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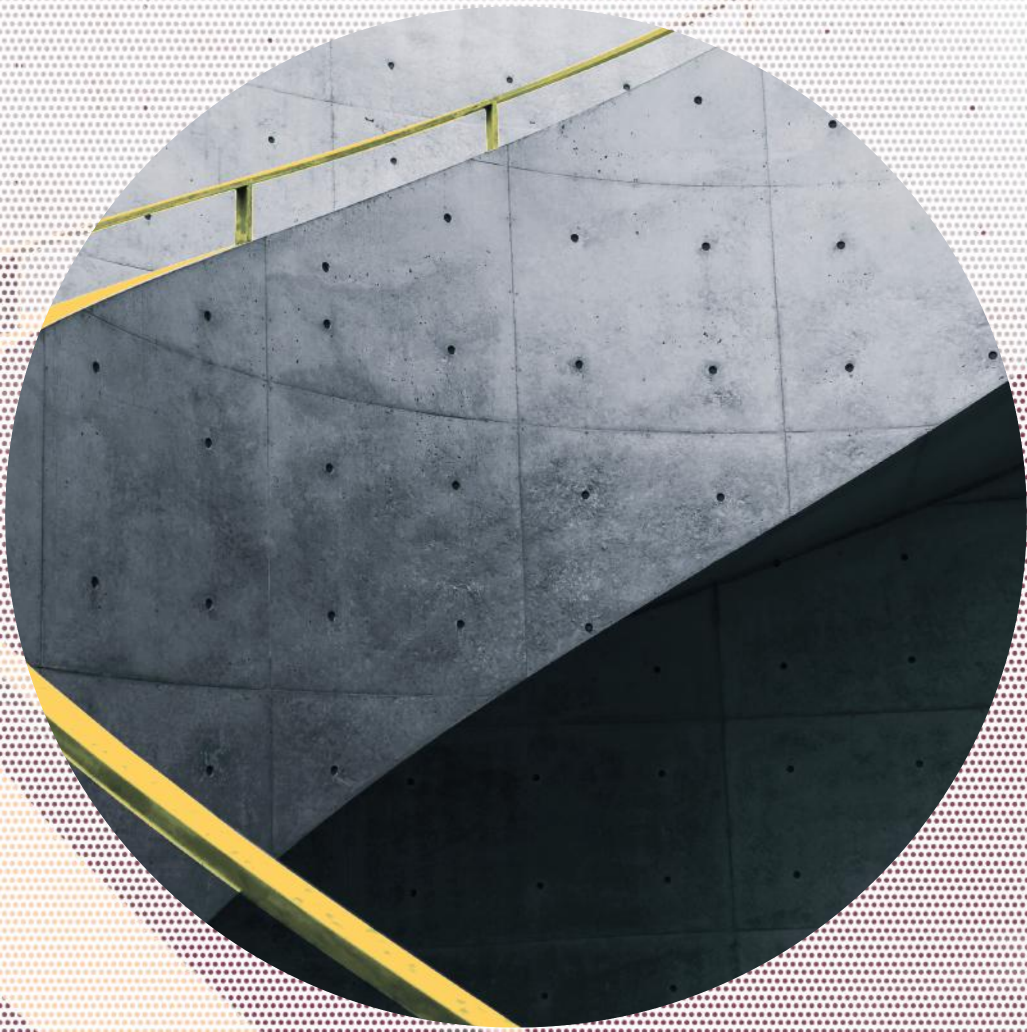
AGENCE DE LA TRANSITION ÉCOLOGIQUE

SECTORAL TRANSITION PLAN FOR THE FRENCH CEMENT INDUSTRY



EXPERTISE

CEMENT

First technical-economic results
Executive summary

FEBRUARY 2021

With the contribution of the European Union LIFE programme

Finance ClimAct

This document is produced by ADEME

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LIFE Finance ClimAct project reference: LIFE 18/IPC/FR/000010 (Action C7.1. Sectoral Transition Plans)
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ADEME would like to thank the following people for their participation and involvement throughout this first study phase on the Sectoral Transition Plan for the French cement industry:
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Laurent TRUCHON, François REDRON, Patrick GUIRAUD (CIMBÉTON)
Jean-Marc POTIER (SNBPE)
Pierre BULTEZ, Sylvain CODRON (EQIOM)
Éric BOURDON, Gilles du MANOIR (VICAT)
Jean-François BRICAUD, Patrick MÉZIÈRE (CIMENTS CALCIA)
Florent DUBOIS, Maud TARNOT, Christophe BOUF (LAFARGEHOLCIM)
Sylvain MATHONNET, Rachel BAUDRY, Aïcha EL KHAMLICHI (ADEME)

CITING THIS REPORT
ADEME. E. Mari, S. Sourisseau, A. Bouxin, C. Borde, G. Daill, S. Padilla, T. Gourdon, 2021. Sectoral Transition Plan for the French cement industry First technical-economic results – Executive summary 20 pages.

This work is available online www.ademe.fr/en/mediatheque

Photo credits: cover Shutterstock

Graphic design: sennse • 645

Printing: Printed in France by Goubault Imprimeur, certified ISO 14001 and Imprim'Vert
This document is printed on 100% PEFC paper.

Brochure ref. 011492 – ISBN web : 9791029717925

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1. Background and summary

1.1. From National low-carbon strategy to the Sectoral Transition Plan

The Stratégie Nationale Bas Carbone (French national low-carbon strategy - SNBC) defines the path France intends to take to achieve carbon neutrality in 2050, a commitment it made following the 21st Conference of the Parties (COP 21) to the United Nations Framework Convention on Climate Change (UNFCCC). For French industry, this path means an 81% reduction in greenhouse gas (GHG) emissions compared with 2015. While there are some guidelines in the literature on industrial decarbonisation (e.g. preferring carbon-free energy and the circular economy), their content and their cost at an operational level have not been detailed. Yet industrialists need medium-term visibility to make their investments. Indeed, as industrial equipment has a lifespan of several decades, today's investments will have consequences until 2050. The Sectoral Transition Plans come within the scope of this time frame faced by industry. For the public authorities, it is also a question of being able to propose effective accompanying policies that encourage decision-making on the investments needed to meet the target of an 81% reduction in industrial GHG emissions by 2050

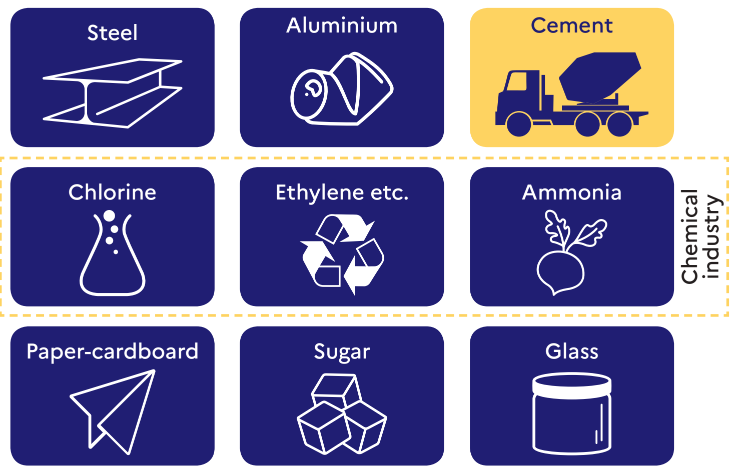
The purpose of this document is to deliver the first results of the Sectoral Transition Plan applied to the cement sector.

