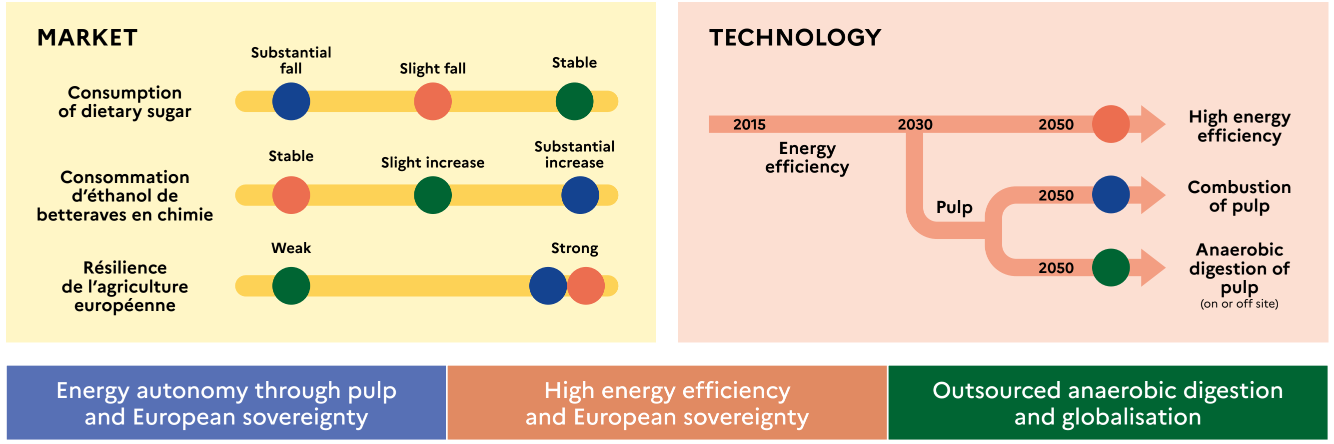
➜ Dehydrated beet pulp © Manee Meena

The second strategy is to get as close as possible to energy self-sufficiency by reducing the increase in electricity drawn from the grid by using beet pulp in the sugar factory to produce the steam and electricity needed for the process. Today, 85% of beet pulp is used as animal feed, either in pressed form (28% dry matter) or in dehydrated form (88% dry matter) for livestock farms further away from sugar factories. In the future, pulp could also be recycled for use by the sugar industry in anaerobic digestion to produce biogas, or direct combustion in boilers after dehydration. Agricultural anaerobic digestion is already expanding rapidly, with the aim of increasing the proportion of biomethane in the French gas network while producing organic fertiliser (digestate). It relies in part on pressed beet pulp, in the same way as other inputs from agri-food industries. The direct combustion of pulp, after dehydration, is not currently deployed in French sugar factories, but could quickly be implemen–ted, with the potential to cover more energy needs than anaerobic digestion for the same quantity of pulp. These different options illustrate the issues surrounding the use of beet pulp, with a compromise between decarbonisation, economic profitability, the quest for autonomy and the local context. The future distribution of beet pulp resources therefore remains to be defined, bearing in mind that the quantity of pulp available depends directly on the year's beet production, and therefore on the prosperity of the industry and its ability to decarbonise.

In order to illustrate the various issues linked to the decarbonisation of sugar factories, such as market uncertainties and the implications of technological choices, the Sectoral Transition Plan (STP) proposes three scenarios with different choices, enabling the risks and opportunities of transition in this sector to be explored.

Three scenarios to illustrate the economic and technological challenges of an ambitious decarbonisation of the sector

Figure 4. Summary of the three transition scenarios in the sectoral transition plan for the sugar industry.



ike other commodities, the world sugar market is structured by the major exporting countries, which determine the price of sugar on the European market and the ability of French sugar manufacturers to pay a good price for sugar beet, and thus encourage farmers to grow it. Furthermore, dietary sugar and alcohol, the main products of the sugar industry, are subject to changing markets: public health policies are tending to encourage lower sugar consumption, and environmental policies are capping the use of fuels derived from agricultural resources that compete with food. In this context, it seems appropriate to integrate the technical and financial challenges of decarbonising industrial sites with the changing European environment in which the sugar sector could evolve. On this basis, three transitional scenarios have been devised, presenting a coherent map of possible futures for the sugar industry.

By 2050, in the ***Energy autonomy through pulp and European sovereignty scenario***, the entire French population has significantly reduced its sugar consumption. This has resulted from ambitious new public health measures. At the same time, the electrification of vehicles has made it possible to redirect the flow of fuel ethanol towards the development of biobased products in the chemical industry, without increasing the amount of agricultural land not used for food. Sugar factories have gradually decarbonised by reducing their energy consumption by 25% and then installing boilers to burn beet pulp, which has been dehydrated by steam dryers.

By 2050, in the ***High energy efficiency and European sovereignty scenario***, public health measures have focused on reducing sugar consumption among the youngest age groups. The reorientation of beet ethanol flows towards chemicals has been reduced because the production of ethanol from resources that do not compete with food (advanced ethanol) has been developed and favoured. Sugar factories have reduced their consumption of coal and gas mainly through very high energy efficiency, made possible by extensive electrification and a significant reduction in pulp dehydration.

In terms of production, European agriculture has remained resilient in these first two scenarios. The European Union has introduced mirror clauses in its free trade agreements, limiting imports of sugar that do not comply with the environmental standards in force in Europe. Research and innovation have made it possible to develop varieties and cropping systems to make them more resilient to climate change, while reducing the impact on ecosystems (soil, biodiversity, water, etc.) and maintaining beet production at the 2019-2023 level. These production volumes, combined with a fall in domestic sugar consumption, have enabled an increase in exports, thereby offsetting the halt to beet production in southern European countries.

By 2050, in the ***Outsourced anaerobic digestion and globalisation scenario***, European agriculture has been weakened. International trade has increased and the European Union has developed free trade agreements without mirror clauses, leading to imports of foreign cane sugar which has replaced French sugar in European countries with sugar deficits; there has been little change in dietary patterns. As sugar production capacity in France and Europe has fallen, manufacturers' capacity to invest has been reduced. The decarbonisation choice has focused on outsourcing the anaerobic digestion of pulp through bilateral contracts with agricultural projects in the form of Biogas Purchase Agreements (BPA).

Table 1. Summary of the main assumptions and technical and economic results of the Sugar Sectoral Transition Plan.

	Energy autonomy through pulp and European sovereignty	High energy efficiency and European sovereignty	Outsourced anaerobic digestion and globalisation
Change in production in 2050 compared with the average for 2019-2023	+0 %	+0 %	-25 %
Change in domestic sugar consumption	-20 %	-20 %	-5 %
Change in the quantity of pulp made available for non-energy uses by sugar manufacturers in 2050 compared with 2015	-70 %	-10 %	-65 %
Level of decarbonisation achieved in 2050 compared with 2015	-96 %	-94 %	-92 %
Decarbonisation investment between 2015 and 2050	€2,500m	€1,750m	€600m
Change in production costs between 2015 and 2050 (excluding raw materials)	+7 %	+13 %	+22 %

Each of these scenarios illustrates different types of dependence in terms of energy supply.

In the ***Energy autonomy through pulp and European sovereignty scenario***, the use of beet pulp for direct combustion in boilers and the anaerobic digestion of washing water ensure the sector's resilience, particularly in the face of variations in energy prices. Little use is made of network gas, and the factories have reduced their energy consumption through partial electrification. However, a large proportion of the pulp can no longer be made available to farmers to feed their livestock. In the ***High energy efficiency and European sovereignty scenario***, energy consumption is very significantly reduced, enabling sugar manufacturers to free themselves in part from fossil fuels while continuing to make beet pulp available to livestock farmers. Despite the development of anaerobic digestion of washing water, dependence on the electricity grid will be much greater in 2050, with the risks that this brings: sensitivity to variations in the price of electricity and possible load shedding since the sugar factories consume electricity in winter. In the ***Outsourced anaerobic digestion and globalisation scenario***, in a situation unfavourable to the industry, outsourced anaerobic digestion enables sugar manufacturers to decarbonise their supplies at a lower cost. If the pulp is used to guarantee part of the supply for anaerobic digestion, it can no longer be made available to farmers.

These three scenarios allow us to explore decarbonisation trajectories in transition scenarios that differ in terms of technology and markets. By cross-analysing their assumptions and results, this simplified foresight approach makes it possible to highlight cross-cutting lessons and avenues for action to facilitate the decarbonisation of the sugar industry.

Key factors in the decarbonisation of the sugar industry

Rapid, extensive decarbonisation possible for the French sugar industry

Regardless of the scenario studied, an extensive decarbonisation of the sugar industry is possible by 2050 and would make it possible to significantly exceed the SNBC2 objective of an 81% reduction in greenhouse gas emissions (with a 92 to 96% reduction in emissions depending on the scenario). In addition, the French sugar industry has the capacity to halve its GHG emissions between 2015 and 2030 by stepping up the efforts made in recent years, particularly in two areas:

• Phasing out the use of coal in the industry by 2030

- by reducing the quantity of dehydrated pulp, by concentrating dehydration on sites that replace coal-fired drum kilns with steam dryers or biomass-fired drum kilns, depending on locally available resources.

• Increased energy efficiency and partial electrification of sugar factories

- by deploying a series of mechanical steam recompressions combined with other energy-saving levers (increasing the exchange surface during the evaporation stage, adding of a cold point and diffusion tower, etc.).

However, this rapid decarbonisation by 2030 will require a high pace of investment, in the region of €50-70m per year, which is about 20% of the tangible asset investment rate observed in the 2018-2021 period within the sector.

Courses of action

1. **Propose public aid for investment and operation (e.g. CCfD - Carbon Contract for Difference - type mechanism), taking into account the seasonal nature of the sugar industry, which means that equipment has to be oversized.**

2. **Support innovation in production facilities, in particular for the development of hydrothermal gasification of distillery vinasse or new technologies for mechanical steam recompression and high-temperature heat pumps.**

3. **Develop the skills and training of a new generation of technicians for equipment for optimising the energy efficiency of the sugar production process.**

The industry should anticipate a fall in the use of sugar in Europe

In order to improve the health of the population, it is necessary to reduce sugar consumption, with priority given to the very young, whose consumption far exceeds WHO recommendations. As a result, European consumption of dietary sugar could fall sharply over the coming decades. At the same time, the gradual electrification of cars will sharply reduce the use of beet ethanol as a fuel between 2030 and 2050. Like some of the dietary sugar, this could be redirected towards the chemical industry in order to develop bio-based products such as ethylene, butadiene, propylene or isobutene, without using more agricultural land. The sugar industry is therefore likely to face major changes in its markets, which could impact its business model and force it to innovate in less mature markets such as biobased chemicals.

Courses of action

7. **Revise the national bioeconomy strategy to bring it into line with the new European and French objectives for ecological transition and sovereignty.**

8. **Support the development of innovative industrial pilots in biobased chemistry.**

Two strategic orientations to be adapted to each site according to local constraints and the concerns of industrial groups

• Seeking energy autonomy

> Partial energy efficiency combined with the combustion of dehydrated pulp in boilers or in-house or outsourced anaerobic digestion of beet pulp, which means a sharp reduction in the quantity of pulp available for animal feed and therefore the development of dedicated crops (such as maize) if livestock numbers are maintained.

This solution makes it possible to limit the increase in the amount of electricity drawn from the grid, but requires a large amount of beet pulp (during the beet season) and wood energy or gas (outside the beet season) to satisfy the steam and electricity production of the factories.

• Maximum energy efficiency through electrification

> through greater deployment of energy efficiency and electrification levers, by eliminating electricity production by cogeneration and developing drawing capacity on the grid.

This solution makes it possible to reduce the quantity of pulp used to produce energy, but it involves modifying the electricity network infrastructure to increase the drawing power, and introduces greater vulnerability to the availability and winter price of electricity.

Courses of action

4. **Take into account the specific characteristics of each site in order to determine the sustainability status of the pulp and facilitate its energy use in situations where this is relevant. In such cases, initiate preliminary discussions between manufacturers and regional biomass units to validate the feasibility of using pulp.**

5. **Study the feasibility of introducing electricity price support schemes that take account of the seasonal nature of sugar beet processing between September and January.**

6. **Initiate discussions between the industry, the French energy transmission system and the French government to include sugar sites in the planning schedule for reinforcement of electricity networks.**

These two orientations are strategic choices, but they can be qualified. Increased application of energy efficiency measures will lead to greater consumption of electricity on the grid and therefore less energy autonomy, even if pulp is mobilised to decarbonise steam production in factories. However, the level of dependence on the electricity grid and the quantity of pulp mobilised can be adapted to each local context.

France has a role to play in reorganising the European sugar industry

The sugar industry has changed radically in recent years. Under the economic constraints generated by the reorganisation of the European sugar market, which led to the end of sugar quotas in 2017 and the integration of new countries into the European Union, industrial groups have restructured to concentrate production on a smaller number of sites without reducing production volumes.

In the future, the market is likely to evolve further as a result of consumption trends in Europe and the pressure exerted on sugar beet growing by the intensification of climate change. As a result, the biogeography of sugar beet could change, leading to a reorganisation of production, partly in France in areas that are already irrigated (12% of the national surface area in 2021), and to a greater extent in southern countries (Spain, Italy), which may no longer be able to grow sugar beet profitably as the effects of climate change increase.

If the area under cultivation and yields stabilise in France despite climate change, the French sugar industry will be in a good position to increase its exports and make an even greater contribution to Europe's sugar self-sufficiency, thereby partly offsetting the reduction in domestic use.

Courses of action

9. **Support the development of agro-ecological practices and research and development of resilience solutions to deal with the effects of climate change on beet growing (agronomy, biocontrol, genetics, robotics).**

10. **Initiate discussions with the European Commission on the future of the European sugar industry to anticipate the reorganisation of production in a context of falling consumption and increasing effects of climate change on European production.**

1. The challenges of decarbonising the sugar industry

1.1. Market prospects are determined by the resilience of European agriculture, public health policies and innovations in chemical products

The French sugar industry is currently 90% supplied by French sugar beet processed in the direct vicinity of factories in mainland France and by sugar cane processed in French overseas departments and regions. National production is equivalent to 30% of the European Union's needs, while France accounts for just 15% of the EU's population.

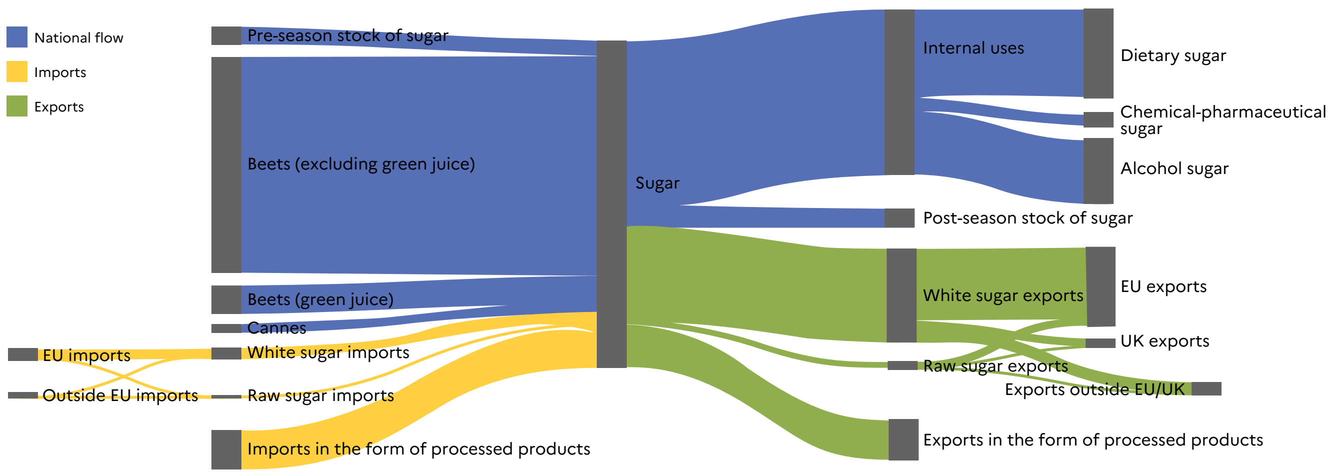
Domestic use is split between food (50%), alcohol and ethanol production (40%) and chemical-pharmaceutical inputs (10%).

Sugar imports are fairly low, mainly consisting of trade with neighbouring European Union countries such as Germany, Belgium and the Netherlands.

Exports, on the other hand, account for a very large proportion of outlets for the national industry, with the equivalent of 40% of production. 80% of exports go to the European Union (mainly Italy, Spain and Belgium) and 10% to the United Kingdom.

In addition to domestic use, the French sugar industry thus plays a significant role in supplying sugar to the European market.

Figure 5. Sankey diagram for the French sugar sector, 2021-2022 season.
Flows expressed in tonnes of sugar equivalent based on data from France AgriMer, Cultures sucre and the CGB.



[13] World Health Organization. Guideline: Sugars intake for adults and children. 2015.

[14] EFSA Panel on Nutrition, Novel Foods and Food Allergens (NDA). Tolerable upper intake level for dietary sugars. EFSA journal. 2022.

[15] Deshayes, C.; Seconda, L.; Reiser, P.; Prinz, P.; Hebel, P. Intake of Free Sugars and Main Food Category Contributors among French Children, Adolescents and Adults. Appl. Sci. 2021.

1.1.1. Reducing consumption of sugary foods to improve French public health

Dietary uses of sugar account for 70% of the outlets for the French sugar industry.

Beet or cane sugar is sucrose, which combines one unit of glucose and one of fructose. It belongs to the family of free sugars, which includes simple sugars added to foods by manufacturers, cooks and consumers, as well as the simple sugars naturally present in honey, syrups and fruit juices.

A distinction is made between free sugars and other sugars: other simple sugars (sugars naturally present in fruit) and complex sugars (composed of several simple sugars, such as the starch present in pasta, rice or potatoes). This distinction was introduced by the World Health Organisation (WHO) to help reduce the risk of chronic metabolic diseases (obesity, high cholesterol, liver disease, type 2 diabetes) linked to sugar consumption. The UN agency defined its recommendations in 2015[13]:

• In adults and children, the WHO recommends that free sugar intake should be reduced to less than 10% of total energy intake (TEI), i.e. around 50g/day (strong recommendation).

• The WHO suggests going further and reducing the intake of free sugars to less than 5% of total energy intake, i.e. around 25g/day (conditional recommendation).

The European Food Safety Agency (EFSA) has shared its recommendations for 2022[14]: « A level of sugar intake at which the risk of dental caries/chronic metabolic diseases is not increased could not be identified over the range of observed intakes, and thus, a tolerable upper intake level or a safe level of intake could not be set. Based on available data and related uncertainties, the intake of added and free sugars should be as low as possible in the context of a nutritionally adequate diet. »

In France, free sugar consumption was measured by CREDOC in 2019[15].

As a proportion of daily energy intake, this survey also shows that every age group under 50 consumes too much free sugar compared with the WHO's standard recommendation. This over-consumption is more marked among children and teenagers.

Finally, the survey shows that 85% of children and adolescents and 48% of adults exceed the WHO's strong recommendation: a maximum of 10% of energy intake covered by sugar.

In this context, public policies based on fiscal leverage (soda tax, 2012) and informational leverage (Nutri-Score, 2017) have been introduced in recent years in an attempt to reduce the amount of sugar present in the foods consumed by the population, and the associated impact on health. These types of measures could be increased between now and 2050.

Table 2. French sugar consumption by age group.

	2019	
	Free sugars/day	% of total energy intake
3 - 6	58 g	16 %
7 - 12	62 g	15 %
13 - 17	82 g	15 %
18 - 34	66 g	13 %
35 - 49	63 g	12 %
50 - 64	51 g	9 %
64 - 75	45 g	8 %
76 +	50 g	9 %

Figure 6. Breakdown of free sugar consumption by French people aged 3 to 17 in 2019 according to CREDOC.

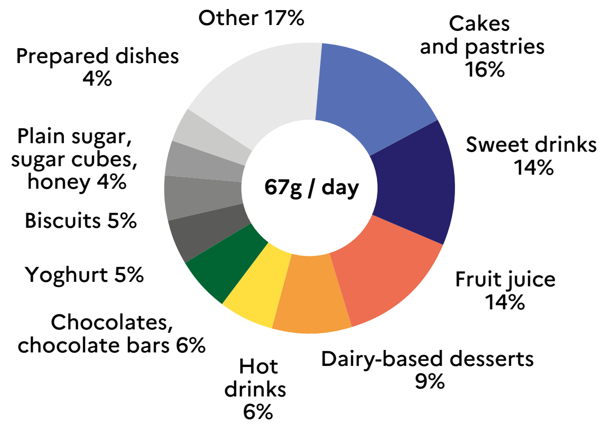
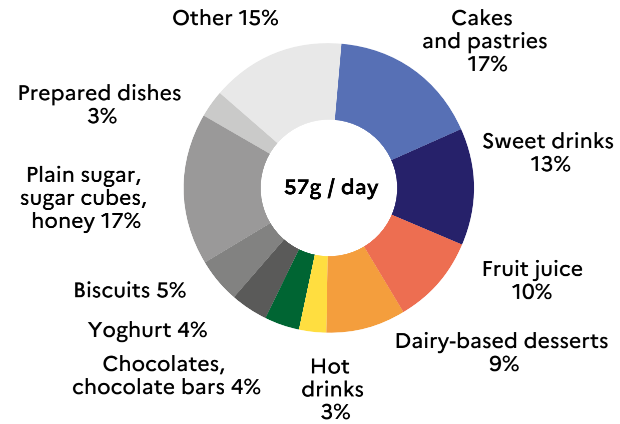


Figure 7. Breakdown of free sugar consumption by French people aged 18 and over in 2019 according to CREDOC.



1.1.2. New outlets for the sugar industry focus on the development of bio-based chemical products

Using sugar to produce alcohol (or ethanol) accounts for 20% of the sector's outlets.

France is Europe's leading ethanol producer. 50% of the volumes produced each year come from sugar beet, and 75% of the volumes are used as fuel (known as bioethanol) mixed with petrol in internal combustion cars (E85 fuel = between 65% and 85% bioethanol; SP95-E10 fuel = up to 10% bioethanol).

However, cars are expected to move away from bioethanol and become progressively more electrified, in line with the CO_2 emission standards for new cars sold in the European Union[16] :

- **-15%** reduction in CO_2 emissions over the period 2025-2029 compared with 2021
- **-55%** reduction in CO_2 emissions over the period 2030-2034 compared with 2021
- **-100%** reduction in CO_2 emissions from 1 January 2035

This means that from 2035, only electric cars and cars running on carbon-neutral fuel will be allowed to be sold in the European Union[17].

So, despite the recent upward trend in bioethanol consumption, which should continue between now and 2030 with the growth in sales of E85 Flex-Fuel conversion kits, the period 2030-2050 should nevertheless see a reduction in fuel ethanol volumes as the number of petrol vehicles in circulation falls.

This flow of ethanol could, however, be redirected towards biobased chemistry, without mobilising more agricultural land. Beet ethanol would then no longer be used as energy in cars, but as a raw material in olefin production plants (ethylene, propylene, butadiene). This new Bioethanol To Olefin (BTO) route is already the subject of industrial projects in Europe and around the world (e.g. the Brazilian petrochemist Braskem's products made from bioethanol derived from cane sugar). The Dutch start-up Syclus (co-owned with a subsidiary of European sugar producer Sudzucker) is aiming for its first bioethanol ethylene production facility in 2026 (using French technology developed by Axens). In France, Michelin and Axens inaugurated an industrial demonstrator in 2023 for the production of butadiene from bioethanol (whether derived from resources competing with food or not), a material used in the manufacture of synthetic rubber. The French company Global Bioenergies announced plans to build the world's first bio-based isobutene production plant in France in 2023, using a genetically modified bacterium to convert the sugar. These demonstrations could pave the way for developing this new process on a commercial basis.

Figure 8. Breakdown of ethanol production by raw material in France in 2022.
Source : FranceAgriMer

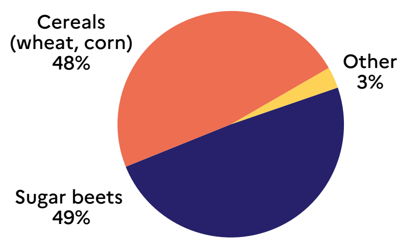
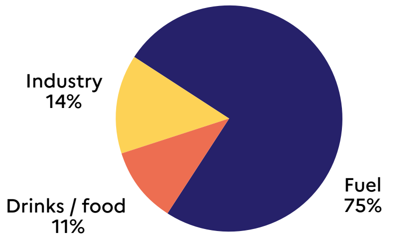


Figure 9. Breakdown of ethanol use in France in 2022.
Source : FranceAgriMer



However, the material and energy uses of sugar raise the question of competition for the use of agricultural land to produce food. It was on this basis that the European Union set a ceiling of 7% for the use of these fuels in the final energy consumption of the transport sector in each EU Member State[18]. Similarly, the recent requirements to incorporate sustainable aviation fuels in aircraft will not allow beet ethanol to find a new outlet, as these fuels will have to come from resources that do not compete with food[19].

This concern about competing uses for agricultural land may also be a factor in the new uses for sugar and ethanol. Beet ethanol production could then gradually find itself in competition with the development of bioethanol projects based on resources that do not compete with food, such as the bioethanol plant run by paper manufacturer Ryam in Tartas. With production equivalent to 2% of current national bioethanol production, and even though other projects such as DESCARTES[20] are ongoing, there is still a long way to go before this new generation of ethanol is at a scale to replace conventional ethanol volumes, although it can already position itself in the new markets.

[16] Regulation (EU) 2023/851 / [17] A number of carmakers, including Renault, Nissan, Peugeot, Citroën, DS, Opel, Fiat, Jeep and Volvo, have even announced that they will sell 100% electric vehicles in Europe from 2030. As for bioethanol, Ford, which was the last manufacturer to offer a full range of E85 vehicles in France, will only be selling one model from 2024. / [18] Directive (EU) 2023/2413 / [19] The resources concerned are listed in Annex IX of Directive (EU) 2023/2413 / [20] Procedure for converting waste into platform sugars: https://librairie.ademe.fr/7170-descartes-procede-de-conversion-des-dechets-en-sucres-plateformes.html

➜ Harvesting of sugar beets © Olivier Uchmanski

1.1.3. European agriculture at a crossroads between the impact of climate change, exposure to international trade and sovereignty

European agriculture is the third major challenge for the future of the sugar industry. France is Europe's leading producer, with around 4 million tonnes of sugar produced each year. It also exports around 30% of its production, most of it to the European Union. The supply of French sugar is currently essential to the food autonomy of the European Union, whose production does not cove consumption: the EU is structurally a net importer of sugar, importing 5 to 10% of its consumption.

In the future, European agriculture faces a twofold challenge:

1. Reducing its impact on the climate and ecosystems (biodiversity, soil, water, etc.) while increasing carbon storage.

2. Maintaining sufficient production volumes to ensure the continent's food sovereignty.

Agriculture must reduce its impact on the climate and ecosystems because it is a primary victim of the various effects of climate change, such as increased water stress in summer, more intense rainfall in autumn, the risk of late frosts and weather favourable to the development of pests in the spring, or the imbalance between these pests and their natural predators. However, while there is a consensus on the objective, scaling up solutions (agronomy, biocontrol, genetics and robotics) takes time. The introduction of these new practices, combined with an increase in the effects of climate change, makes it difficult to predict future yields, which have been relatively stable over the last 10 years[21].

While this uncertainty is present throughout the European Union, the member countries are not equally vulnerable to the effects of climate change, which raises the question of the future distribution of beet production in Europe up to 2050 and beyond. Like other crops, sugar beet could see its biogeography move northwards as part of a technical and economic trade-off between farmers and other crops. In this context, countries such as Spain and Italy could sharply reduce their sugar production (by around 550,000 tonnes a year between 2019 and 2022).

Finally, since sugar is a global commodity, the development of European agriculture must also be seen in the context of trade that could be facilitated by agreements between the European Union and other regions of the world (Brazil, India, the United States, etc.). By allowing sugar or ethanol to be imported with reduced customs tariffs, these trade agreements could destabilise the European sugar market, with repercussions on the price of sugar beet and therefore on farmers' willingness to produce it, by putting sugar beet and sugar cane producers who do not have the same environmental and social production rules in competition with each other.

[21] Excluding the 2020-2021 season, during which yields fell by 30% as a result of a combination of severe drought and heavy pressure from the Beet yellows virus, against which protection was provided by the use of neonicotinoids in seed coatings. These products were banned in France in 2018 to reduce the impact on biodiversity, then reauthorised in 2021 and 2022 before being permanently banned in 2023.

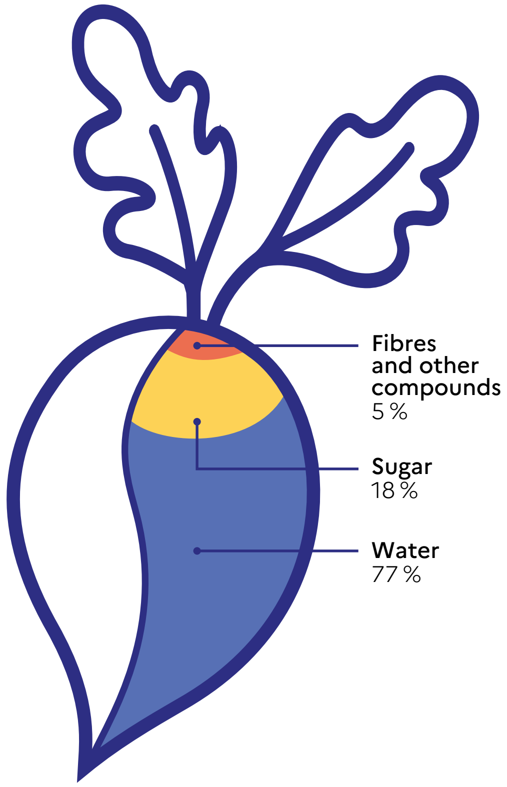
1.2. Sugar production uses a lot of gas in a thermally integrated process

1.2.1. Sugar factory operating process

The sugar process consists of extracting the sugar (sucrose) by separating it from all the other components of the plant.

1 Harvesting and transport: in mainland France, the sugar beet season runs from the end of September to December or January, when all the beet is harvested, delivered to the sugar factory and processed. The average supply radius for sugar factories is 30 km, with storage time for beet reduced to a strict minimum in order to preserve its sugar content.

2 Washing and cutting: the beets are stirred in a wash to separate them from earth, grass and stones. Clean beets are cut into thin strips called «cossettes».



3 Diffusion: the sweet juice is extracted from the cossettes by diffusion in a long cylinder through which they pass in a counter-current of water heated to 70°C, resulting ina raw juice containing around 85% water. The spent cossettes, or «pulp», are used for animal feed (85%) and to produce biogas through anaerobic digestion (15%).

4 Filtration: the juice obtained contains impurities that need to be removed (mineral salts, organic compounds, etc.). They are precipitated by adding milk of lime and double carbonation (adding CO_2), and finally filtered to separate the purified sugar juice from the calcium-rich precipitates, known as skimmings, which are spread on fields to correct the pH of the soil. The lime and the CO_2 required for this stage are produced in on-site lime kilns in which limestone is calcined at temperatures close to 900°C to supply the two reagents.

5 Evaporation: at this stage, the filtered juice contains around 15% sugar and 85% water. Brought to the boil in pipes in contact with steam, the juice passes through a series of evaporators (generally 5 or 6 «evaporating effects») to become a syrup that is 65 to 70% sucrose. This stage is at the heart of the thermal system for the sugar process: the cogeneration plant supplies steam directly to the first evaporation effect, where the steam reaches around 130°C, before being decreased from effect to effect, with each tank receiving steam at a lower temperature than the previous one. The evaporator also makes it possible to redistribute some of the steam from each effect to the other processing units in the sugar factory, which require lower temperatures.

At the end of the evaporation stage, a syrup is obtained that can be crystallised directly or stored for later crystallisation - the spring syrup season, or used in the distillery to produce alcohol.

➜ Transporting sugar cossettes to diffusion © SpiritArt

6 Crystallisation: the syrup completes its concentration in boilers operating under partial vacuum at 78°C to prevent caramelisation. Very fine crystals (icing sugar) are introduced to seed the syrup. The crystallisation process becomes more widespread and the result is the «cooked mass», formed of multiple small crystals suspended in a syrup coloured by residual impurities. The residue obtained at the end of this stage, known as molasses, can then be used for various applications such as ethanol production, animal feed, or yeast and bacteria production.

7 Spinning: the cooked mass is sent through turbines fitted with a perforated sheet metal basket, where, under the action of centrifugal force, the syrup is evacuated while the crystallised white sugar is deposited on the sides of the basket.

8 Drying and packaging: still hot and humid, the white granulated sugar is passed through hot air dryers. It is then cooled and stored in silos, where it stabilises before being packaged.

The factories are supplied with steam and electricity by a cogeneration plant. Historically, cogeneration plants were designed to produce electricity, but energy efficiency measures have gradually reduced steam consumption and, in parallel, electricity production. Sugar factories are therefore connected to the electricity network to ensure their operation, albeit with fairly low drawing powers and little margin available without generating major changes to the network infrastructure.

In addition to the main sugar process, there are additional stages at certain sites:

- **Dehydration of beet pulp:** the majority of beet pulp is currently used for animal feed, which means that some of it needs to be dehydrated to make it easier to transport and incorporate into compound feeds. The dehydration stage consists of exposing the pressed pulp (i.e. before dehydration) to air at high temperature (between 800°C and 900°C) in a drum-dryer kiln independent of the sugar process, or to steam in a steam-dryer device integrated into the sugar process.
- **Fermentation of juices, syrups and molasses:** after sugar, alcohol is sugar factories' second main product. It is obtained by fermentation of the sugar juice from the purification stage, or from the syrup obtained after evaporation, or from the molasses remaining after crystallisation, each of which has different levels of purity. When ethanol is formed, biogenic CO_2 (fixed by the plant as it grows) is emitted. The residue obtained after fermentation, distillation and, depending on the use of the alcohol, rectification, dehydration and refining, is called vinasse. This potassium-rich by-product is used as a fertiliser.

The various stages above highlight the many co-products that can be recovered for industrial, agricultural or energy uses: beet pulp, molasses, skimmings, vinasse, and soil and water returned to the fields.

Greenhouse gas (GHG) emissions in the sugar industry have changed little since 2008. They are around 2 Mt per year, or 3% of French industrial emissions[22], and vary depending on changes in production. Three sites were among the 50 French industrial sites that emitted the most greenhouse gases in 2019. GHG emissions are concentrated in sugar factories in mainland France, since the use of bagasse as an energy source in the French overseas departments and territories has made it possible to decarbonise cane sugar production.

Specific emissions vary from one year to the next depending on a number of factors: tonnage of beet processed, industrial choices concerning the proportion of pulp to be dehydrated, trade-offs between sugar and alcohol production, and the length of the syrup season.

[22] Data from the annual declaration of pollutant emissions and waste (GEREP).