By jointly building these Sectoral Transition Plans with key players in the sector, **ADEME wants to offer visibility to both industry and investors, and also to public authorities, to achieve the objective set by the SNBC.** The project is therefore a continuation of the work carried out for the SNBC, dividing heavy industry into 9 sectors (shown in Figure 1) to offer specific decarbonisation solutions to the industrial problems of each sector.

Unlike the vast majority of work based on national, European or international literature, which essentially focuses on the industrial transition from a technological point of view, the project adopts a 360° vision including consideration of markets, costs, financing and jobs. Integrated into a European LIFE[1] programme entitled Finance ClimAct[2], these transition plans are based on cross-analysis of the deployment of decarbonisation technologies, the cost this represents, to anticipate financing needs in particular, and the effects on competitiveness and the impact of market developments in terms of demand and competition by 2050. The effects on employment and the possible changes in skills necessary to adapt to the transition are also discussed in the Sectoral Transition Plans, as are the topics of regional roots and the degree of a region's dependence on the industrial sector studied.

Ultimately, this work should lead to the formulation of "public-private" action plans to speed up the transition of these key sectors.

Figure 1. The 9 industrial sectors that will be the subject of a Sectoral Transition Plan.



[1] The LIFE programme is the EU's funding instrument for the environment and climate action created in 1992. The funding period 2014-2020 had a budget of €3.4 billion.

[2] https://presse.ademe.fr/2019/12/finance-climact-mobilisation-pour-un-plan-daction-sur-la-finance-durable.html?hilite=%27FINANCE%27%2C%27CLIMACT%27

Project Finance ClimAct with funding from Life

30 **people** working full time on the project

18 **million euro** budget

5 **years**

Project partners

I4CE Institute for Climate Economics · Ministère de la Transition Écologique · Banque de France · 2° Investing Initiative · GreenFlex · Finance for Tomorrow · ADEME · AMF · ACPR

1.2. The French cement industry in a few figures

16.5

million tonnes

Cement production in 2018

(down 23% in 10 years) or about 0.5% of world production and about 9% of European production, for domestic consumption of about 18.6 million tonnes (Mt).

27 production sites and 5 industrial groups

LafargeHolcim, Ciments Calcia, Eqiom, Vicat and Imerys Aluminates (formerly Kerneos which produces calcium aluminate cement for specific applications).

Between 2010 and 2016, the turnover of the cement industry hovered around €2.5 billion (in current euros).

Energy consumption represents about 30% of the cost of production in this sector.

Clinker imports

(intermediate product that goes into cement and is responsible for all the CO_2 emissions of a cement plant), which were quite stable until 2013,

BUT INCREASED 5- TO 6-FOLD BETWEEN 2013 AND 2018

mainly from Spain and countries of North Africa and the Middle East. In 2018, the net balance of clinker imports represented about 5% of the clinker used in mainland France.

Foreign trade in cement

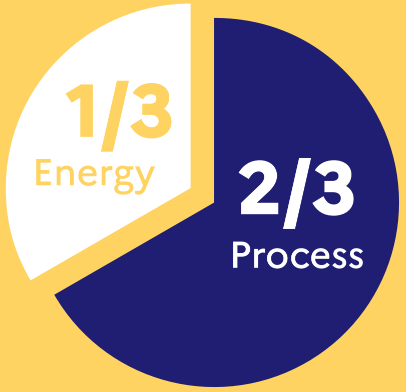
France imports almost 3 times more cement than it exports. The net import balance of 1.9 Mt in 2018 represents about 10% of domestic consumption, which has remained constant for the past 10 years. Trade in cement is mainly with neighbouring countries such as Spain, Belgium and Italy.

5000

direct jobs on average since 2010

spread throughout the country and 18,000 indirect jobs.

Origin of cement industry emissions



Difficult to overcome by "classic" measures of changing the energy mix

63%

of cement consumption is in the building sector and 37% in public works.

Approximately 10 million tonnes of CO_2-eq each year, or **12.5% OF INDUSTRY GREENHOUSE GAS EMISSIONS** and 2% of total emissions in France.

1.3. Decarbonisation of the cement industry: main decisive factors

An analysis that crosses technological route...

A first step of the project is to build a technological route that combines various decarbonisation levers in a coherent and realistic way, while quantifying the impacts on energy consumption, the emissions specific to cement, and the cost of production.

At this stage of the analysis, only mature technologies and/or technologies that are readily identified as a significant challenge for decarbonisation have been modelled. The decarbonisation potential associated with other more innovative levers (such as electrification or alternatives to clinker) will be modelled in future work.

➜ Alexey Rezvykh/Shutterstock.com

The potential of Carbon Capture and Storage (CCS) technology, on which the sector is relying heavily to decarbonise its industry, has also been taken into account. Since this is still a very expensive technology, and its long-term deployment in France is not yet established, the results of this summary are systematically presented with and without CCS.

...and change in demand for cement...

To assess the level of total emissions from the sector, the technological route has been coupled with two scenarios for changes to the volume of cement production by 2050. These have been obtained using a modelling tool to estimate demand levels from cement consumption sectors, and thus to obtain material production trajectories (the "PEPITO" tool, see section 2.2.). The first scenario corresponds to a trend of the BAU ("Business As Usual") type, in which demand for cement increases slightly until 2050, mainly due to population growth. The second scenario, named "SNBC/ADEME", is a scenario of decreasing demand (through regulatory constraints on the level of new construction) which was has been modelled in accordance with the assumptions of the national low-carbon strategy (SNBC) and/or ADEME's 2050 visions (the SNBC/ADEME scenario).

...to deduce the impact on CO_2 and the economic issues

Table 1. Summary of the first results of the Sectoral Transition Plan for the French cement industry

		Application of the "mature" technological route		
Demand scenario	% change in demand for cement in 2050 vs 2015	% reduction in emissions from the cement sector in 2050 vs 2015	CAPEX (independent of demand scenarios)	Change in total cost of production
BAU	+5%	- 32% without CCS	€3.3bn without CCS	- 10% to + 20% without CCS depending on the starting point
		- 44% with CCS		
SNBC/ADEME	-15%	- 43% without CCS	€4.4bn with CCS	+ 40% to + 70% with CCS depending on the starting point
		- 54% with CCS		

KEY FINDINGS:

- **Need for innovation to achieve the decarbonisation objectives:** the technological levers modelled are not enough.
- **Economic criticality of the CCS solution:** current market mechanisms are insufficient to make this technology viable.
- **Significant impact of demand for cement:** the evolution of the new build market will largely determine decarbonisation in the sector

FROM A TECHNOLOGICAL POINT OF VIEW, THIS FIRST FINDING IS DUE TO 3 MAIN REASONS

1.
Two-thirds of emissions come from the production process (decarbonation of limestone) and therefore cannot be removed using energy efficiency technologies or changes to the energy mix.

2.
The deployment of CCS is constrained by the limited possibilities for storing CO_2 on French territory or offshore (in the current state of scientific knowledge), making only 20% of the cement plants in France potentially eligible for this technology at a cost that is far from negligible.