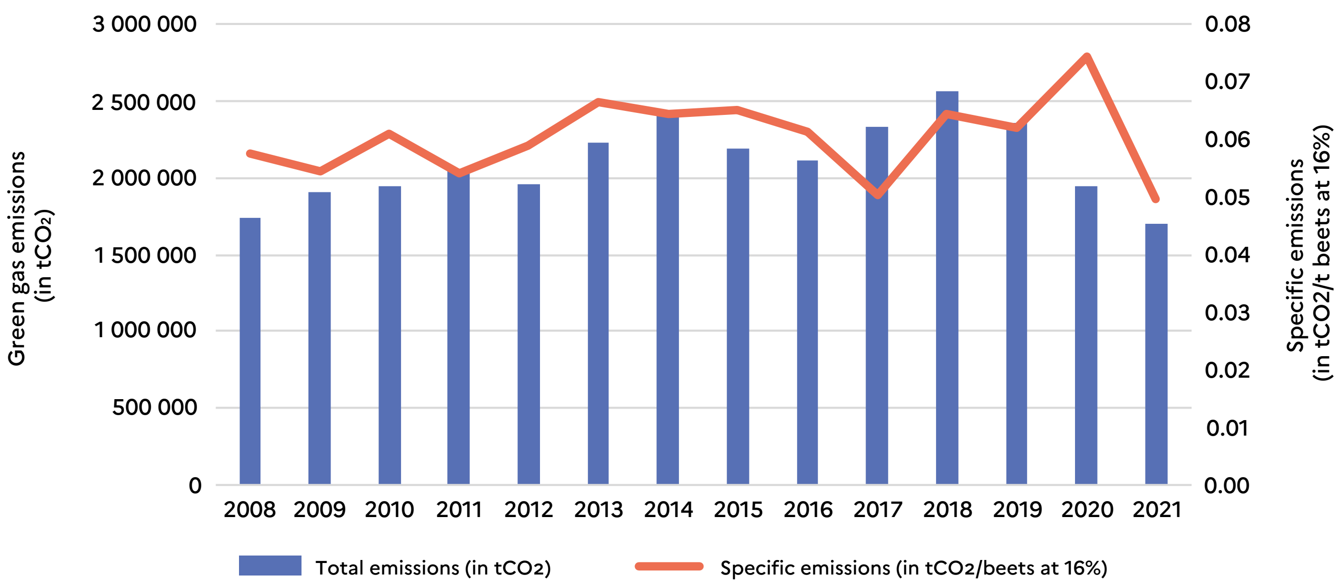
CO_2 from the combustion of fossil fuels in the sugar beet sector accounts for all sectoral emissions in three areas:

• Heating systems in sugar refineries and distilleries account for 77% of CO_2 emissions in the manufacturing process. These emissions come mainly from the combustion of natural gas.

• Beet pulp dehydration facilities account for 16% of CO_2 emissions in the manufacturing process. These emissions come from high-temperature ovens used to dry the pulp. Coal is the main fuel used for these facilities.

• Lime kilns account for 7% of CO_2 emissions in the manufacturing process. The quicklime used to purify the juice is produced from limestone heated by burning coke or anthracite.

Figure 10. Total (tCO_2) and specific (tCO_2/tbeets at 16%) emissions from sugar factory operations.
Sources: EU ETS transaction log, I Care and Agreste processing



Biogenic CO_2: an additional contribution by the sugar industry to decarbonisation

Every year, France produces around 17 million hectolitres of agricultural alcohol from 12 distilleries, including 7 sugar factory distilleries. In the sugar factory distilleries, the sugar contained in the juice after the diffusion stage, and the syrups or beet molasses are transformed into raw alcohol by fermentation and distillation, and then into the final product by rectification, refining and/or dehydration, depending on the intended market.

During fermentation, 80 kg of CO_2 are generated for each hectolitre of alcohol produced. Unlike CO_2 emitted by the combustion of fossil fuels or during the calcination of limestone, this CO_2 is considered biogenic, with a zero emission factor in carbon accounting because it is captured from the air during the photosynthesis process.

The advantage of CO_2 from fermentation is that it comes out of the distilleries almost pure (98%) and therefore requires little investment to process. Currently, 3 of the 12 distilleries capture and then use this biogenic CO_2 for various industrial and agricultural applications (soda production, reducing the pH of industrial effluents, increasing the concentration of CO_2 in agricultural greenhouses).

In addition to these applications, biogenic CO_2 can contribute to decarbonising France in two other ways:

• Capture and geological storage of biogenic CO_2 to help France meet its climate objectives by 2050

• Capture and use of biogenic CO_2 to obtain a product that replaces fossil resources, such as synthetic fuels produced from CO_2 and H_2.

With 8 million hectolitres of alcohol produced from beet sugar, the sugar-alcohol sector currently generates 650,000 tonnes of biogenic CO_2 per year, which could represent an additional contribution by the sugar industry to the fight against climate change if this CO_2 is captured and then stored or recycled in products that replace fossil fuels.

1.2.2. Main technological levers for decarbonising the sugar process

There are four main families of decarbonisation levers: technological levers for energy efficiency (lever 1) and levers for decarbonising the energy mix of the cogeneration plant (lever 2), pulp dehydration facilities (lever 3) and lime kilns (lever 4).

Lever 1: Energy efficiency

The first family of decarbonisation levers consists of reducing energy consumption per tonne of beets processed in the factory. Energy efficiency technologies can be divided into two families:

• **Passive energy efficiency:** the principle is to reduce waste heat losses by using more efficient equipment, and/or maximising heat recovery by optimising the plant's thermal system. This can be achieved by improving the performance of exchangers throughout the factory, increasing the evaporation surface area (by adding evaporating effects and/or adding evaporation surface area for each effect), adding a cold point, installing a vertical diffusion tower, or recovering carbonation vapours.

• **Active energy efficiency (through electrification):** due to the complexity of individual energy systems in sugar factories, and the need to maintain thermodynamic balance within the process, passive energy efficiency actions are generally complemented by active energy-saving actions. In each sugar factory, a complex energy scheme ensures an efficient thermal balance between the need for heat and the need for electricity, by recycling the steam several times. Reducing the steam requirement of one of the process stages is only useful if the other processing stages using the same kilowatt-hours of steam (at a slightly lower temperature) also benefit from energy efficiency measures.

Technologies are therefore used that can be deployed on their own so as to reduce steam requirements. These consist of mechanical vapour recompression (MVR) – already deployed – and high-temperature heat pumps (HTHP) - at the industrial demonstrator stage. Their general principle is the same: the temperature of steam that has already been used (e.g. from the evaporation outlet) is increased by means of electrical work, so that it can be used again. Fossil fuel consumption for steam production is thus replaced by an electricity requirement, with the coefficient of performance (COP) characterising the quantity of thermal energy recovered per unit of electrical work. This is between 4 and 6 for mechanical vapour recompression and between 2 and 4 for high-temperature heat pumps.

Lever 2: Decarbonisation of steam production

Boilers in cogeneration plants are the main fuel consumers in sugar factories. Today, they are mainly fuelled by natural gas. A major lever for decarbonising sugar production is to decarbonise the energy mix that powers cogeneration plants, with the main challenge lying in the energy use of beet pulp. Most of this is currently used as animal feed (85% in 2022), but it could also be used to generate energy for the cogeneration plant, either by combustion or anaerobic digestion:

• **Energy recovery from pulp by combustion** could have covered between 80 and 90% of the energy needs of sugar factories in 2015 (use of all pulp). This requires dehydrating the pulp beforehand and replacing gas-fired boilers with biomass boilers.

• **Energy recovery from pulp and other residues through anaerobic digestion** could have covered around 60% of the energy needs of sugar factories in 2015, by replacing fossil gas with biogas. It is also possible to recover effluents and organic waste (washing water, grasses and rootlets, distillery vinasses) in the form of biogas through anaerobic digestion, with a potential of around 10% of the factories'energy requirements, either on site or with partners (farmers in particular). Several pulp anaerobic digestion projects are underway, generally on sites adjacent to the sugar factory. Anaerobic digestion of washing water has also already been implemented (5 to 7% of the sugar factory's needs), requiring anaerobic digestion equipment adapted to this very liquid input, but should become more widespread. Anaerobic digestion of washing water has also already been tested, covering 5 to 7% of the sugar factory's needs. It requires anaerobic digestion equipment adapted to this very liquid input, but should become more widespread. At the same time, hydrothermal gasification of vinasse is now receiving particular attention as a way of making distilleries more self-sufficient in gas, although the technology is still at the demonstrator stage in Europe.

Lever 3: Decarbonisation of pulp dehydration

Current dehydration units consist of drum kilns, powered by fossil fuels (mainly coal and, to a lesser extent, network gas). Decarbonising the mix for dehydration units is possible in two ways:

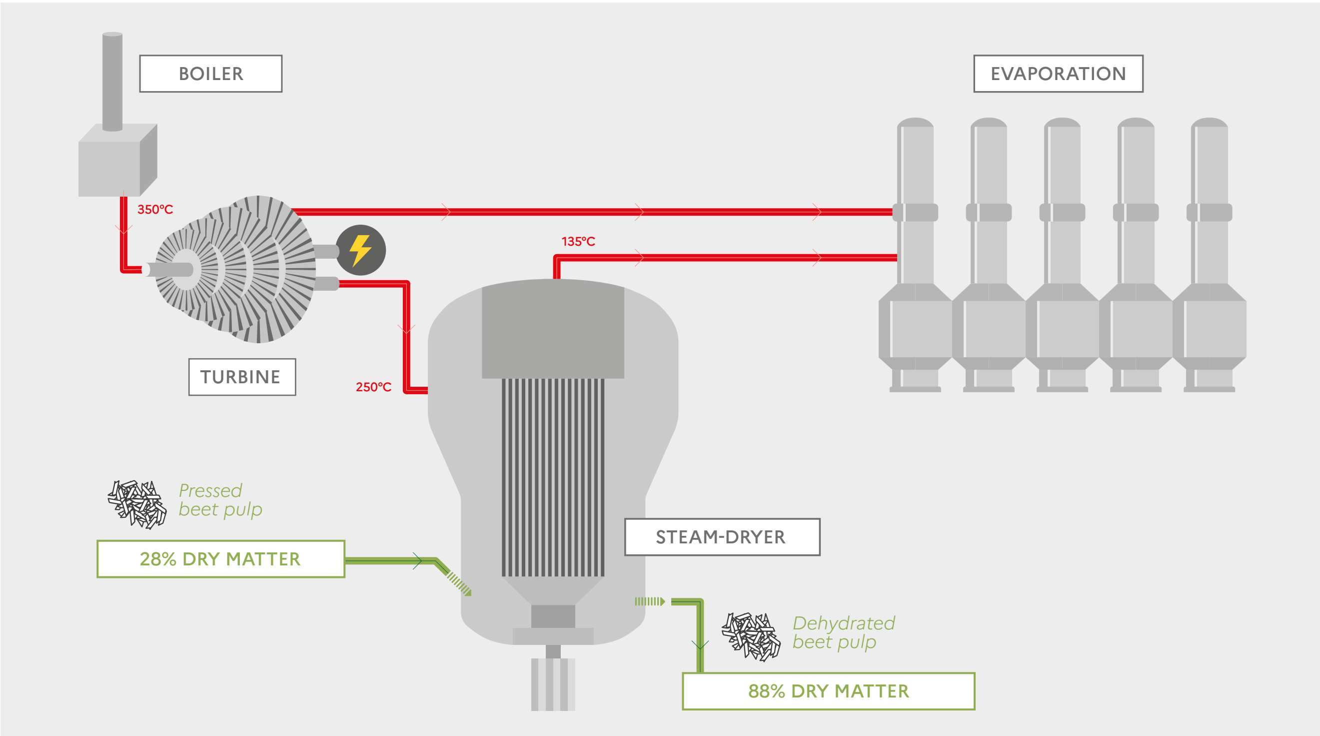
- **Modification of fuel in drum kilns.** The current drum kilns could be replaced by wood-energy kilns.
- **Installation of a steam dryer**, which uses the steam produced by the sugar factory's boiler to dehydrate the pulp. This technology is already deployed at Lesaffre in Nangis and at Cristal Union in Sainte-Emilie.

Lever 4: Decarbonisation of lime kilns

The aim is to replace the coke and anthracite that make up the energy mix in lime kilns with less carbon-intensive energy sources:

- The first option is to **replace coke and anthracite** with network gas or biogas, which will provide the heat (and the process CO_2) needed for the lime kilns.
- The second option is to **outsource lime production** and buy it from manufacturers with more efficient facilities that would capture and store both energy and process emissions over the long term (CCS). One consequence of this outsourcing of lime production would be a shortfall in CO_2 produced by sugar manufacturers during the calcination of limestone, which is used in the purification stage for the carbonation of lime. An alternative solution would be to capture the biogenic CO_2 emissions from the fermentation stage in the distillery and use them for the lime carbonation.

Figure 11. Operation of steam dryers to dehydrate beet pulp.



When the pulp is inside the steam dryer, it is kept in suspension in a fluidised bed by steam at 250°C. The main fan at the bottom blows the steam through perforated plates on which the pulp is kept suspended by the swirling action. Some of the steam produced by the boiler is sent at high pressure to the steam dryer, then recovered at low pressure after dehydration of the pulp to supply the evaporation unit. Integrating the steam dryer and supplying it with high-pressure steam thus reduces the turbine's capacity to produce electricity.

1.2.3. Two technological challenges for decarbonising the sugar industry: energy efficiency and the use of pulp

A major increase in demand for electricity from the grid?

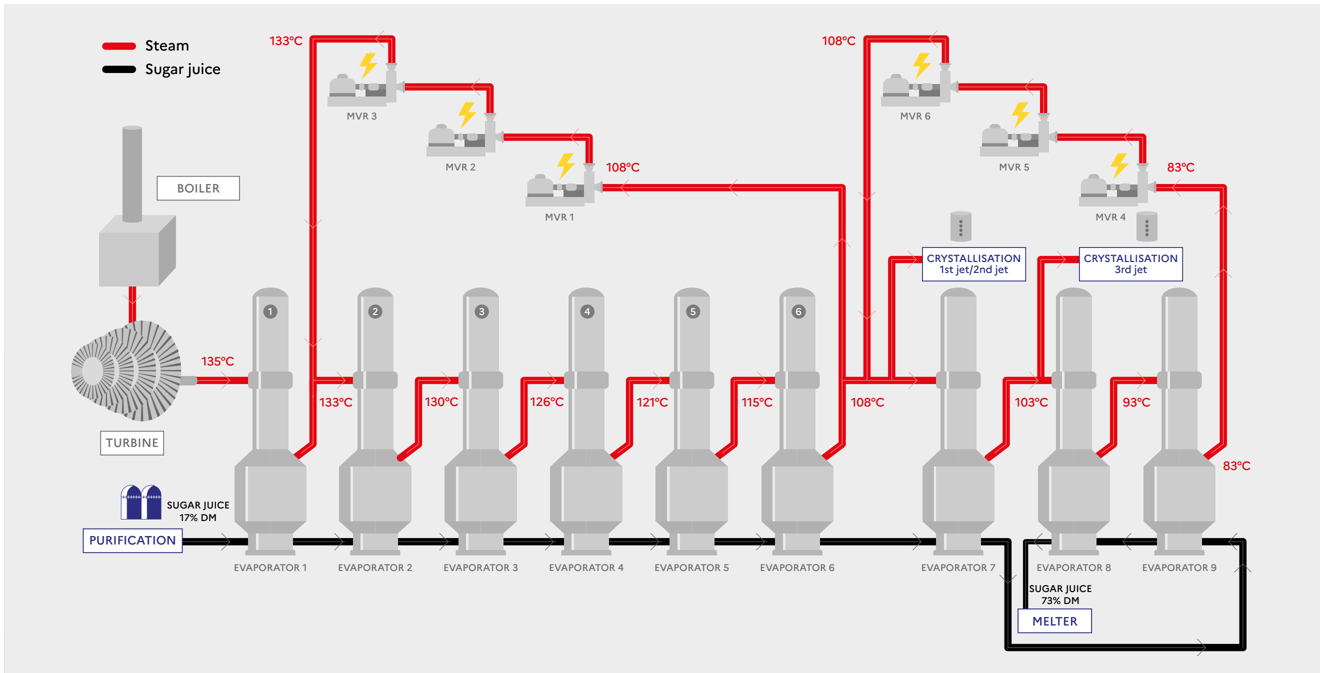
To reduce the sector's dependence on fossil fuels, one option is to reduce the energy consumption of sugar factories by implementing complementary passive and active energy efficiency solutions, in other words, electrification. These energy efficiency initiatives, which enable steam to be recycled several times over, can be deployed more or less intensively in sugar factories, with the dual advantage of reducing GHG emissions and sugar and alcohol production costs.

While energy efficiency systems reduce the need to produce steam, they increase the factory's electricity requirements. Lower steam consumption leads to lower generation of electricity at the cogeneration plant. At the same time, the installation of the steam dryer also reduces the plant's capacity to generate its own electricity, and steam recycling equipment, such as that enabling mechanical steam recompression, requires electricity to operate. This increase in demand for electricity from the grid faces a number of challenges:

- Electricity transmission infrastructure is currently insufficient to supply sugar factories, and the geographical location of factories (in the middle of fields) makes connection to the electricity transmission network time-consuming and costly, and therefore results in significantly higher power demands.
- Electricity prices are higher in the winter, when the sugar factories are in operation.

Partial electrification of sugar factories seems essential to decarbonising them, but will have to be carefully planned. The level of electrification (partial or maximum) will depend on local situations and each company's dependence choices.

Figure 12. Principle of steam recycling in the sugar factory's evaporation unit, inspired by the De Smet Engineers & Contractors projects.



In the diagram, the steam from the cogeneration plant (boiler + turbine) is fed into the first evaporator. The steam that emerges at a lower temperature is then used in the second evaporator as heating steam, and so on for the other evaporators. To further optimise the process, it is possible to add mechanical steam recompressions (here at the outlet of the 6th and 9th evaporators) which, by means of electrical work, would raise the temperature of the steam in order to reintroduce it as heating steam in other evaporators or to send it to other stages in the sugar process (crystallisation).

How can beet pulp be used?

Beet pulp has a high intrinsic energy value, which is used in different forms and for different purposes:

• Today, the vast majority of pulp is used for animal feed (85%), either in pressed form (28% dry matter) or dehydrated form (88% dry matter) for export to regions further away from sugar mills (dehydration enables transport costs to be reduced).