3.
In practice, decarbonisation of the fuel mix for cement plants is not 100% achievable: there always remains a certain fraction of fossil-fuel carbon in substitute fuels.

The issues around the technological aspects therefore lie in **the need to invest heavily in mature solutions and in particular the integration of other types of substitute for clinker.** In this respect, calcined clays appear to be an interesting solution in a new cement material mix that would allow for a reduction in clinker production.

On the other hand, it seems essential to step up the search for innovative solutions to reduce process emissions. For example, recycling construction industry waste to reintroduce concrete fines as raw material in the manufacture of new hydraulic binders[3] or performing accelerated recarbonation of concrete to reuse it as aggregate[4], would not only contribute to decarbonisation of the chain, but also respond to the challenges of structuring the circular economy.

Indeed, French cement plants consume about 20% more energy than the best cement plants today (see details in part 3.5.1). Given that energy accounts for about 1/3 of the cement industry's emissions, a 15-20% increase in energy efficiency would reduce emissions by 5-7% at the level of a cement plant. Mobilising funding to enable cement plants to meet the standards of the Best Available Techniques (BATs) can be considered an indispensable first step and one with no downside. In particular, this will allow for decarbonisation of the fuel mix by including a higher proportion of substitute fuel.

The renovation of cement plants in France seems to be both an important decarbonisation lever, because it can be deployed in the short term, but also an essential condition for any innovation project.

Concerning demand for cement, the context in which the cement sector will evolve in the coming years is also a key issue. **The demand for concrete and more particularly the rate of new construction will have a very strong impact on the production of cement** in the years to come, and *ultimately* on the industry's decarbonisation trajectory. The effort needed to reduce CO_2 emissions through technology will be less if demand falls (e.g. the SNBC/ADEME scenario), rather if it rises (e.g. the BAU scenario). In this context, strategic thinking will be needed, both by companies to meet future market expectations, and by public authorities to facilitate the transition to cement that is lower in carbon, but nevertheless remains indispensable for the construction sector. Hence, several actions may have a strong impact on the transition of the cement sector, both at national level (e.g. environmental building regulations, public procurement, standardisation of new types of cement, etc.) and at local level (local urban planning policy, limitation of land take, etc.). Industry will have to think how to imagine the cement plant of the future and its new business model ("waste recovery hub", new support services to end customers for optimum use of concrete in structures, etc.), compatible with a low-carbon trajectory.

To go further...

Since the SNBC target of an 81% reduction is not achieved with the technologies and levers that are possible in the short and medium term, other levers need to be thought of and activated in the coming years. Several avenues have been identified in the course of discussions with industry, particularly on innovation (e.g. what potential can be expected from the use of CO_2 and new binders in the decarbonisation strategy?) and on the evolution of concrete demand, in order to be able to offer new, more ambitious routes.

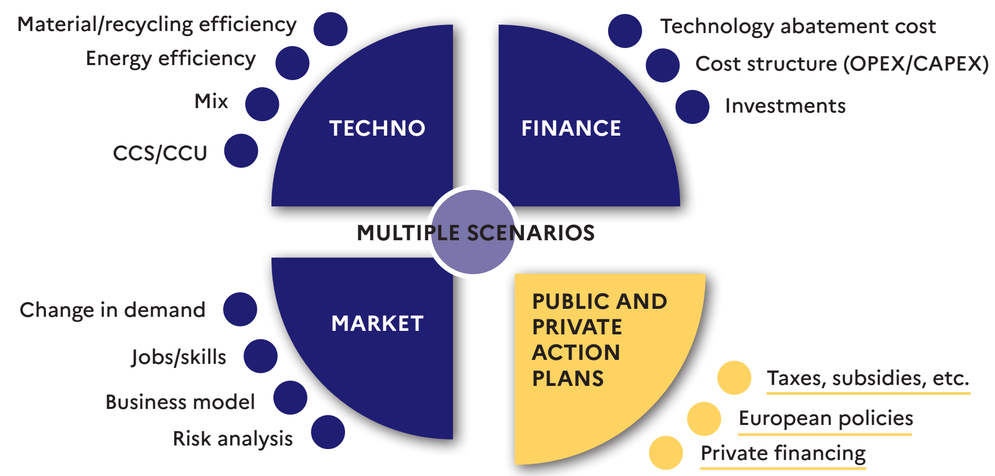
Finally, barriers to the activation of decarbonisation levers (investment, innovation, development of channels, deployment of infrastructure) will be discussed with industry, its customers, public authorities, NGOs and financiers, with the aim of proposing a public-private action plan to engage all the sector's stakeholders in the transition of the cement industry.

➜ Photo of VICAT/Peille - Kiln interior

As the potential changes in the sector are many, building this action plan will be based on scenario-based thinking. Several scenarios will be built in parallel with updating ADEME's prospective visions for 2030-2050, which aim to think up possible and consistent decarbonisation paths to be followed by all sectors, including the cement industry. Each of these scenarios will make it possible to identify specific issues and recommendations for action to be taken.

The results of the Sectoral Transition Plan, including the action plan, will be published by early 2021.

Figure 2. The 360° vision of a Sectoral Transition Plan to shed light on the sector's low-carbon transition



[3] The Recybeton project (2012-2018) aimed to use construction sector waste in concrete, but experiments were also carried out to include recycled material in cement. For further information: https://www.pnrecybeton.fr/

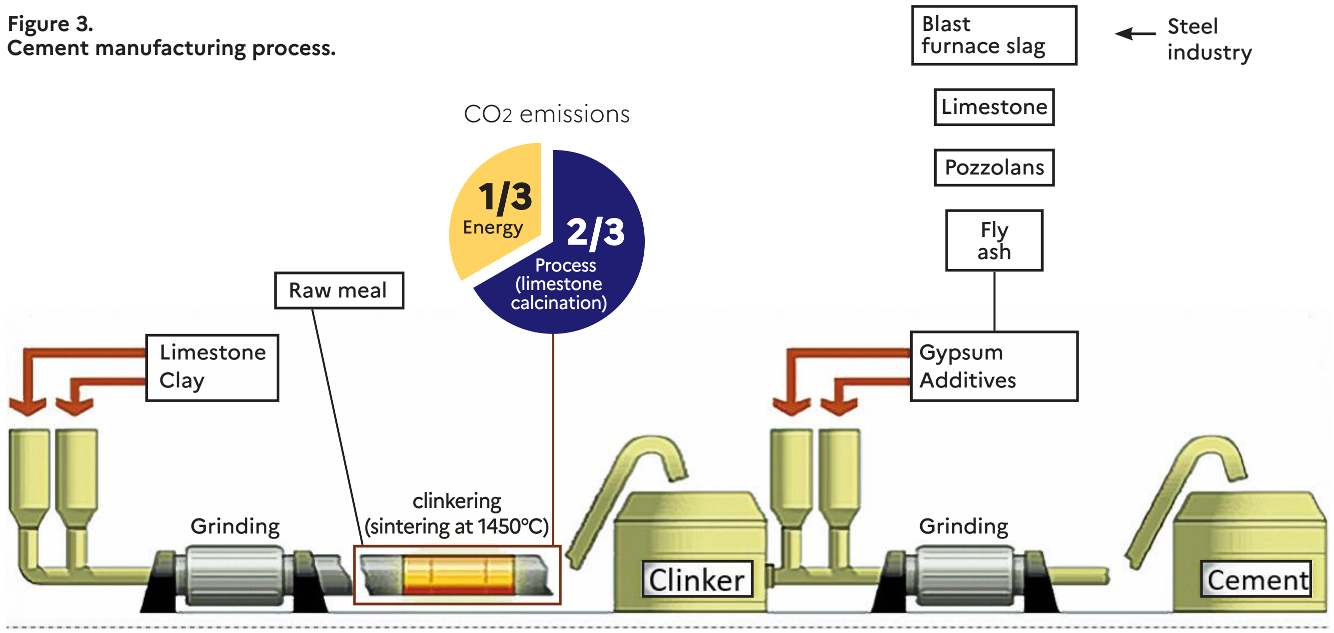
[4] The FastCarb project, launched in 2018, aims to speed up storage of CO_2 in recycled concrete aggregate: https://fastcarb.fr/