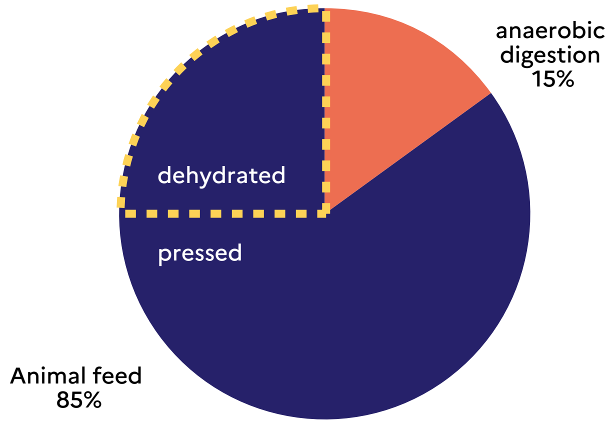
• At the same time, agricultural anaerobic digestion is expanding rapidly in order to increase the proportion of biomethane in the French network while at the same time obtaining organic fertiliser, and could also be developed using pressed beet pulp, in the same way as other inputs from the agri-food industry. While this is still a relatively little-used recovery method, it has been on the increase in recent years.

It is also possible to supply a sugar factory with biogas from the anaerobic digestion of pulp. However, as energy consumption is concentrated over a short period of the year, it would seem more appropriate to outsource this biogas production by signing long-term contracts (in the form of Biogas Purchase Agreements, BPAs) with agricultural project developers who would use the pulp to complement other inputs.

• Finally, another way of recovering energy from pulp is to burn it directly at the sugar plant, after dehydration.

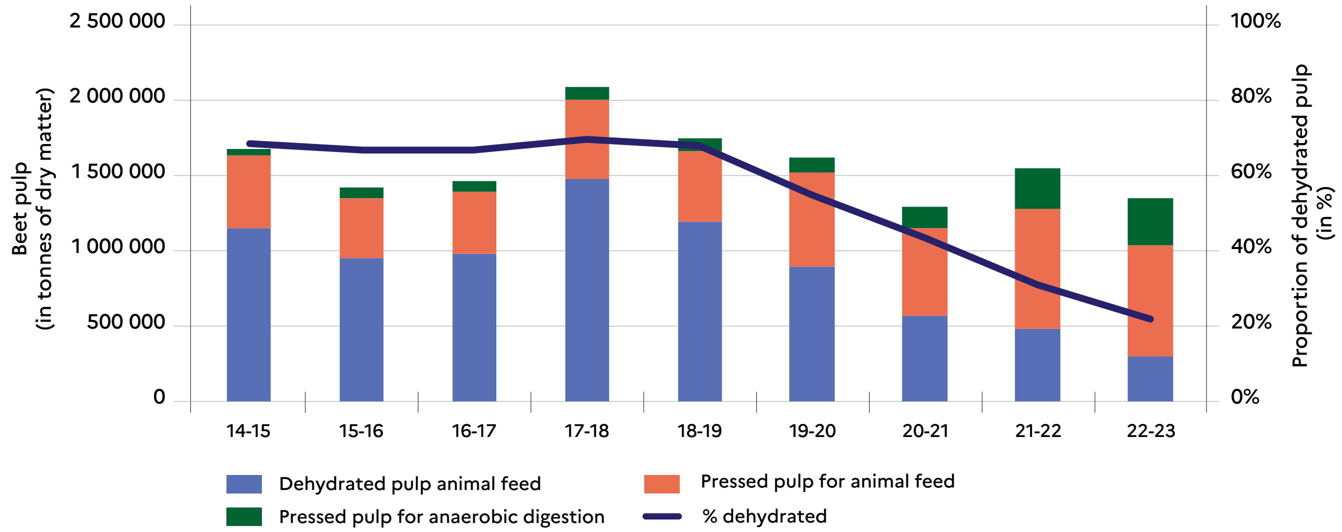
These different options illustrate the issues surrounding the use of beet pulp, with a compromise between decarbonisation and economic profitability for each actor in the sector. On the one hand, farmers can benefit from cheap, local cattle feed, while on the other, sugar manufacturers have the possibility of a major decarbonisation lever. Energy recovery from pulp itself raises a number of questions: digestate from anaerobic digestion provides organic fertiliser for farmers, but the biogas produced provides less energy than combustion for a given quantity of pulp; combustion provides greater independence from fossil fuels, but requires the integration of a steam dryer into the sugar factories' thermal systems, and reduces the quantity of organic fertiliser available to farmers.

Figure 13. Beet pulp outlets in 2022 as a percentage of dry matter tonnage.
Source : ARTB



The future distribution of beet pulp resources therefore remains to be defined, bearing in mind that the quantity of pulp available depends directly on the year's beet production, and therefore on the prosperity of the industry. It should also be noted that several factors can influence this distribution, such as the feed requirements of the livestock farms. While pulp currently accounts for a very small proportion of animal feed on a national scale, it is an important resource for livestock farming close to sugar mills, and its use means that less French farmland is used to produce animal feed.

Figure 14. Changes in pulp production and uses.
Source : ARTB



2. Three contrasting scenarios to illustrate the challenges of sugar decarbonisation

2.1. Three transition scenarios for achieving the decarbonisation objective of the National Low-Carbon Strategy

2.1.1. Method for building the scenarios

The methodology for building scenarios is the same for the three sugar STP scenarios: the aim is to establish a decarbonisation trajectory based on existing technological levers, whose potential has been identified by industry actors in different transition scenarios, with the objective of achieving at least an 81% reduction in greenhouse gas emissions in 2050 compared with 2015 (SNBC2 target for industry).

In the case of the Sectoral Transition Plan for the sugar sector, six structuring factors described below have been selected, the different combinations of which make it possible to construct three decarbonisation scenarios, with associated challenges for each of the factors:

Market factors

• Consumption of dietary sugar: changes in the population's consumption habits for sweetened products, the quantity of sugar contained in the products of food manufacturers, and public health policies (taxation, regulations, information).

• Consumption of beet ethanol for chemical products: development of biobased products from ethanol, development of advanced ethanol (from resources that do not compete with food).

• Resilience of European agriculture: introduction of mirror clauses in European free trade agreements, impacts of climate change on crops, research/innovations and new crop management techniques, changes in European beet biogeography.

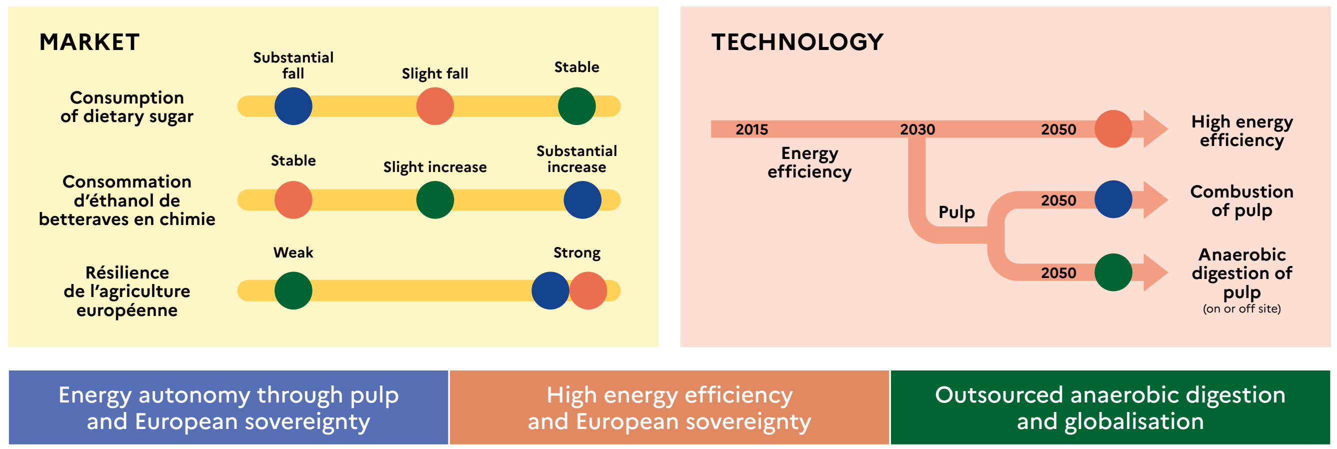
Technological factors

• Energy efficiency: the level of deployment of passive and active energy-saving solutions (mechanical steam recompression) and impact on electricity production by cogeneration and on drawing capacity on the electricity grid.

• Use of dehydrated pulp as fuel: the search for energy autonomy, level of local demand for pulp, integration of steam dryers.

• Use of pressed pulp to produce biomethane by anaerobic digestion: level of local demand for pulp, return to the soil of organic fertilisers from pulp.

Figure 15. Structuring factors in the construction of the 3 scenarios.



By 2050, in the ***Energy autonomy through pulp and European sovereignty*** scenario, the entire French population has significantly reduced its sugar consumption. This has been brought about by the introduction of ambitious public health measures. At the same time, the electrification of vehicles has made it possible to redirect the flow of fuel ethanol towards the development of bio-based products in the chemical industry, without increasing the amount of agricultural land not used for food. Factories have gradually decarbonised by reducing their energy consumption by 25% and then installing boilers to burn beet pulp, which has been dehydrated by steam dryers.

By 2050, in the ***High energy efficiency and European sovereignty*** scenario, public health measures have been targeted to reduce sugar consumption among the youngest age groups. The reorientation of beet ethanol flows towards chemicals has been reduced because the production of ethanol from resources that do not compete with food (advanced ethanol) has been developed and favoured. Factories have reduced their consumption of coal and gas mainly through very high energy efficiency, made possible by extensive electrification and a significant reduction in pulp dehydration.

In terms of production, European agriculture has remained resilient in these first two scenarios. The Member States have introduced mirror clauses in trade agreements, reducing imports of sugar that do not comply with the environmental standards in force in Europe. Research and innovation have made it possible to develop varieties and cropping systems to make them more resilient to climate change, while reducing the impact on biodiversity and maintaining beet production at the 2019-2023 level. These production volumes, combined with a fall in domestic sugar consumption, have compensated for the halt to beet production in southern European countries.

By 2050, in the ***Outsourced anaerobic digestion and globalisation*** scenario, European agriculture has been weakened. International trade has increased and free trade agreements without mirror clauses have developed, enabling imports of foreign cane sugar which has replaced French sugar in European countries with sugar deficits; there has been little change in dietary patterns. As sugar production capacity in France and Europe has fallen, manufacturers' capacity to invest has been reduced. The decarbonisation choice has focused on outsourcing the anaerobic digestion of pulp through bilateral contracts with agricultural projects in the form of Biogas Purchase Agreements (BPA).

A comparison of these three scenarios highlights non-exclusive means of decarbonisation that differ greatly. They do not cover all possible scenarios, but they enable us to consider the alternatives. Their purpose is not to make predictions or to demonstrate that only these three scenarios are possible, but rather to shed light on the implications of different technological choices, market risks and opportunities, convergences between scenarios and courses of action to accelerate the decarbonisation of the sector. The narrative of the scenarios was constructed by ADEME. The technological levers for decarbonisation and their potential for activation are the result of a consultation exercise with manufacturers in the sector.

➜ Sugar beet processing factory © Philippe Montigny

2.1.2. Overview of the three narratives: contrasting scenarios to shed light on the challenges of decarbonising the industry

In order to compare the three proposed narratives, Table 3 summarises all the scenario orientations, both in terms of potential market developments and the technological levers deployed. The quantitative figures for these assumptions are presented in the full report.

Table 3. Summary of the narratives for each scenario and the main assumptions made.

	Energy autonomy through pulp and European sovereignty	High energy efficiency and European sovereignty	Outsourced anaerobic digestion and globalisation
Sugar industry outlets	Dietary sugar: **significant fall in consumption** supported by proactive public health policies: significant reduction in the proportion of daily energy intake provided by sugars Alcohol: **maintenance of conventional alcohol** shifted from transport to chemical products	Dietary sugar: **medium reduction** in sugars in daily energy intake: lower consumption among young people in particular Alcohol: **reduction in consumption of conventional ethanol** in favour of the development of advanced ethanol	Dietary sugar: **maintenance of sugar** in daily energy intakes Alcohol: **slight decrease** in conventional alcohol
French and European agriculture	**Maintenance** of French production: 0% change between the average for 2019-2023 and 2050 **Increase** in exports in the EU **European sovereignty**, reduction in trade flows outside the EU	**Maintenance** of French production: 0% change between the average for 2019-2023 and 2050 **Increase** in exports in the EU **European sovereignty**, reduction in trade flows outside the EU	**Decrease** in French production: 25% decrease between the average for 2019-2023 and 2050 **Decrease** in exports in the EU, **European agriculture not protected** and increase in sugar imports from outside the EU
Treatment of pulp and availability outside sugar factories	**Combustion of pulp** to decarbonise sugar factories Significant dehydration for combustion **Alternative required for animal feed**	Pulp not used for decarbonisation Significant reduction in pulp dehydration **Pulp available for animal feed**	Pulp recycled **by anaerobic digestion for use in sugar factories** Very little dehydration **Alternative required for animal feed**
Energy efficiency	**Some facilities** undergo major renovations, including partial electrification	**Maximum energy efficiency** by active energy saving, electrified distilleries, electrical connection of sites to the national grid	**Minimal energy efficiency:** sugar factories with little electrification
Decarbonising the energy mix	Cogeneration mix based on pulp combustion and anaerobic digestion of washing water: **energy resilience for sugar factories** Major development of the steam dryer	Cogeneration mix based on network gas and anaerobic digestion of pulp, washing water and residues on certain sites	Cogeneration mix based on **biomethane from outsourced anaerobic digestion and anaerobic digestion** of washing water at certain sites

2.2. Results of the scenarios: rapid, in-depth decarbonisation of the sugar sector is possible

In all three scenarios, the decarbonisation trajectory is in line with the objectives of the National Low-Carbon Strategy. They even exceed this target, decarbonising the sector by more than 90% compared with 2015. A variety of technology packages are mobilised, all of which are sufficiently mature to be deployed rapidly, with limited uncertainties over their availability and the associated investment costs compared with other industrial sectors.

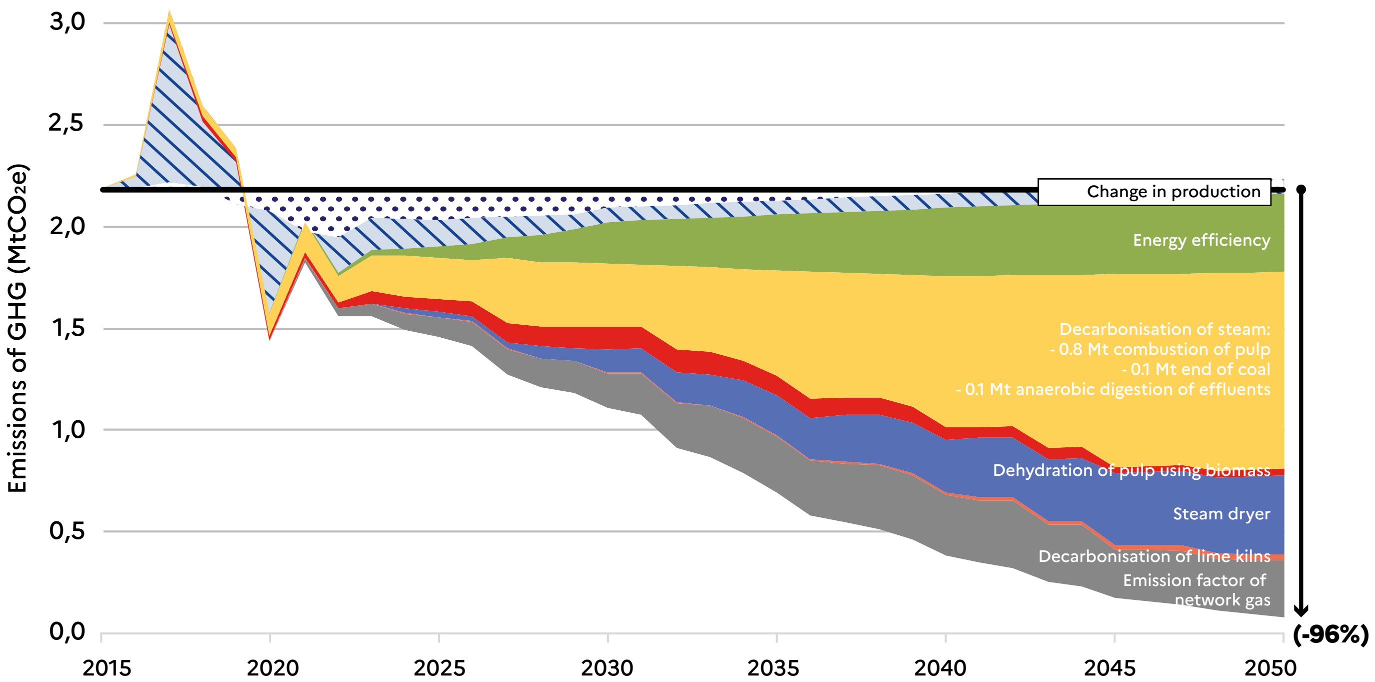
2.2.1. *Energy self-sufficiency through pulp and European sovereignty:* the resilience of the sector ensured by high levels of investment

Decarbonisation made possible by beet pulp combustion and energy efficiency

In the ***Energy autonomy through pulp and European sovereignty*** scenario, emissions are reduced by 96% in 2050 compared with 2015, while there is little change in the quantity of beet processed, as shown in the figure below. By 2030, emissions will have been reduced by 49% compared with 2015, mainly as a result of the end of coal-fired boilers, improvements in energy efficiency and changes to the pulp dehydration mix (conversion of drum kilns from coal to wood biomass) already in place. Subsequently, the levers, which are already mature, are gradually put in place, starting with the combustion of beet pulp, which accounts for 44% of the reduction in GHG emissions. The process has also been significantly optimised: energy efficiency and the installation of a steam dryer, necessary to increase the proportion of dehydrated pulp, will each reduce emissions by 18% in 2050 compared with 2015.