2. Which paths to decarbonisation by 2050?

2.1. The cement manufacturing process: essential to an initial understanding of the challenges of decarbonisation of the sector

The manufacturing process for ordinary Portland cement as shown in Figure 3 can be summarised under two main headings: manufacturing clinker and preparation of cement from clinker and other constituents.

Figure 3.
Cement manufacturing process.



➜ Computer graphic by Eric Menneteau, CNRS

Clinker is a dark grey constituent that can be considered the active ingredient: it gives the cement its hydraulic binder properties, i.e. it hardens in contact with water. Clinker is obtained by sintering a previously ground mixture of limestone (80%) and clay (20%) which are relatively abundant raw materials and well distributed geographically. This is partly why the cement industry is very localised and cement is not widely transported. Sintering takes place in a rotary kiln at 1450°C and represents the vast majority of the energy consumption of a cement plant. It is at this stage that almost all the emissions of a cement plant occur: about 1/3 are due to thermal energy consumption and 2/3 are due to the chemical reaction of limestone calcination during which limestone (chemical formula $CaCO_3$) decomposes into calcium oxide (quicklime, CaO) and CO_2. Once the clinker is formed, it cools down on leaving the kiln and the heat given off is reused elsewhere in the process.

The clinker is then ground and mixed with other constituents to produce cement with the required properties. These secondary constituents can either be industrial by-products (such as blast furnace slag, which is a by-product of the steel industry, or fly ash from coal power plants) or naturally occurring materials (such as limestone and natural pozzolan). Preparation of cement from clinker can be carried out independently in grinding units or cement mills. This is a trend that has been observed for several years: some players import clinker from abroad (notably from North Africa and the Middle East) and produce cement for the French market in mills generally located near sea ports. This practice can clearly be considered a form of carbon leakage.

2.2. The challenge of identifying the technological route and the demand scenarios

A technological route based on mature technologies...

The modelling of various transition technologies has allowed the construction of a coherent and realistic technological route illustrating the challenges facing decarbonisation of the cement industry. In consultation with stakeholders, the main decarbonisation levers for the cement industry, presented in Figure 4, have been identified and modelled using an Excel tool. The amount of investment required to implement these levers and their impact on the cost of cement production were also estimated in the tool.

...coupled with two scenarios for cement demand

With 9.5 million tonnes of cement consumed in France in 2014, the new-build sector represents 53% of the demand (18 Mt consumed in 2014 across all sectors). Figure 5 shows the material flows from the extraction of the limestone and clay required for clinker production through to the final consumption of concrete for different uses. In addition to the importance of new build to the sector, it is also and above all the low proportion of cement in concrete that is striking, compared with the high proportion of sand and aggregate.

Figure 4. Main decarbonisation levers for the cement industry[5][6].

Lever 1
Upgrading

In the jargon of the profession, "*upgrading*" is the conversion of an old cement plant into a new and more efficient one, operating using the most efficient process known to date. This decarbonisation lever is therefore only an energy efficiency measure.

Lever 2
Fuel mix

Energy consumption accounts for about 1/3 of a cement plant's emissions. These can be reduced by replacing fossil fuels (coal and petroleum coke) with lower-carbon fuels incorporating a biomass fraction.

Lever 3
Clinker content

Clinker is an intermediate material that goes into the final composition of the cement and its production represents almost all the emissions of a cement plant. Producing cements with a lower clinker content is equivalent to producing less clinker and thus reducing emissions.

Lever 4
Incremental

The "incremental" category consists of a group of seven technologies more or less commonly used in the sector that can contribute in small ways to the decarbonisation of the production tool, in an "incremental" way. The modelling of these technologies is based on ECRA and BREF data.

Lever 5
Carbon capture and storage (CCS)

This technology, not yet deployed on an industrial scale, aims to trap the CO_2 in an impermeable geological formation and can therefore theoretically cut out almost all of a site's emissions. It consists first of capturing, purifying and concentrating CO_2 from industrial sites and then transporting it to a storage site.

[5] ECRA (European Cement Research Academy): https://ecra-online.org/fileadmin/redaktion/files/pdf/CSI_ECRA_Technology_Papers_2017.pdf
[6] BREF (Best Available Techniques Reference Document): https://aida.ineris.fr/sites/default/files/directive_ied/CLM_BREF_042013.pdf

➜ Photo of VICAT/Alternative Fuels - Storage of whole tyres - Lifting grapple

PEPITO tool: Prospects for evolution of industrial production for a zero-carbon trajectory

PEPITO[11] is an Excel modelling tool developed in partnership with the NEGAWATT ASSOCIATION that aims to assess the levels of demand for materials from the 9 most energy-intensive industrial sectors (steel, aluminium, cement, glass, chlorine, ammonia, ethylene, paper/cardboard and sugar) based on scenarios of the evolution of consumer markets for these materials (mechanical, electrical, textile, transport, etc.). These scenarios are based on assumptions made up to 2050 on a set of more than 200 parameters (demographics, recycling rate, per capita consumption of capital goods, number of kilometres travelled by vehicle, etc.). The PEPITO tool can be made available free of charge on request to: transition.industrie@ademe.fr

The change in the pace of construction by 2050 is therefore an important issue for the cement industry. As an example, it has been estimated that a 10% reduction in the number of new builds (houses and collective housing) would result in a decrease of about 3% in cement production (all other things being equal, without any change in current construction systems and practices). Beyond construction, the projection of demand has also taken account of the change in the number of kilometres of road networks and installed renewable energy capacities.

Two scenarios aiming to more generally describe a transition environment in which a technological route would apply have therefore been considered[7].