In 2050, the residual emissions are made up mainly of purchased network gas: a significant reduction in network gas consumption (70%, made possible by the combustion of pulp and energy efficiency) and the gradual decarbonisation of gas in the network will make it possible to reduce emissions linked to this energy vector. However, there is greater demand on the electricity grid, particularly as a result of the installation of steam dryers, which reduce the quantity of steam going to the turbo-alternator and thus the production of electricity by cogeneration: the consumption of electricity purchased from the grid is doubled.

Figure 16. ***Energy autonomy through pulp and European sovereignty*** **scenario - Greenhouse gas emissions from the sugar industry between 2015 and 2050**



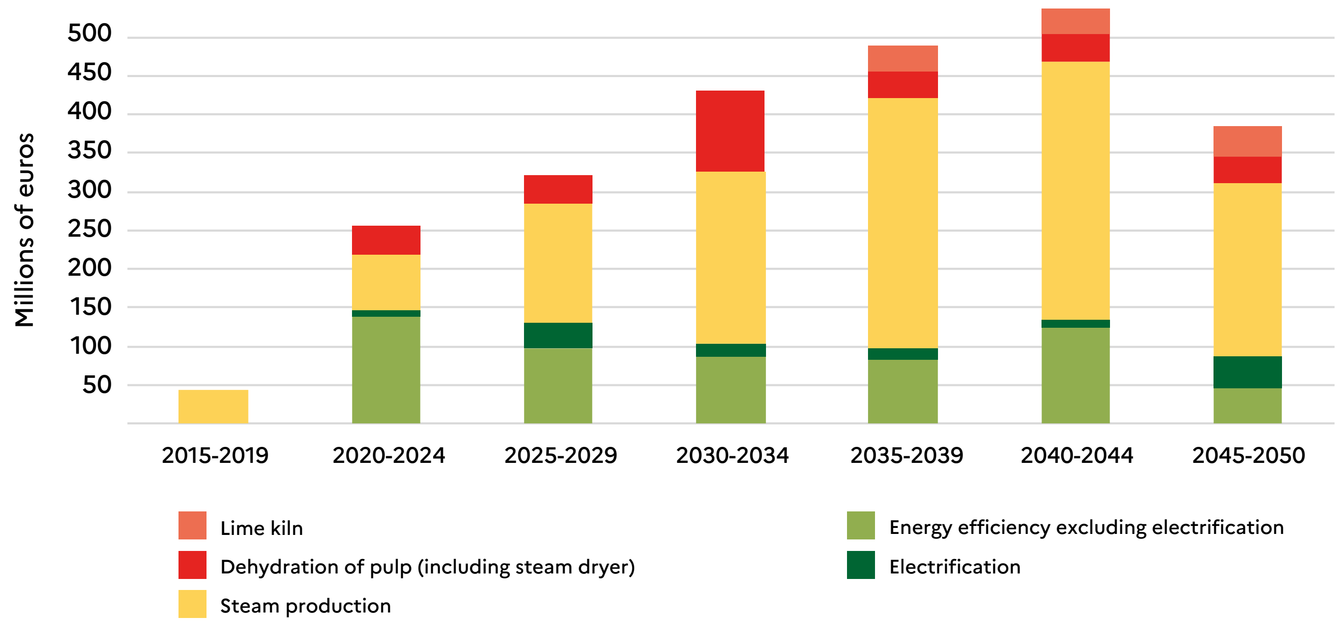
Scope 1, excluding biogenic CO_2 emissions

In addition, the resilience of sugar factories and their independence from fossil fuels depends on the use of beet pulp for combustion. While the demand for pulp for animal feed decreases with the reduction in livestock numbers by 2050, the pulp made available will not be enough to feed the remaining livestock, which will switch to other feedstuffs (maize in particular). As pulp is mainly used for energy purposes in sugar factories, and to a lesser extent as feed for livestock, the development of anaerobic digestion using pulp is greatly reduced between 2030 and 2050.

Major investments to replace gas boilers with biomass boilers, and install steam dryers

In total, the amount of investment needed to achieve decarbonisation in this scenario amounts to €2.5 billion spread over the period 2015-2050[23] as shown in Figure 17. More than half of the investment is dedicated to replacing cogeneration plants so that beet pulp can be used for combustion: this item represents a total of €1.1 billion. It should be noted that investment is particularly high over the period 2030 to 2045, reaching between €400m and €460m per 5-year period. All the energy efficiency measures represent an investment of around €700m, and the installation of the steam dryers would cost a total of €280m.

Figure 17. ***Energy autonomy through pulp and European sovereignty*** **scenario - Decarbonisation investments per 5-year period between 2015 and 2050**



[23] The main decarbonisation investments made between 2015 and the date of the work are included in the modelling, in the same way as for the three proposed transition scenarios.

2.2.2. *High energy efficiency and European sovereignty:* decarbonisation driven by energy efficiency

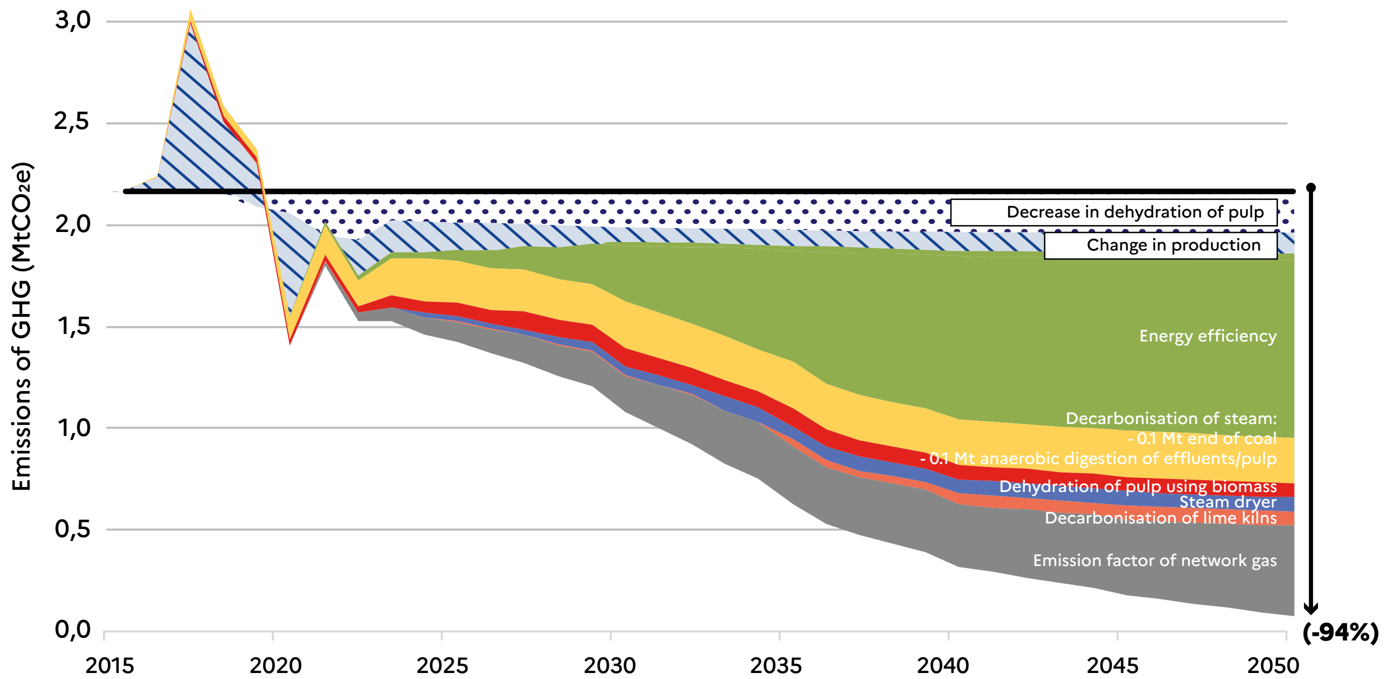
Decarbonisation enabled by maximum energy efficiency, in particular through electrification

In the ***Maximum energy efficiency and European sovereignty*** scenario, emissions are reduced by 94% in 2050 compared with 2015, while there is little change in the quantity of beet processed, as shown in Figure 18. As energy efficiency levers have already been identified by industry and are mature, they are gradually put in place, enabling emissions to be reduced by 13% by 2030 and 40% by 2050. They are complemented by the change in the cogeneration plant's mix, which in this case corresponds to the deployment of anaerobic digestion of washing water and grasses and rootlets (-10%), and to a lesser extent by the decarbonisation of pulp dehydration (-3%) and the outsourcing of lime production (-3%). Lastly, reducing the proportion of dehydrated pulp reduces dedicated energy consumption and the associated greenhouse gas emissions. By 2030, emissions will be 49% lower than in 2015.

In 2050, the residual emissions consist mainly of purchased network gas and the use of coke and anthracite for lime kilns when production is not outsourced. Despite a 60% reduction in network gas consumption compared with 2015, the latter remains significant. In this scenario, the decarbonisation of network gas is therefore more important than in the ***Energy autonomy through pulp and European sovereignty*** scenario (20% of the reduction in GHG emissions compared with 13%). However, much more electricity is drawn for the grid, given the major deployment of energy efficiency measures through electrification, with electricity consumption expected to quadruple between 2015 and 2050. Dependence on the gas and electricity networks is therefore significant, and introduces more risk as the plants operate during the winter period, with possible load shedding requirements on the electricity network.

On the other hand, the operation of sugar factories depends very little on the use of beet pulp, which can continue to be used for animal feed and anaerobic digestion. On-site consumption of pulp represents less than 5% of available pulp. This pulp is mainly pressed (28% dry matter) and tends to be used on farms close to sugar factories in order to limit energy consumption and the costs associated with dehydration and transport.

Figure 18. *High energy efficiency and European sovereignty* scenario - Greenhouse gas emissions from the sugar industry between 2015 and 2050



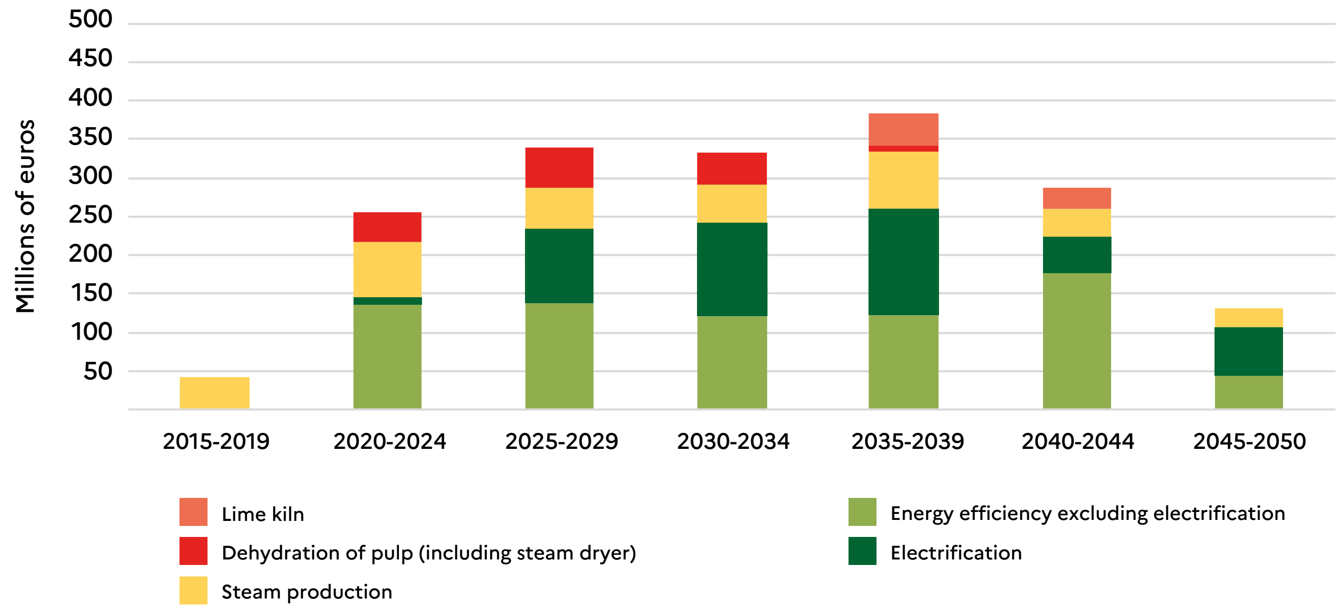
Scope 1, excluding biogenic CO_2 emissions

Major investment in energy efficiency, particularly electrification

In total, the amount of investment needed to achieve decarbonisation in this scenario amounts to €1.8 billion spread over the period 2015-2050[24] as shown in the figure below. Most of the investment is dedicated to energy efficiency in sugar factories: €1.22 billion, including €476 million specifically for process electrification. These costs include the cost of connecting the sugar factories to the electricity transmission network, which will then consume three times as much grid electricity as is currently the case. These investments are based on mature technologies that can be deployed very early: in this scenario, investments are spread between 2025 and 2045.

The decarbonisation of the energy mix of the cogeneration plant, the dehydration of the remaining pulp and the equipment following the outsourcing of lime production (quicklime hydration unit, carbonation adjustment equipment) represent €351m, €139m and €70m respectively. In this scenario, while investment is lower than in the ***Energy autonomy through pulp and European sovereignty*** scenario, it remains substantial, although spread over a period from 2025 to 2045.

Figure 19. *High energy efficiency and European sovereignty* scenario - Decarbonisation investments per 5-year period between 2015 and 2050



[24] The main decarbonisation investments made between 2015 and the date of the work are included in the modelling, in the same way as for the three proposed transition scenarios.

2.2.3. *Outsourced anaerobic digestion and globalisation:* low-cost decarbonisation at a high price for the industry

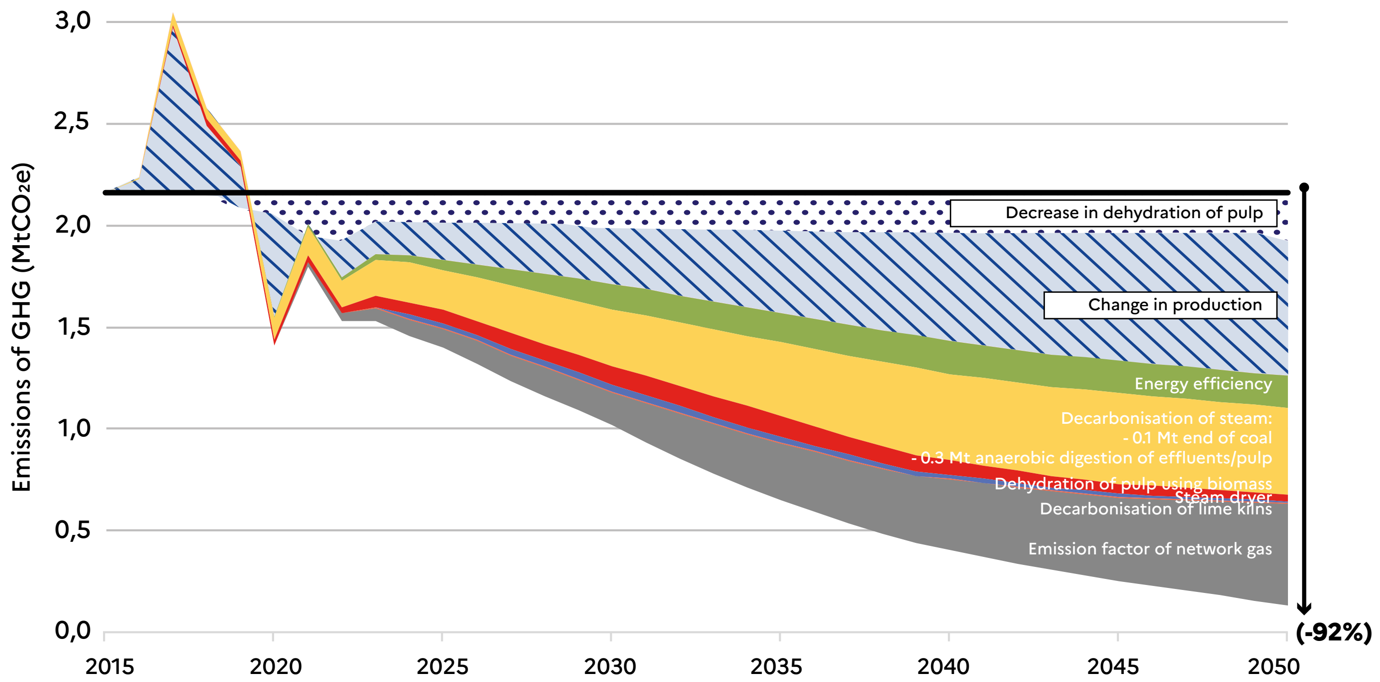
Decarbonisation linked mainly to a fall in production, but also to the anaerobic digestion of pulp and effluents

In the ***Outsourced anaerobic digestion and globalisation*** scenario, emissions are reduced by 92% in 2050 compared with 2015, due in particular to the 25% reduction in the quantity of beet processed, as illustrated by Figure 20. The fall in production and the reduction in the proportion of dehydrated pulp play a significant role in reducing emissions (-41% of emissions in 2050 compared with 2015), but with a reduction in French sugar exports to Europe and therefore greater dependence on European imports from the major sugar cane-producing countries. The ability of sugar manufacturers to invest in decarbonisation is greatly reduced, and only minimal energy efficiency actions and decarbonisation of the cogeneration plant mix are implemented. These reduce GHG emissions from French sugar factories by 7% and 19% respectively. The sector is then decarbonised as the emission factor for network gas falls, contributing to a 23% reduction in emissions. By 2030, emissions will be 52% lower than in 2015, taking into account the fall in production.