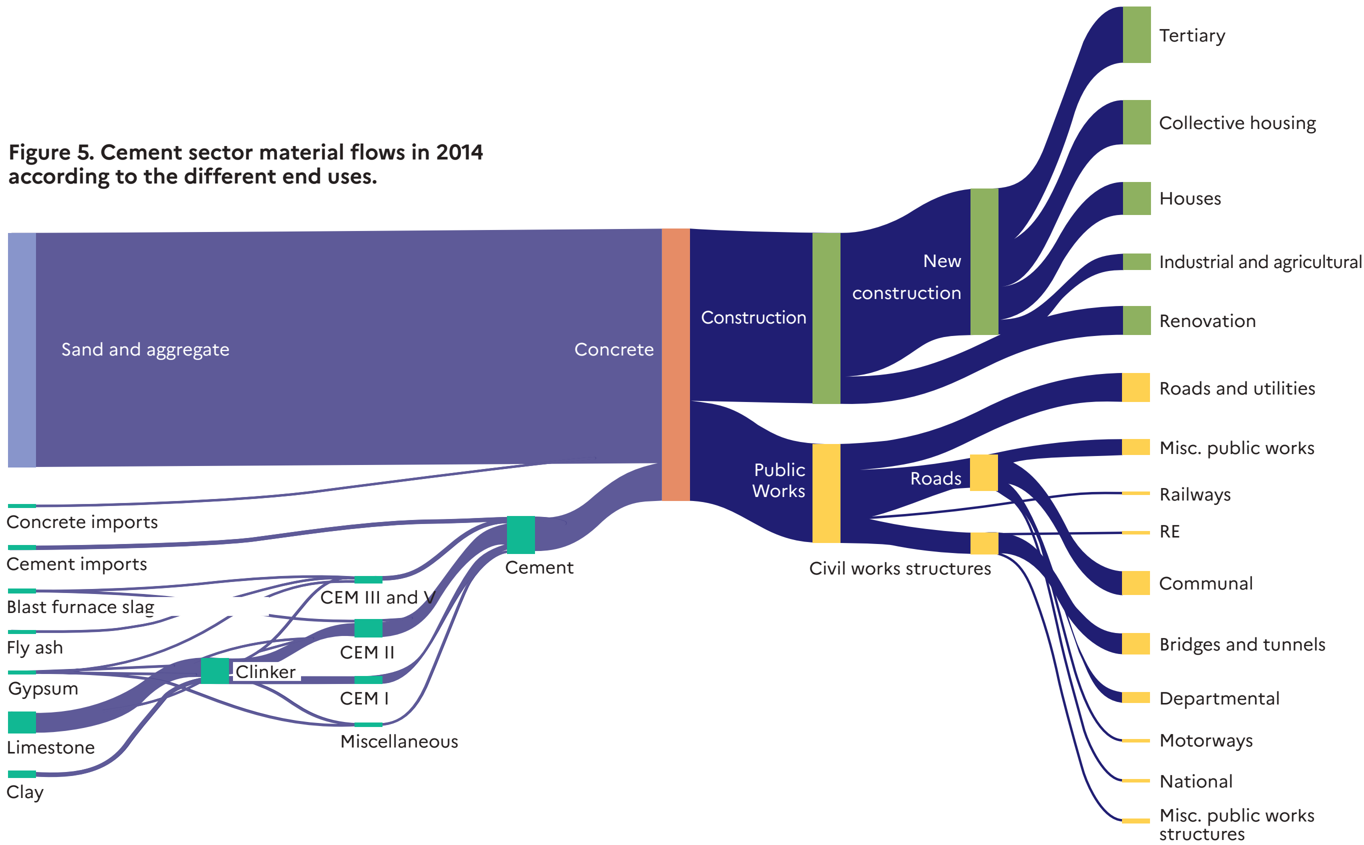
These application scenarios have been modelled using the PEPITO tool (see box opposite).

• Cement production in the **Business *As Usual* (BAU) scenario** reflects the absence of regulatory constraints on the number of new builds, on the kilometres of roads or on speeding up installation of renewable energies (mainly wind), thus leading to an increase in the need for concrete. In fact, the demand *ultimately* depends on concrete. The construction and public works sectors are the only consumer sectors. In this scenario, the lack of change in regulations or policy direction also applies to potential concrete substitutes, and market shares (82% for concrete and 3.3% for wood for collective housing) therefore remain at the same level in 2050 as in 2014 (baseline year for modelling the demand). The cement content in concrete is also maintained at a constant level in both construction and public works. Similarly, the production/consumption ratio is maintained because there is no change in the level of cement imports to France.

• Conversely, in the **SNBC/ADEME scenario**, a greater degree of willingness on the part of public authorities is considered. This is mainly reflected in regulatory constraints on the number of new builds and in particular a gradual decrease in the number of houses built, reaching -50% by 2050 compared with 2014 (ADEME calculation based on the SNBC assumption).

This assumption reflects a decrease in the number of new builds each year (flow) and not in house numbers overall (stock). Indeed, over the past decade, according to INSEE[8], the rate of increase in the number of housing units has increased at around double the rate of population growth. To cope with the increase in the population by 2050, additional construction will also have to be more focused on the principal residence rather than the secondary residence[9]. Similarly, so-called "vacant" housing[10] will be identified and put on the market. These initial "macro" analyses can be refined in view of potential regional disparities, when the Sectoral Transition Plans are broken down by region. The market share of wood as an alternative material in new construction is increasing in the tertiary and collective housing sectors (10% and 20% respectively by 2050) where it competes with concrete. It should be noted, however, that concrete is likely to remain a material of choice for certain types of construction where the opportunities for substitution are limited. Given its marginal share in concrete consumption, the development of renewable energies, especially wind, is not enough to compensate for the decrease in the need for concrete, and therefore cement.

Figure 5. Cement sector material flows in 2014 according to the different end uses.



[8] INSEE study "374,000 additional housing units each year between 2010 and 2015" (https://www.insee.fr/fr/statistiques/3572689#titre-bloc-14)

[9] The INSEE study also shows that the share occupied by principal residences in this growth in the stock observed over the last decade has fallen in favour of vacant housing and second homes.

[10] According to INSEE, vacant housing represented 8.4% of the 36.3 million housing units in mainland France in 2018 (https://www.insee.fr/fr/statistiques/3676693?sommaire=3696937)

[11] Industrial transition - a prospective exercise for energy and materials: towards a production level modelling tool (https://www.ademe.fr/industrial-transition-a-prospective-exercise-for-energy-and-materials-towards-a-production-level-modelling-tool)