In 2050, the residual emissions consist mainly of purchased network gas and the use of coke and anthracite for lime kilns: network gas consumption falls by 35%. In this scenario, the decarbonisation of the network gas emission factor thus has a more important role than in the two previous scenarios. Given the deployment of energy efficiency measures through electrification, there is a slight increase in demand for grid electricity: +10% between 2015 and 2050.

Furthermore, the resilience of sugar factories in a sector that is in an unfavourable position in this scenario is based on the use of Biogas Purchase Agreements (BPAs). These biogas supply contracts are facilitated locally by the availability of beet pulp for anaerobic digestion. As a result, this pulp is no longer available for animal feed, and farmers are gradually having to switch to other sources of supply (maize in particular) for their livestock. The biogas from these BPAs could cover around a third of requirements in 2050 by mobilising 50% of the available pulp.

Figure 20. *Outsourced anaerobic digestion and globalisation* scenario - Greenhouse gas emissions from the sugar industry between 2015 and 2050



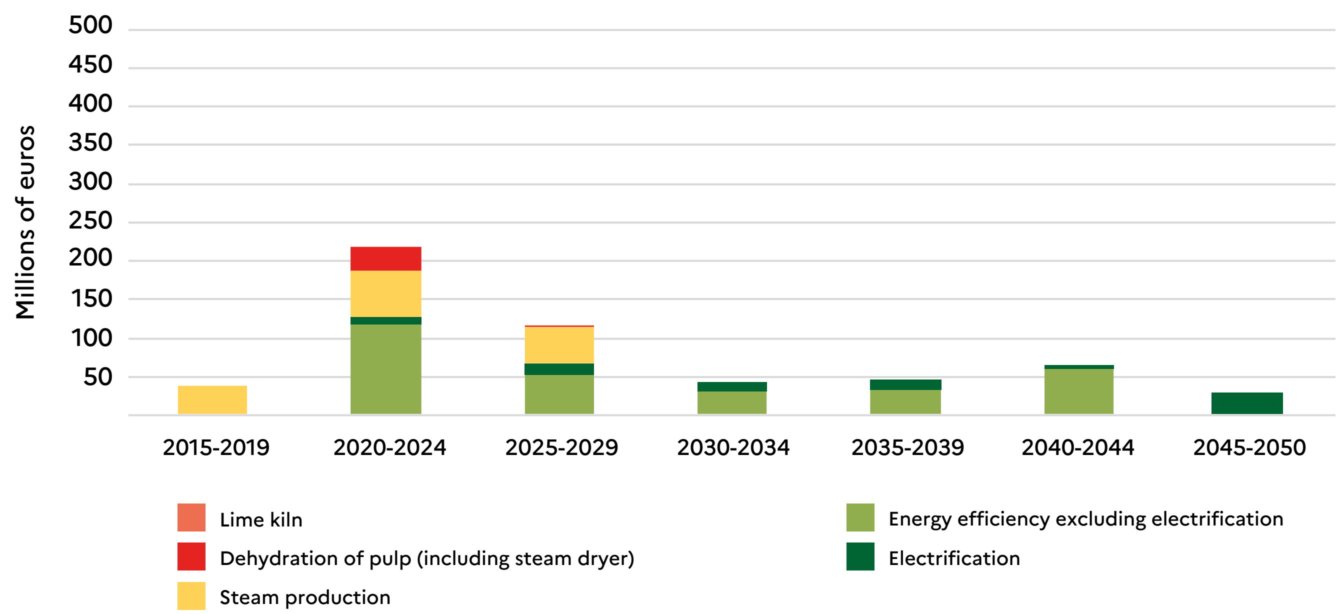
Scope 1, excluding biogenic CO_2 emissions

Very limited investment, mainly in energy efficiency, masking the high production costs associated with outsourcing anaerobic digestion

In total, the amount of investment needed to achieve decarbonisation in this scenario amounts to €607m spread over the period 2015-2050[25] as shown in Figure 21. This represents less than a quarter and a third less investment respectively than in the other two scenarios. Most of the investment has been made in energy efficiency in sugar factories - €399m, including €64m specifically for electrification of processes - and in the deployment of anaerobic digestion of pulp, herbs and rootlets in certain sugar factory-distilleries (operating all year round) and anaerobic digestion of washing water at all sites (€169m).

Investments are concentrated almost exclusively in the period 2020 to 2029, which includes investments already made and some additional investments in the coming years. This total amount of investment can also be explained by the industry's low investment capacity in an unfavourable context (fall in production, fall in exports).

Figure 21. *Outsourced anaerobic digestion and globalisation* scenario - Decarbonisation investments per 5-year period between 2015 and 2050



[25] The main decarbonisation investments made between 2015 and the date of the work are included in the modelling, in the same way as for the three proposed transition scenarios.

2.3. Comparative analysis: mature levers and varied sources of energy supply for a successful objective

2.3.1. Summary of lessons learned

The three decarbonisation scenarios proposed illustrate different trajectories for the sugar industry, in all cases exceeding the decarbonisation objective for the industrial sector set in the current SNBC, with around 50% fewer GHG emissions in 2030 and more than 90% fewer in 2050 than in 2015. Decarbonising the sugar industry is therefore possible using proven technologies.

Between now and 2030, the industry has the capacity to halve its GHG emissions compared with 2015, firstly by permanently phasing out coal (a process that is already well underway, with the last coal-fired boilers being replaced by gas-fired boilers, and by reducing dehydrated pulp and changing the equipment used for this: steam dryers and biomass kilns). At the same time, the industry must continue to implement energy efficiency solutions (mechanical steam recompression, addition of effects and evaporation units, adding of cold points and diffusion towers).

Over the period 2030-2050, manufacturers will either choose to step up energy efficiency measures to reduce primary energy requirements to a minimum, which will involve greater dependence on the national electricity grid and uncertainties over the price of electricity, or they will opt for energy autonomy by making massive use of beet pulp as a fuel or input for anaerobic digestion, to the detriment of current users of this resource who will see its availability diminish and will have to look for alternatives. These choices will have to be adapted to the local context of the industrial sites and according to the strategies of the sugar companies and cooperatives, with a possible complementarity between these two solutions, in particular in the case of industrial sugar refinery-distillery platforms that operate all year round. More broadly, the development of anaerobic digestion of washing water would appear to be a useful way of helping to further reduce the residual amounts of network gas used in factories. These solutions could be supplemented in the future by hydrothermal gasification of distillery residues, or by innovations in high-temperature heat pumps if they reach maturity and become competitive with current solutions.

In terms of uses, the consumption of dietary sugar could be reduced under the impetus of proactive public policies to reduce the impact of sugar on health. At the same time, the gradual electrification of vehicles means that the sugar-alcohol fuel outlet could be redirected towards the chemical industry, to develop biobased olefins (ethylene, butadiene, propylene) or isobutene from crystallised sugar, without using more agricultural land. However, a new balance will have to be found with the development of alternatives to beet ethanol.

Finally, the future of the French sugar industry can only be seen in the context of the wider resilience of European agriculture faced with the intensifying effects of climate change. In particular, changes in beet biogeography should be anticipated, likely resulting in a reorganisation of European production. In this context, if European agriculture is subject to rules similar to those of its international competitors and supported in its agro-ecological transition to maintain beet production, then the French sugar industry may be in a position to increase its contribution to European sugar autonomy.

The three situations thus illustrate the advantages and disadvantages of the energy sources used and the dependencies generated, and the residual consumption of network gas and electricity. However, there is a consensus around the deployment of (i) energy efficiency through electrification of all sugar factories and (ii) anaerobic digestion of beet washing water, which could account for between 5 and 10% of the final energy consumption of sugar factories in 2050. On the other hand, the ideal level of deployment of energy efficiency has not been defined, and differs according to the two main strategies chosen by actors in the sector: ensuring the autonomy of sugar factories by using beet pulp for combustion, or reducing fossil fuel consumption as much as possible through maximum deployment of energy efficiency levers. These two trends also reflect local realities in terms of the location of sugar factories and the demand for pulp from nearby farmers.

➜ Cristal Union factory in Arcis sur Aube © Cristal Union

Table 4. Summary of the main results for the 3 scenarios.

		Energy autonomy through pulp and European sovereignty		High energy efficiency and European sovereignty		Outsourced anaerobic digestion and globalisation	
	2015	2030	2050	2030	2050	2030	2050
Production (millions of tonnes of sugar beet)	33,6	32.3	32.3	32.3	32.3	28.9	23.3
Network gas consumption (GWh/year)	6 112	5 822	1 659	5 870	2 557	5 521	2 908
Grid electricity consumption (GWh/year)	452	666	916	868	1 783	530	494
Grid electricity consumption per tonne of beet (% compared with 2015)	13 kWh	+53 %	+111 %	+100 %	+311 %	+36 %	+58 %
Energy consumption excluding grid electricity per tonne of beet (% compared with 2015)	260 kWh	-17 %	-30 %	-23 %	-55 %	-14 %	-20 %
Pulp available for non-sugar uses (% compared with 2015)	100 %	87 %	32 %	94 %	93 %	75 %	37 %
Direct GHG emissions ($MtCO_2e$/year)	2 183	1 109	79	1 119	134	1 048	170
Decarbonisation (% of 2015 emissions cut)	0 %	-49 %	-96 %	-49 %	-94 %	-52 %	-92 %
Cumulative decarbonisation investments (€m)	–	619	2 461	639	1 780	431	607

2.3.2. Focus on changes in the quantity and use of pulp

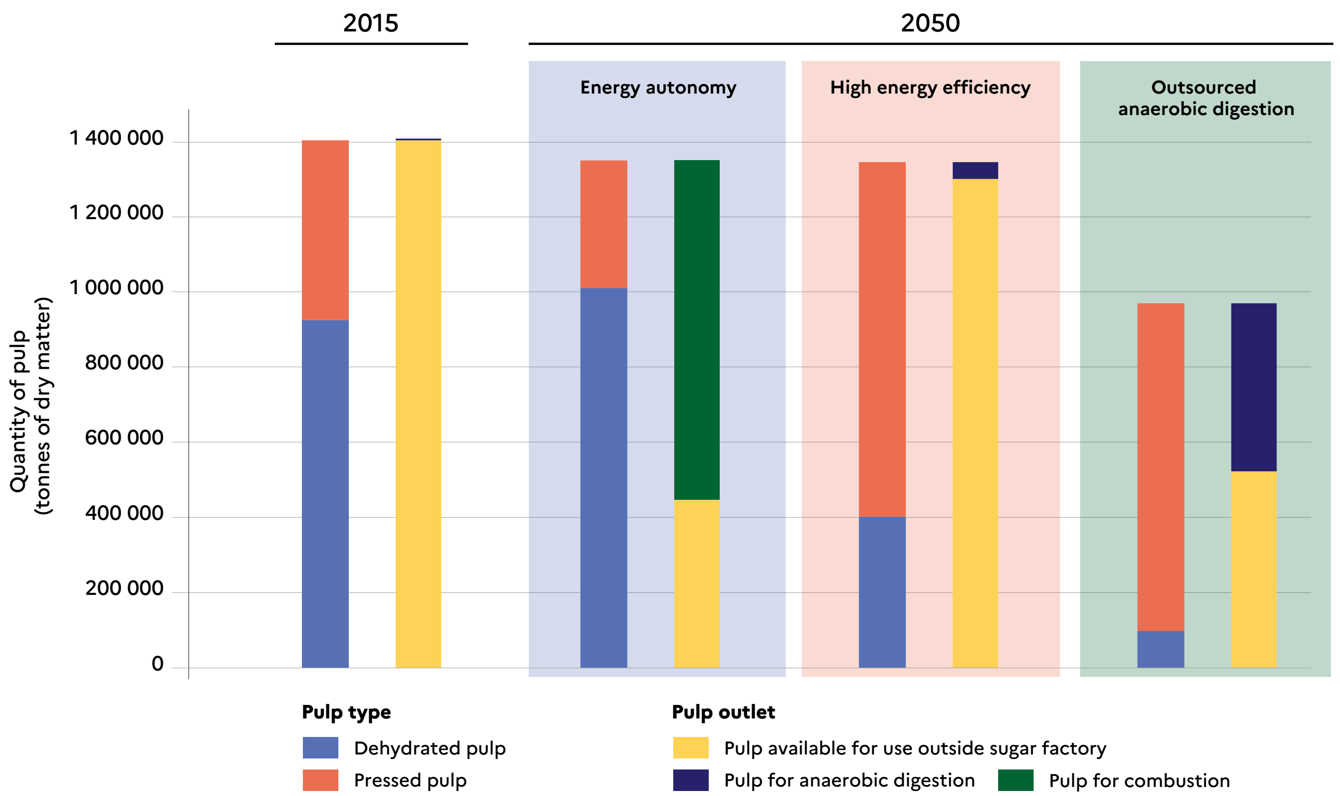
With a ratio of 50 kg of pulp dry matter per tonne of beet, the primary factor in the availability of pulp is the volume of beet production. In 2050, in the Energy autonomy and High energy efficiency scenarios, the total amount of pulp available is virtually the same as in 2015 (around 1.3 Mt of dry matter available per year), while in the Outsourced anaerobic digestion scenario, the use of pulp will have to be adjusted in line with the 30% reduction in beet production compared with 2015.

The second factor influencing the availability of pulp is the trade-off between seeking energy autonomy in sugar factories and maintaining the sale of pulp for animal feed. In 2050, the Energy autonomy and Outsourced anaerobic digestion scenarios will mobilise 500,000 tonnes of pulp for energy use, enabling the decarbonisation of sugar factories (dehydrated pulp burnt in boilers in the first case, anaerobic digestion of pressed pulp by a third party via a BPA in the second case). The Energy Efficiency scenario uses the least amount of pulp for energy purposes, with a view to preserving the use of pulp as a raw material and its outlet in animal feed. As a result, only 50,000 tonnes of pulp are used by sugar factories for anaerobic digestion at a few sugar factory distilleries, which supply the sugar factory during the beet processing period (September-January) and the distillery the rest of the time.

Finally, the third factor is the choice of energy recovery from pulp in dehydrated form (to obtain a fuel that can be used in boilers) or in pressed form (as an input for anaerobic digestion). The calorific value of a tonne of raw pulp depends on its dry matter content. So, for an equivalent tonnage of moist pulp, using this pulp after dehydration in a steam dryer increases the coverage of thermal requirements compared with recovering energy from pulp by anaerobic digestion. It is important to note, however, that burning pulp in this way does not allow the nutrients produced by the digestate from the anaerobic digestion of pulp to be recovered and used as fertiliser by farmers.

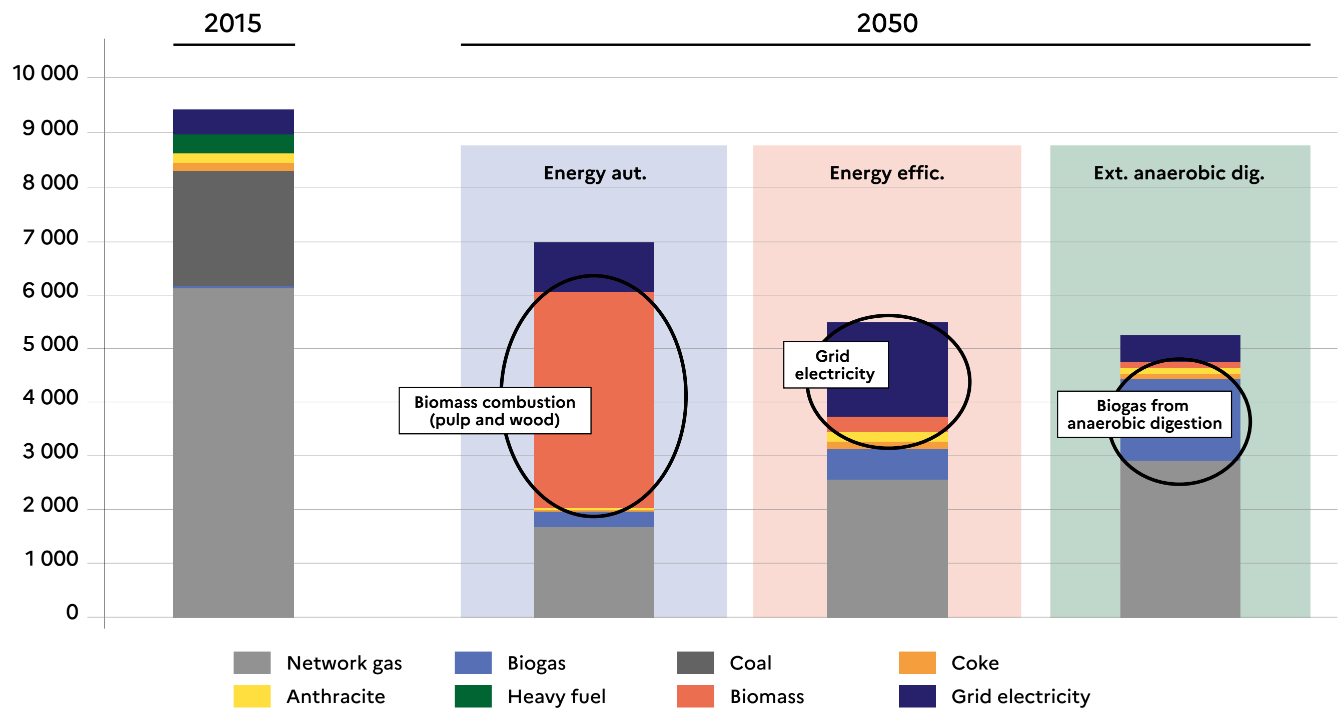
Overall, the High Energy Efficiency scenario is the one that enables pulp distribution to be maintained for its current uses (animal feed and anaerobic digestion outside sugar factories) by making greater use of energy efficiency levers but at the cost of greater dependence on grid electricity and a smaller reduction in gas consumption.