2.3. Technological solutions still not sufficient for satisfactory decarbonisation by 2050

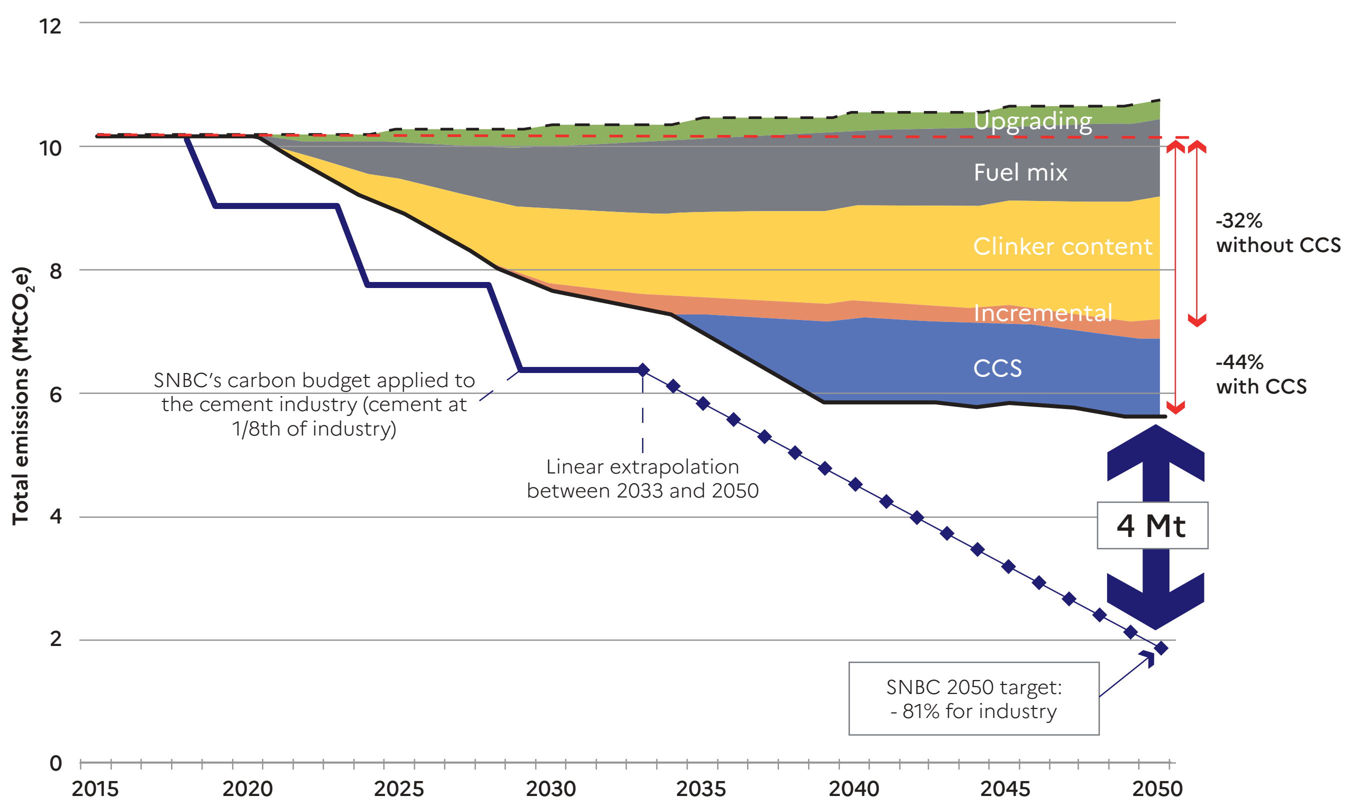
In a trend-based scenario (the BAU scenario[12]) for the change in demand for cement by 2050, **mainly indexed to population growth[13]**, total emissions from the cement industry increase around 5% compared with 2015. If all the identified decarbonisation levers were implemented in this scenario (*upgrading*, fuel mix change, clinker reduction and incremental improvements), this would result in a reduction of around 30% in emissions, without Carbon Capture and Storage (CCS) technology.

This parallels the SNBC emissions trajectory, at least until 2040, but does not reach it.

The SNBC sets a target of a 35% reduction in emissions for the industry between 2015 and 2030. Even including CCS technology, which according to ADEME would only be feasible in 5 cement plants[14], the reduction in overall emissions would be 44% by 2050 compared with 2015 (Figure 6). This only goes half way, since a further cut of just under 4 MtCO2-eq would be needed to reach the SNBC target in 2050.

On the other hand, the new European plan on energy and climate presented in September 2020 by the European Commission[15] gives the target of a 25% reduction in emissions for industry between 2015 and 2030, which translates into annual emissions of 7.7 MtCO2-eq in 2030 for the cement industry. **This European target,** less ambitious than the SNBC's for industry, **is reached in 2030 with the proposed technological route.**

Figure 6. Change in greenhouse gas emissions from the cement sector by 2050
BAU scenario.

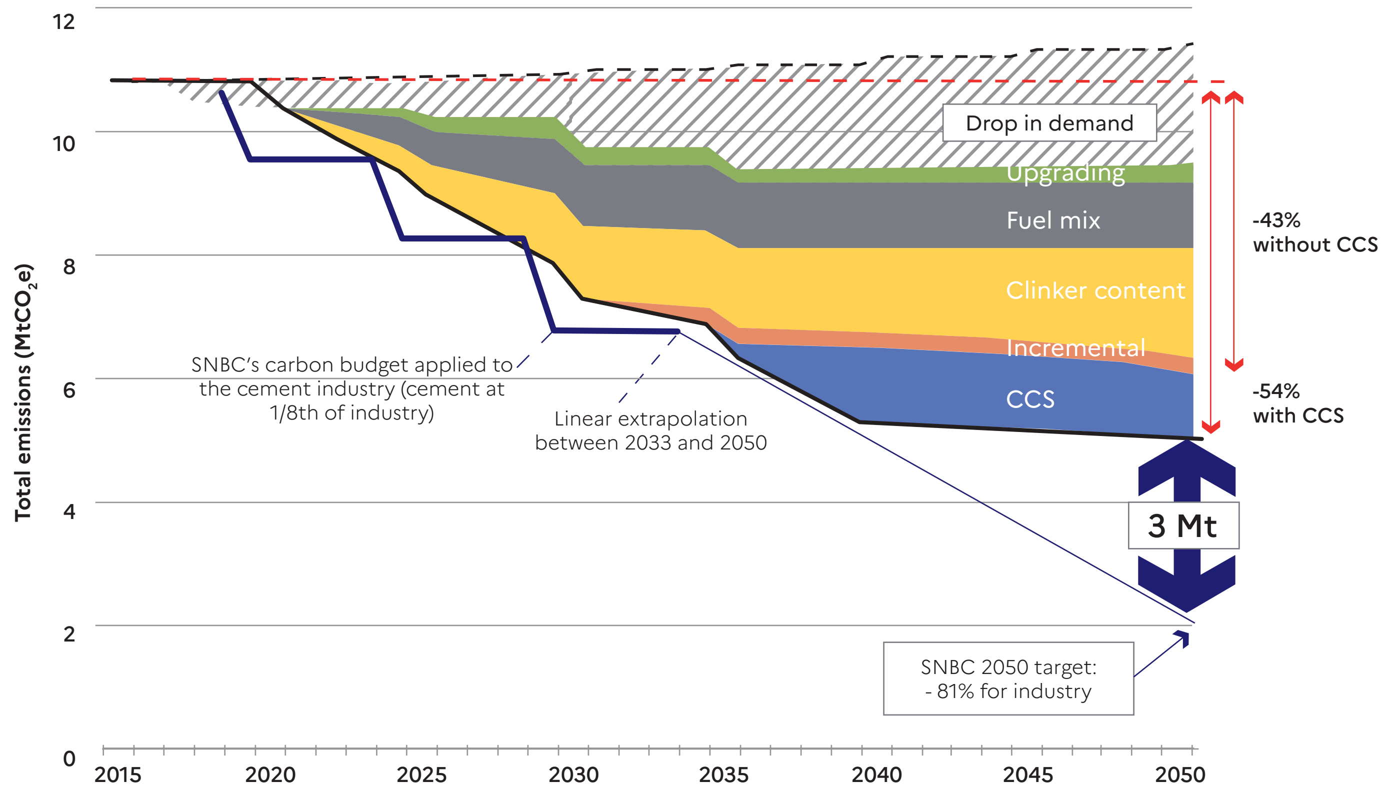


In a second scenario in which the reduction in demand is modelled according to the assumptions of the national low-carbon strategy (SNBC) and ADEME's 2050 visions (the SNBC/ADEME scenario – slowdown in the pace of new construction), total emissions from the cement sector are expected to decrease by about 15% under this single assumption of declining demand. If, in addition, all the identified decarbonisation levers were implemented, this would result in a reduction compared with 2015 of 43% of emissions without CCS and 54% with CCS (Figure 7).

In this scenario, the drop in emissions in the sector closely follows the SNBC trajectory, until 2040 when it stalls due to the lack of additional technological solutions.
The European target for 2030 is also comfortably achieved and exceeded.

[12] Business *As Usual* (BAU) baseline scenario
[13] The assumptions associated with the demand scenarios are detailed in the appendices.
[14] ADEME Opinion on Carbon Capture and Storage in France: https://www.ademe.fr/avis-lademe-captage-stockage-geologique-co2-csc-france
[15] https://ec.europa.eu/clima/sites/clima/files/eu-climate-action/docs/com_2030_ctp_en.pdf

Figure 7. Change in greenhouse gas emissions from the cement sector by 2050
SNBC/ADEME scenario.



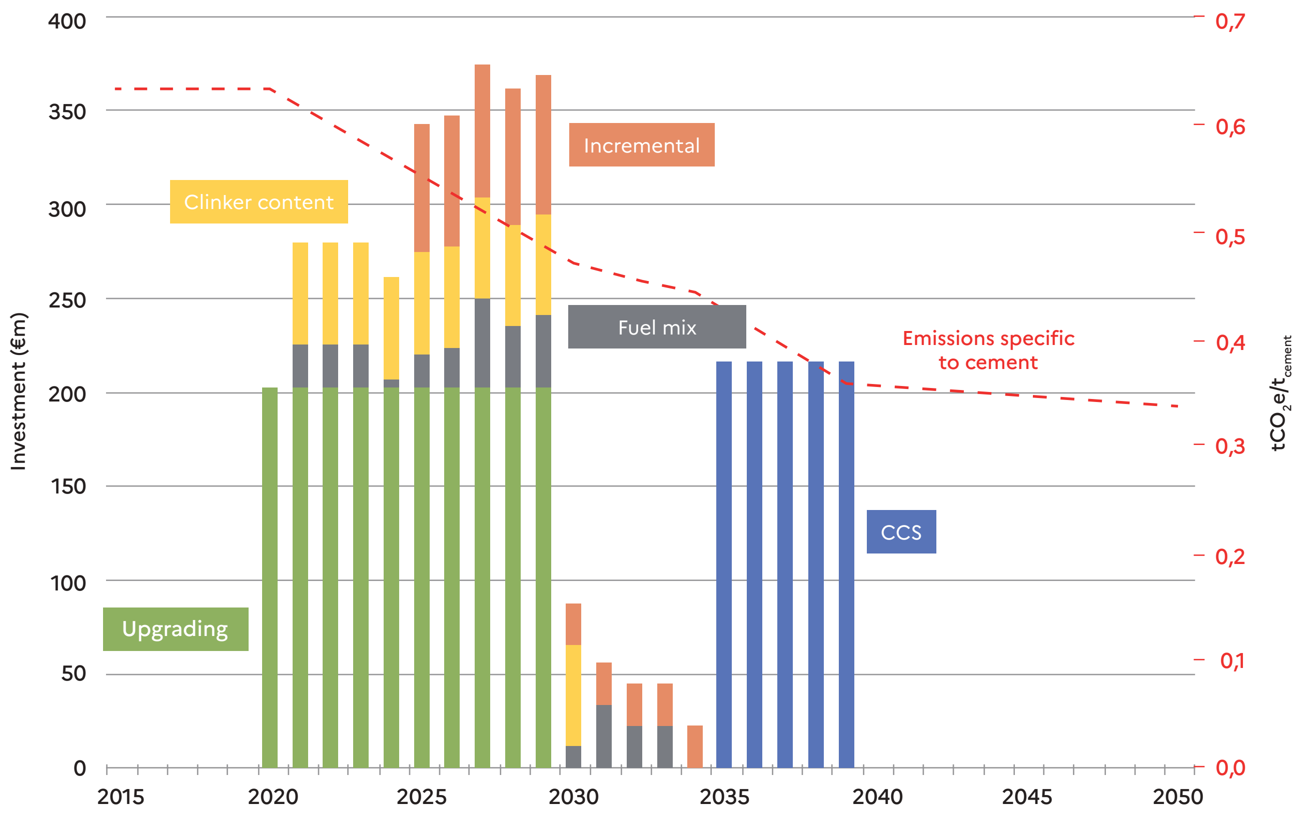
2.4. Massive investments to be made now, not only to develop innovative technologies!

The investment needed to set up these decarbonisation levers (regardless of the change in demand) has been estimated at about **€3.3bn without CCS for the entire French cement sector** (Figure 8). 60% of this investment is for upgrading cement plants, with the installation of new kilns that approach BAT[16] performance levels. In addition, these mature technologies can be deployed in the short term: the investment timetable is therefore highly concentrated in the coming years. In addition, if the investments needed to set up CCS are added (only the capture component for those plants that are "eligible", and not transport and storage), the total investment is estimated at around **€4.4bn**. While waiting for the roll-out of CCS as from 2035, the period 2030-2035 thus presents a "trough" or slowdown in investment.

To put these figures in perspective, the "average gross tangible investment" over the period 2013-2017 for the cement, lime and plaster manufacturing sector (NAF code 23.5) amounts to €172m per year[17] or approximately €5.2bn cumulatively over 30 years. Thus, on the assumption that the cement sector captures the bulk of the investment made in the sectoral cluster, the modelled path appears to be consistent with the scale of cement industry investments.

The two major challenges, in the first approach, would be to maintain the scale of investments while accelerating them over a period of 10 years, and not 30 years.

Figure 8. Cement sector investment timetable and change in specific emissions with CCS (excluding capital cost).



[16] Best Available Techniques (BATs) identified in the European BREF documents: https://aida.ineris.fr/sites/default/files/directive_ied/CLM_BREF_042013.pdf

[17] Estimate based on INSEE data: https://www.insee.fr/fr/statistiques/4226063?sommaire=4226092

2.5. Modelling the French cement sector and its production costs

On the basis of the current structure of the cement sector, mostly represented by three major clinker manufacturing processes, three reference plants have been modelled (Figure 9). These virtual plants illustrate the three cement manufacturing processes most commonly used in France: one plant using the **dry process with precalciner**, one plant using the **dry process without precalciner** and one plant using the **semi-dry process**.

The construction of the reference plants was based on data from French cement manufacturers (source: energy audits and site energy performance plans). Each reference plant is described by its equipment, major phases of cement preparation, specific energy consumption (thermal and electric) and fuel mix. The third bar chart in Figure 9 shows the French cement sector as modelled as a first approximation.

The decarbonisation levers apply differently to each reference plant. The decarbonisation scenarios therefore have a different impact on the cement production costs depending on the reference plant (see Table 2). An example of a semi-dry process plant is shown in Figure 10.