Figure 22. Quantity of pulp produced and breakdown by use in each scenario.
Pulp available for use outside sugar factories corresponds to pulp used for animal feed and anaerobic digestion



2.3.3. Focus on energy consumption

Figure 23. Energy consumption in sugar factories in 2015 and 2050.
Note: "Biomass" includes wood chips and beet pulp used for combustion.



Beyond the use of pulp, the four energy issues highlighted by the scenarios concern total energy demand, electricity and gas purchased from the grid, and the end of coal.

Electricity drawn from the grid accounted for just 5% of the factories' final energy consumption in 2015. This could change significantly as a result of three factors:

• The deployment of mechanical vapour recompression (MVR) enables substantial energy savings, but requires electricity to operate: 1 kWh of electricity for 4 to 6 kWh of steam generated

• By deploying MVRs and other energy efficiency levers (increasing the evaporation exchange surface area), it is possible to reduce the amount of steam that needs to be generated for the cogeneration plant. If the turbo-alternator is maintained as it is at present, this drop in demand and therefore in steam production will lead to a drop in electricity production, and therefore an increase in the electricity drawn from the grid.

• Deploying steam dryers reduces the cost of pulp dehydration by integrating it into the sugar manufacturing process. On the other hand, by recovering some of the high-pressure steam leaving the boiler, the steam dryers reduce the quantity of steam destined for the turbo-alternator and therefore the production of electricity, which leads to an increase in electricity drawn from the grid.

These three factors explain the two- to five-fold increase in grid electricity demand (mainly in the winter). Energy savings therefore represent a key element in the decarbonisation of industrial sites, but come up against a choice of dependence on the electricity grid: the greater the energy savings, the less electricity the cogeneration plants will produce, and the more dependent the factories will be on the electricity grid and the winter price of electricity. In this context, the Energy autonomy scenario is limited to a reduction of around 25% in thermal requirements per tonne of beet processed, while the High Energy Efficiency scenario reduces thermal requirements per tonne of beet processed by 50%.

The use of network gas represents the residual energy that has not been reduced by energy efficiency or substituted by biomass. Network gas consumption is reduced by 70% in the Energy autonomy scenario, by 60% in the High Energy Efficiency scenario and by 50% in the Outsourced anaerobic digestion scenario. In each scenario, the biogas produced by the anaerobic digestion of pulp, grass, rootlets and washing water (whether or not outsourced) covers 5%, 15% and 35% of heating requirements respectively.

Finally, coal, which is mainly used for pulp dehydration in 2024, will be phased out by 2030 through a combination of the installation of steam dryers and the substitution of wood energy for coal (all scenarios), as well as a reduction in the level of pulp dehydration (Energy Efficiency and Outsourced anaerobic digestion scenarios).

2.3.4. Focus on changes in outlets and production volumes

Possible market developments highlight the uncertainties that exist in the downstream scenarios, such as the place of sugar in diets and the uses of beet ethanol in transport and chemicals, but also upstream with the resilience of European agriculture.

As far as domestic uses are concerned, it is the possible changes in consumption of dietary sugar that make the biggest difference. By implementing strong public health measures, national consumption is reduced by 30% in the ***Energy Autonomy*** scenario, taking demographic change into account (each age group falls below 8% sugar in daily energy intake, i.e. 40 g/day). Through measures targeted at the youngest age groups, national consumption is reduced by 15% in the ***High Energy Efficiency*** scenario (each age group falls below 10% sugar in daily energy intake, i.e. 50 g/day). In the ***Outsourced anaerobic digestion*** scenario, consumption remains stable at 60 g/day.

The domestic use of sugar to make alcohol will vary between now and 2050, depending on the development of ethanol in the chemical industry. In the Energy Autonomy scenario, biobased chemistry gradually mobilises the flows of beet ethanol that are no longer directed towards transport due to the electrification of vehicles, without mobilising more agricultural land. These outlets are less developed in the Energy Efficiency scenario, in which producers of ethanol from resources that do not compete with food take over the new growth markets.

In terms of upstream agricultural issues, the ***Energy autonomy and European sovereignty*** and ***Energy Efficiency and European Sovereignty*** scenarios refer to favourable contexts for the resilience of European agriculture. The European Union has introduced mirror clauses in its free trade agreements, limiting imports of sugar that do not comply with the environmental standards in force in Europe. Research and innovation have made it possible to develop varieties and cropping systems to make them more resilient to climate change, while reducing the impact on biodiversity and maintaining beet production at the 2019-2023 level. These production volumes, combined with a fall in domestic sugar consumption, have enabled French exports to increase by 400,000 tonnes, offsetting the halt to beet production in southern European countries.

By 2050, in the ***Outsourced anaerobic digestion and globalisation*** scenario, European agriculture has been weakened. International trade has increased, and the European Union has developed free trade agreements without mirror clauses, allowing foreign cane sugar to be imported, replacing some of the French sugar in European countries with sugar deficits. As a result, French exports fall by around 1 million tonnes.

Figure 24. Sugar usage in the 3 scenarios.

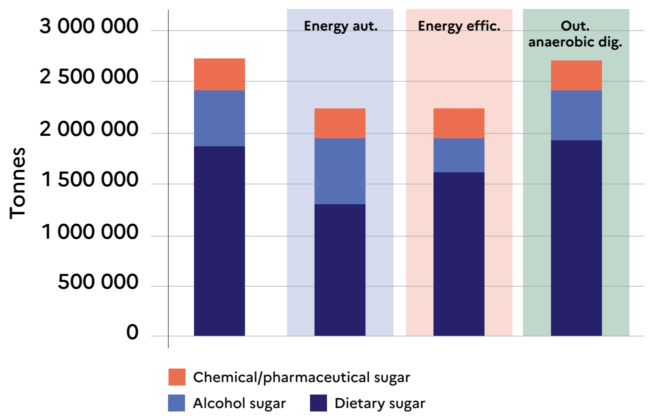
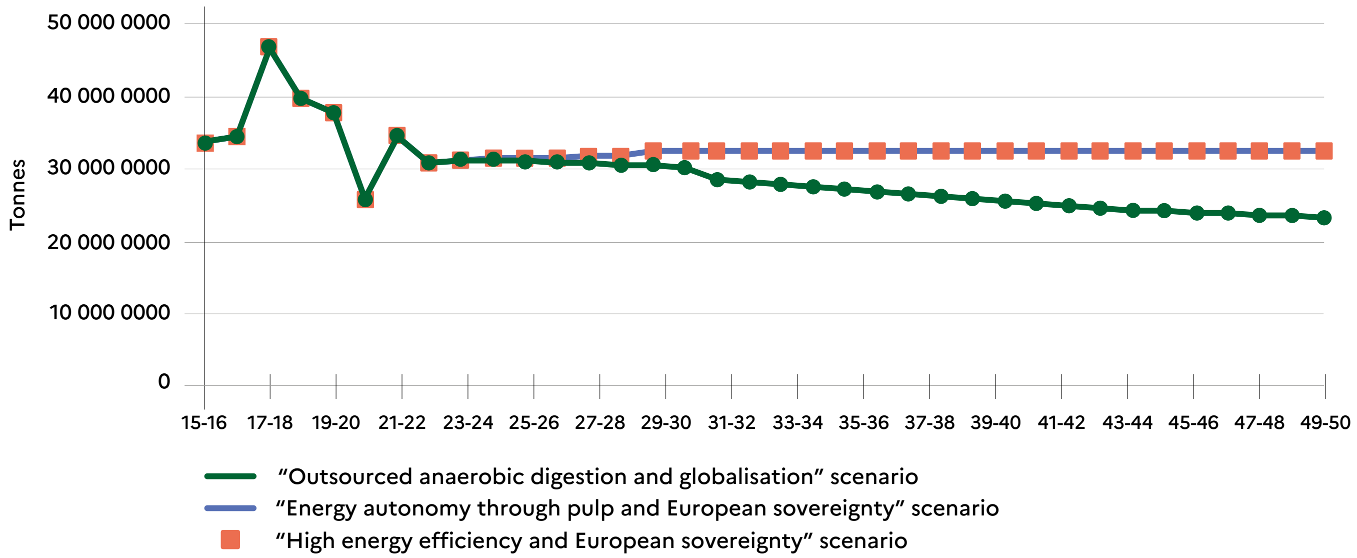


Figure 25. Beet production at 16% between 2015 and 2050 in the three scenarios.



3. Socio-economic analysis

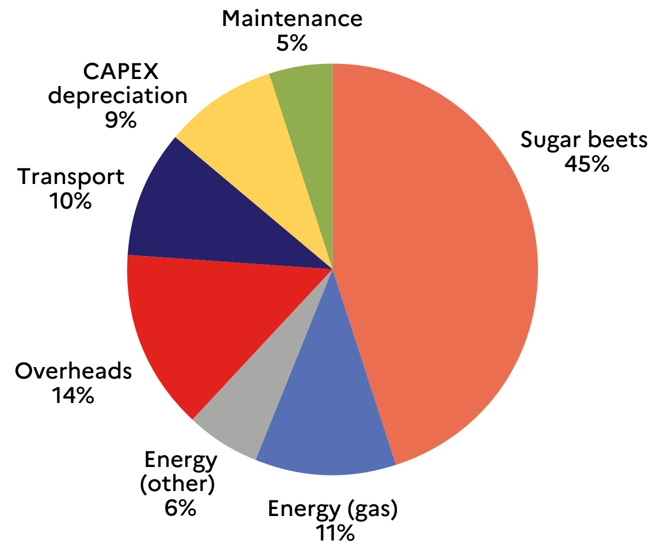
3.1. The lower the investment in decarbonisation, the higher the production costs

The proposed decarbonisation scenarios also illustrate the variability of the economic impact of decarbonisation on the sugar sector. As a result, there is a change in production costs in the transition trajectories. In 2015, the average cost of processing a tonne of beet for the production of sugar and alcohol was estimated at €54/tonne of beet.

As the second cost item, changes in network gas and electricity prices play a central role in the evolution of the sugar industry's production, as do changes in the price of the CO_2 quota within the European Emissions Trading System (EU-ETS), which was modified in May 2023[26].

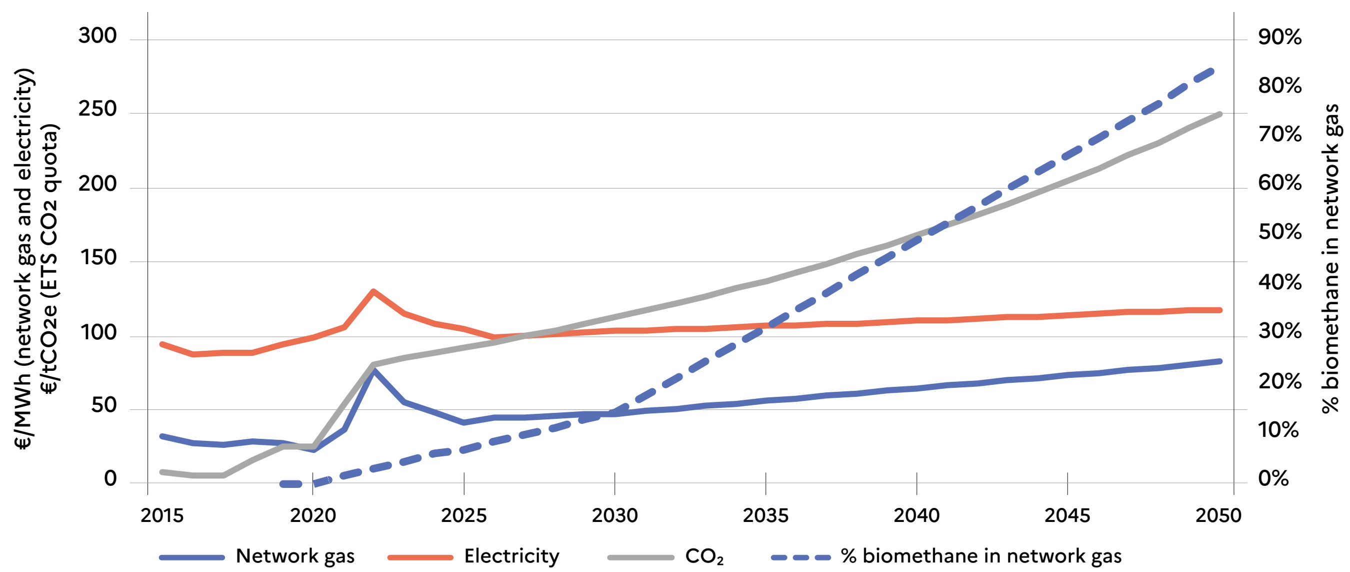
We considered three price trajectories (low, central, high) for network gas, electricity and the CO_2 quota. In the central price trajectory, expressed in constant euros, the price of the carbon allowance rises from €80/tCO_2 in 2022 to €250/tCO_2 in 2050, the price of electricity rises from €95/MWh between 2015 and 2020 to €120/MWh and the price of network gas rises from €30/MWh between 2015 and 2020 to €80/MWh in 2050. For gas, we have assumed the gradual integration of biomethane into the network, reaching 85% by 2050. The cost of beet pulp is also taken into account in the scenarios: it is not paid for by the sugar manufacturers (who generally buy the whole beet and not just the sugar it contains), but its use represents a loss of income, as it would otherwise be resold as animal feed or for anaerobic digestion.

Figure 26. Breakdown of processing costs for a tonne of sugar beet in 2015.



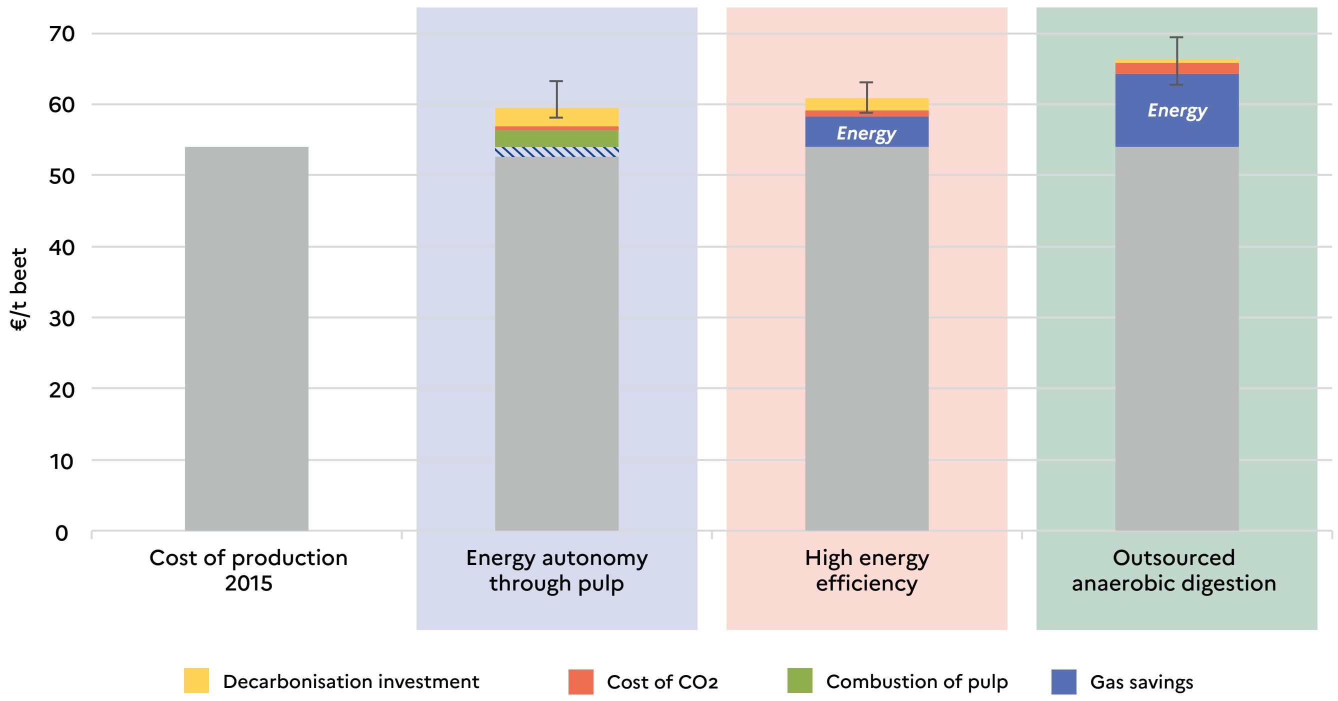
Given the uncertainty surrounding the beet purchase price offered by manufacturers to farmers, we have looked more specifically at the additional cost of production compared with 2015 excluding the purchase of beet.

Figure 27. Assumptions derived from the central trajectories relating to the price of electricity, the CO_2 quota, network gas and the level of decarbonisation of network gas considered in the three scenarios.



[26] Directive (EU) 2023/959

Figure 28. Increase in production costs in 2050 compared with 2015, per tonne of beet by scenario.
The error bars represent the range of variation between « high » and « low » price trajectories for gas, electricity and the ETS CO_2 quota



Overall, production costs are very sensitive to the energy and CO_2 price assumptions considered. The construction of low and high trajectories for these parameters highlights similar production costs for the Energy autonomy through pulp and the High energy efficiency scenarios.

For the ***Energy autonomy through pulp and European sovereignty*** scenario, the additional cost is estimated at €4/tonne of beet in 2050. This increase is linked to the depreciation of decarbonisation investments (68% of the cost differential in 2050), and the loss of income linked to the use of beet pulp for combustion (which cannot then be sold to farmers). However, using pulp in this way saves on network gas purchases. The additional cost remains limited thanks to the sites' energy autonomy.

In the ***High energy efficiency and European sovereignty*** scenario, the additional cost rises to €8/tonne of beet. This is mainly due to increased expenditure on energy, and more specifically to two combined effects: rising energy prices and the switch from fossil gas to electricity. Despite significant efforts on energy efficiency, this scenario shows a strong dependence on energy networks, and therefore a significant sensitivity to variations in energy costs (61% of the additional cost in 2050). There is also the considerable impact of decarbonisation investments (26% of the additional cost in 2050), and the weight of CO_2 (13% of the extra cost in 2050). The additional cost of production is therefore not only greater than in the ***Energy autonomy through pulp and European sovereignty*** scenario, but also subject to greater variability depending on the availability of energy.

Finally, in the ***Outsourced anaerobic digestion and globalisation*** scenario, the additional cost rises sharply, reaching €12/tonne of beet by 2050. This is mainly due to the increase in energy costs, while consumption has fallen relatively little: they account for 83% of the rise in production costs. According to the assumptions made by ADEME, these energy costs are linked to the increase in the cost of network gas, the increase in the proportion of biogas from anaerobic digestion, which takes a growing share of the energy mix, and the increase in the cost of electricity. There is also the considerable impact of decarbonisation investments (3% of the additional cost in 2050), and the weight of CO_2 in the transition period for industrial sites. This additional production cost is therefore much higher than in the ***Energy autonomy through pulp and European sovereignty*** and ***High energy efficiency and European sovereignty*** scenarios.

In the ***Energy autonomy through pulp and European sovereignty*** scenario, the CAPEX required is very high (higher than in the other two scenarios), but avoids high production costs, particularly for energy. In the long term, provided the financial resources are mobilised, it will enable sugar manufacturing to continue. In the ***High energy efficiency and European sovereignty*** scenario, the CAPEX to be invested remains significant but is 30% lower than in the previous scenario. On the other hand, production costs (excluding beet) in 2050 are higher in this scenario: to around €54/tonne of beet processed in 2015, more than €7/tonne of beet processed is added, compared with €4/tonne of beet processed in the previous scenario, according to the assumptions made. Lastly, in the ***Outsourced anaerobic digestion and globalisation*** scenario, the sugar industry's severely weakened investment capacity means that CAPEX for decarbonisation cannot exceed €607m. This has a direct impact on production costs: the remaining sugar factories are heavily dependent on external energy supplies, and on the variability of energy costs. The extra cost of production is €12 per tonne of beet processed. These transition trajectories show the advantages and disadvantages of different investment strategies, which have an impact on production costs.

3.2. Abatement costs to shed light on the comparison between levers

The deployment of the various technologies is associated with an abatement cost. This is measured in €/tCO_2 and makes it possible to compare the average cost of deployment in a given sector. The estimated values are based on a calculation methodology that takes into account manufacturers' investment and operating costs, as well as a number of assumptions about changes in costs that are consistent with the modelling[27].

Method – abatement cost of technologies

Two indicators can be used to compare the cost of developing technologies: their additional cost and their abatement cost.

The **additional cost** associated with a technology is defined as the difference between the expenditure associated with the application of a technology (the discounted sum, using a discount rate r, of the CAPEX and operating expenses (OPEX), over a fixed period T).

This indicator is used to assess the profitability of a technology. If the additional cost is zero, it will be profitable at the end of the project. If it is negative, it will be profitable before the end of the project. If it is positive, the project is not profitable. In particular, if the savings in operating costs are too small (or if ΔOPEX is positive), the investments may never pay for themselves, whatever the duration of the project.

$$Surcoût = \sum_{t=0}^{T-1} \frac{\Delta CAPEX_t + \Delta OPEX_t}{(1+r)^t}$$

The **abatement cost** of a technology is defined as the additional cost of this technology in relation to the cumulative quantity of CO_2 that it avoids over the life of the project compared with the situation where the existing installations are maintained.

This indicator makes it possible to compare the cost-effectiveness of decarbonisation levers with a view to prioritisation, but it must be supplemented by other indicators such as maturity, the level of decarbonisation enabled by each technology or the way they are linked together[28].

$$Coût\ d'abattement = \frac{Surcoût}{\sum_{t=0}^{T-1} \Delta CO2_t}$$

[27] These assumptions are detailed in the full Sugar STP report.

[28] With the objective of total decarbonisation, rather than partial decarbonisation, the use of low-cost technologies that only partially reduce emissions can create a counter-productive technological lock-in.

How to interpret the abatement cost curve?

The wider the rectangle (measured on the x-axis), the greater the volume of emissions that can be reduced by the lever. For example, the steam production decarbonisation lever offers more abatement potential than energy efficiency in the Energy autonomy scenario (graph on the left) despite a lower abatement cost for partially deployed energy efficiency.

When the abatement cost of a technology is negative (measured on the y-axis), its deployment generates OPEX savings (network gas, CO_2) that more than offset the initial CAPEX investment, which is amortised over the lifetime of the equipment.

Note: Abated emissions correspond to the difference between emissions in 2050 and in 2015.

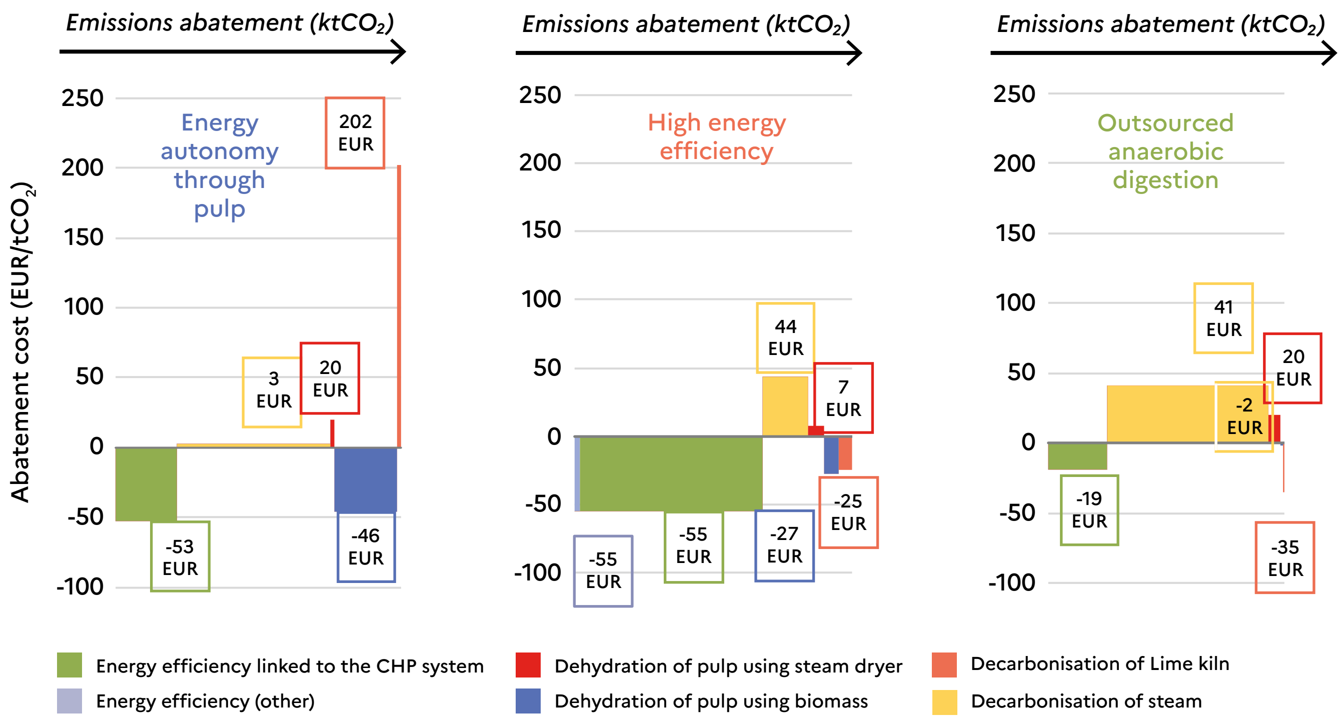
We note that energy efficiency measures have a negative abatement cost in the three scenarios proposed, i.e. whatever the level of deployment proposed, illustrating the relevance of this "no regrets" lever, with a level of deployment to be modulated by site according to the choice of maximising energy autonomy, which implies a large mobilisation of pulp, or maximising energy efficiency, which implies greater dependence on the electricity market and grid.

Furthermore, it appears that decarbonising steam production will make it possible to cut a significant volume of greenhouse gases in all three scenarios but the cost varies depending on the technologies chosen. Burning pulp (the primary option in the ***Energy autonomy*** scenario) is the most economically efficient choice per tonne of carbon avoided, compared with the other options: anaerobic digestion of effluent on all sites and pulp on a few sites (the primary option in the ***High Energy Efficiency*** scenario) or outsourced anaerobic digestion of pulp (the primary option in the ***Outsourced anaerobic digestion*** scenario).

Lastly, with regard to pulp dehydration, the most economically efficient choice appears to be dehydration by steam dryer (primary option in the ***Energy Autonomy*** scenario) compared with the simple substitution of coal and gas in conventional drum kilns (primary option in the ***High Energy Efficiency*** and ***Outsourced anaerobic digestion*** scenarios in addition to the reduction in the quantity of pulp dehydrated). This is mainly due to the low cost of steam in the ***Energy Autonomy*** scenario, which is produced from this dehydrated pulp, compared with a wood-energy price that gradually rises.

The abatement costs provide additional economic analysis of the decarbonisation levers, which must, however, be accompanied by the consideration of other aspects in order to have a complete view of the options available, such as local specificities (level of use of pulp for livestock farming), the availability of resources (wood energy) and company strategies (level of dependence on the electricity grid and level of reduction in pulp made available to livestock farmers).

Figure 29. Comparison of abatement costs by scenario.



3.3. Jobs

The sugar industry is seasonal, operating at full capacity for only three or four months of the year. It is therefore made up of permanent and seasonal jobs, with staff numbers varying according to the period: during the beet season or between beet seasons.

In 2007-2008, the French sugar industry employed 7,500 people during the beet season and 5,400 between seasons, spread across 30 sugar factories. Against a backdrop of changes in the European sugar market, national companies and cooperatives have gradually restructured, with 25 sugar factories in 2008, 21 sugar factories in 2020 and 20 sugar factories in 2023. By 2022-2023, the workforce had reached 5,400 during the season and 4,200 between seasons. This has occurred in a context of relatively stable production (excluding the challenges of the end of sugar quotas in 2017-2018 and the yellows virus outbreak in 2020-2021), with the remaining sugar factories having both increased their daily production capacity and the duration of the beet season[29].

As far as direct employment is concerned, maintaining beet production in the Energy autonomy through pulp and European Sovereignty and ***High Energy Efficiency*** and ***European Sovereignty*** scenarios helps to maintain jobs in sugar factories and distilleries. However, the past tendency of sugar manufacturers to concentrate activity on a smaller number of sites, in order to achieve economies of scale and concentrate investment in decarbonisation, could continue over the coming decades and have negative effects on employment in the sector. In the ***Outsourced anaerobic digestion and globalisation*** scenario, production in 2050 falls by 25% compared with the 2019-2023 average, having a major impact on the sugar industry. By way of comparison, and assuming constant labour productivity, this represents the loss of around 1,500 jobs in sugar factories. Such a development would necessarily involve restructuring industrial sites, so as to concentrate activity in regions with the best agricultural yields.

Based on discussions with manufacturers in the sector, it has been determined that the decarbonisation levers envisaged do not imply any significant increase or decrease in jobs in sugar factories. They involve equipment that is familiar to site employees, without the installation of breakthrough technologies that are more complex to grasp. On the other hand, as in all industrial sectors, industry actors are highlighting the need to renew the generations of technicians in order to have the human resources to operate the new equipment[30]. Partnerships between manufacturers, equipment suppliers, training centres, regions and local authorities need to be developed to facilitate recruitment in the industrial sector.

➜ Cristal Union employees in front of the diffusion unit © Cristal Union, Eric Larrayadieu

In terms of indirect employment, the sugar sector is characterised by agricultural jobs associated with beet production. However, it is not possible to establish a correlation between the volume of beet processed in sugar factories and changes in agricultural employment. If sugar plants were to close, beet growers could switch to other crops without the loss of jobs. However, a decline in the sugar industry could lead to a loss of confidence on the part of the farming community, which could have an impact on the renewal of generations in beet production areas.

[29] CEFS data.

[30] La Fabrique de l'Industrie. Pénurie de compétences et réindustrialisation: un étonnant paradoxe (Skills shortages and reindustrialisation: a surprising paradox). 2023.

Index of tables and figures

FIGURES

TABLES

Acronyms and abbreviations

AAMF - Association of Anaerobic Digestion Farmers in France
ADEME - French Agency for Ecological Transition
ARTB - Beet Technical Research Association
BPA - Biogas Purchase Agreement
CCNUCC - United Nations Framework Convention on Climate Change (UNFCCC)
CE - European Commission (EC)
CEFS - European Committee of Sugar Manufacturers
CGB - General Confederation of Beet Growers
CIBE - International Confederation of European Sugar Beet Growers
COP - Coefficient of performance
CPB - Biomethane Production Certificate
CCUS - Carbon Capture Utilisation and Storage
DGEC - French Directorate General for Energy and Climate
DROM - French overseas department and region
EU-ETS - Emission Trading System
GHG - Greenhouse gases
ITB - Beet Technical Institute
MACF - Carbon Border Adjustment Mechanism (CBAM)
MB - Raw material
€m - Millions of euros
MS - Dry Matter (DM)
ONRB - National Observatory of Biomass Resources
PAC HT - High-temperature heat pump (HTHP)
PPA - Power Purchase Agreement
PTS - Sectoral Transition Plan (STP)
RED - Renewable Energy Directive
RMV - Mechanical vapour recompression (MVR)
SER - Renewable Energies Union
SNBC - French National Low-Carbon Strategy
SNFS - National Union of French Sugar Manufacturers
SNIA - National Union of the Animal Feed Industry and Nutrition
UE - European Union (EU)

ADEME AT A GLANCE

At ADEME – the Agency for Ecological Transition - we are firmly committed to fighting climate change and the depletion of resources.

On all fronts, we mobilise citizens, economic actors, and local and regional authorities, giving them the tools they need to move towards a more resource-efficient, low-carbon economy that is fairer and more harmonious.

In every field – energy, circular economy, food, mobility, air quality, climate change adaptation, soil, etc. - we advise, facilitate, and help to fund numerous projects, from the research stage through to sharing solutions.

At every level, we put our expertise and forward-looking capabilities at the service of public policies.

ADEME is a public body under the supervision of the Ministry for an Ecological Transition and Territorial Cohesion, the Ministry of the Economy, Finance and Industrial and Digital Sovereignty and the Ministry for Higher Education and Research.

www.ademe.fr

ADEME
COLLECTIONS

FACTS AND FIGURES
ADEME is a reference: It provides objective analysis on the basis of regularly updated statistical indicators.

KEYS FOR ACTION
ADEME is a facilitator: It draws up practical guides to help stakeholders implement their projects in a methodical manner and/or in compliance with regulations.

THEY'VE DONE IT
ADEME is a catalyst: Stakeholders talk about their experiences and share their know-how.

EXPERTISE
ADEME provides expertise: It reports on the results of research, studies and collective work conducted under its supervision.

HORIZONS
ADEME looks to the future: It proposes a prospective and realistic vision of the challenges of the energy and ecological transition, for a desirable future to be built together.

RÉPUBLIQUE FRANÇAISE
Liberté
Égalité
Fraternité

ADEME
AGENCY FOR ECOLOGICAL TRANSITION

EXPERTISES

SUGAR
Summary report

If France is to achieve carbon neutrality by 2050, its industry will need to decarbonise. To this end, the current National Low-Carbon Strategy (SNBC2) sets GHG reduction targets for industry of 81% by 2050 compared with 2015. At the heart of agri-food industry, sugar production is used in food, transport and chemicals, and is responsible for 3% of the GHG produced by French industry. The necessary energy transition in this sector represents a real technological, financial, economic and regulatory challenge.

The three scenarios developed achieve a reduction in GHG emissions of 50% in 2030 and more than 90% in 2050 compared with 2015, in very different transition contexts but with technologies that have already been tried and tested. They show that rapid and far-reaching decarbonisation of the sector is possible between now and 2030 by moving away from coal and continuing to deploy energy efficiency solutions. After 2030, depending on local conditions and their industrial strategy, the companies and cooperatives in the sector will either move towards energy autonomy to limit their dependence on the electricity grid by using beet pulp (for combustion or anaerobic digestion) to the detriment of animal feed, or towards seeking maximum energy efficiency through electrification, giving priority to pulp for animal feed, while accepting their vulnerability to electricity prices in winter. In some cases, these two options could be complementary.

These far-reaching changes are envisaged in a context of changing downstream outlets (less dietary sugar for better health, less sugar-ethanol used as fuel in cars but more ethanol used to develop biobased chemical products) and upstream, with European agriculture having to make the agro-ecological transition to cope with the increased effects of climate change, which could alter the biogeography of crops in Europe. If the conditions are right, the French sugar industry will be well placed to maintain its contribution to Europe's sugar self-sufficiency, with a reorganisation of production.

The Finance ClimAct project contributes to the implementation of France's National Low-Carbon Strategy and European policy on sustainable finance. It aims to develop new tools, methods and knowledge that will enable (1) energy-intensive industries to promote investment in energy efficiency and the low-carbon economy, (2) financial institutions and their supervisors to integrate climate issues into their decision-making processes and align financial flows with energy-climate objectives, and (3) savers to integrate environmental objectives into their investment choices.

The consortium, coordinated by the French Agency for Ecological Transition, also includes the French Ministry for Ecological Transition, the Autorité des marchés financiers (French Financial Markets Authority), the Autorité de contrôle prudentiel et de résolution (French Prudential Supervision and Resolution Authority), the 2° Investing Initiative, the Institut de l'économie pour le climat (Institute for Climate Economics), the Institut de la Finance Durable (Paris Sustainable Finance Institute) and RMI.

Finance ClimAct is an innovative programme with a total budget of €18 million and €10 million in funding from the European Commission.

Duration: 2019-2024

Finance ClimAct

With the contribution of the European Union LIFE programme. The European Commission is not responsible for any use made of the information contained in this work.

012588

9 791029 724053

www.ademe.fr