While capital investments are not dependent on the production level of the plants and therefore on the demand scenario, it is important to show their impact on the cost of production through the concept of "amortised CAPEX", which corresponds to the cost of financing and depreciation reduced to the annual production.

+50%

Order of magnitude of expected impact of CO_2 capture on cost of production

Figure 9. Number of cement plants and emissions related to clinker production by manufacturing process in 2015.

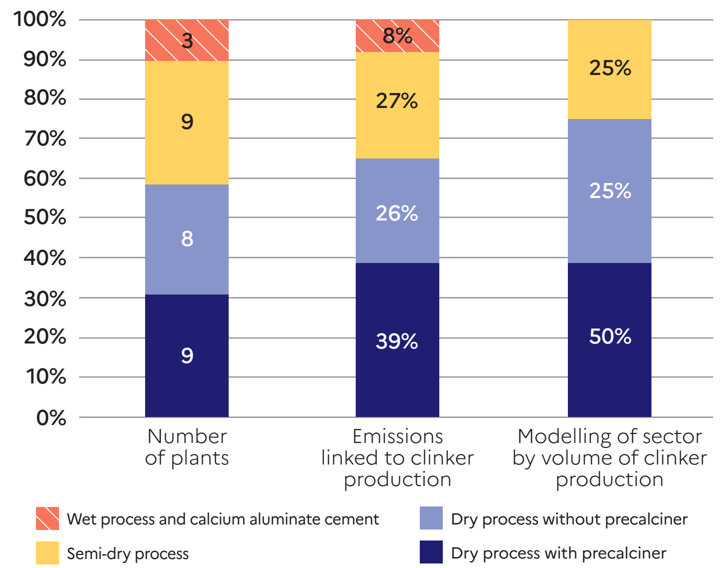
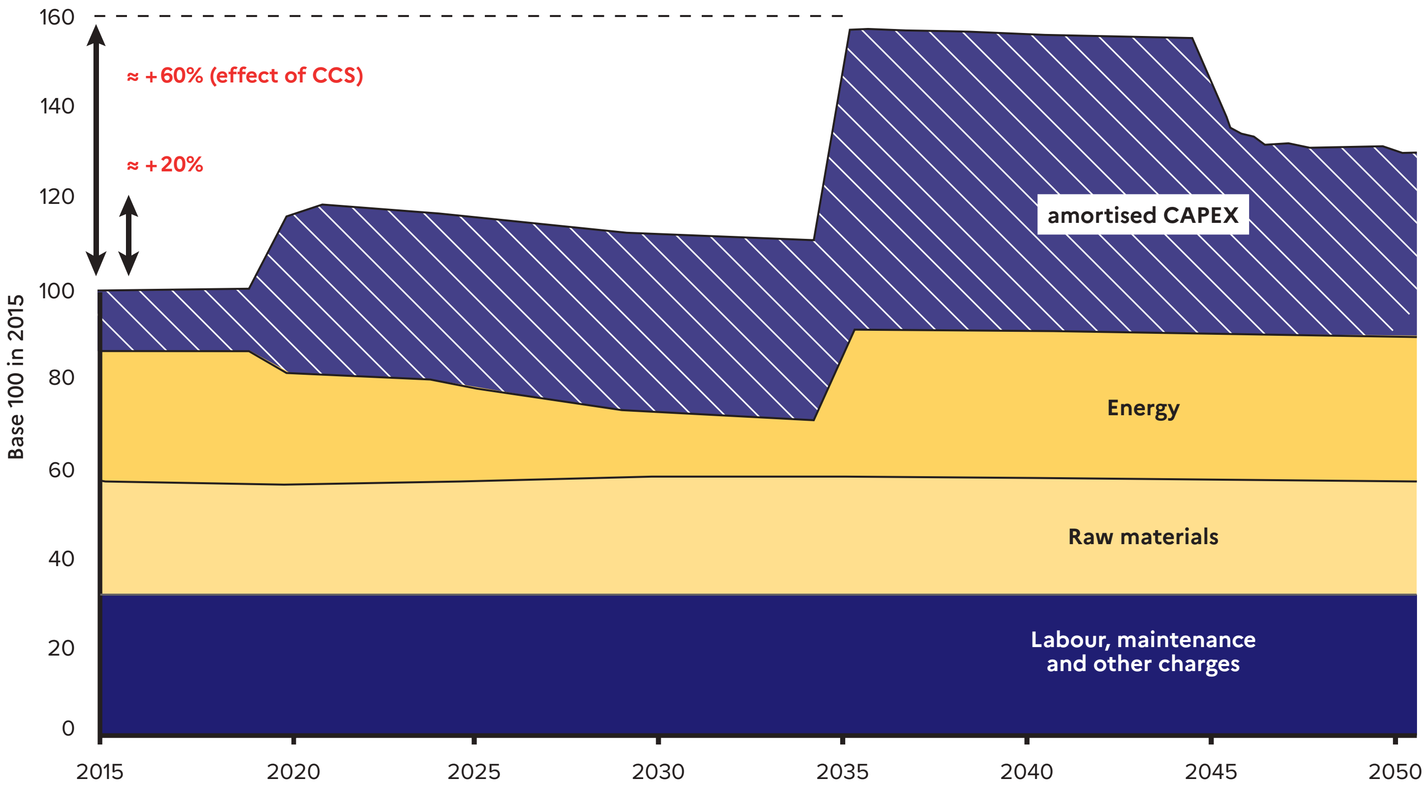


Table 2. Main results obtained for each reference plant.

	Reference plant	% decarbonisation between 2015 and 2050	Total investment/plant	% increase in production cost
Without CCS	Dry process with precalciner	-25%	≈ €45m	≈ -10%
	Dry process without precalciner	-33%	≈ €205m	≈ +15%
	Semi-dry process	-28%	≈ €200m	≈ +20%
With CCS	Dry process with precalciner	-95%	≈ €245m	≈ +45%
	Dry process without precalciner	-95%	≈ €405m	≈ +55%
	Semi-dry process	-95%	≈ €400m	≈ +65%

Figure 10. Example of the change in production cost in a route with CCS for a plant using the semi-dry process.



It turns out that **application of the technological route to a plant using the "dry process with precalciner" and without CCS technology** would reduce the production cost of a tonne of cement (shown without the carbon cost which is assumed to be constant for the moment) by about 10% (Table 2). This decrease is **mainly due to the reduced energy cost** which itself is directly linked to (1) the increasing use of substitute fuel, considered as being less expensive and (2) the decrease in clinker production (which also, however, results in a slight increase in raw material costs). Thus, it appears that the transition as modelled by this technological route can be an economic opportunity for plants already using the dry process with precalciner. **However, the situation is significantly different for plants using the "dry process without precalciner" or "semi-dry process":** the *upgrading* operation they undergo in the first place has the effect of sharply increasing the cost of production by around 20% through the "Amortised CAPEX" item (this is the "step-up" effect that can be seen in 2020). Once the investment has been amortised, assumed in the model to be after 25 years (i.e. in 2045), the cost of production goes back to the level of the plant using the dry process with precalciner.

On the other hand, the application of the technological route including CCS, again under a BAU demand scenario, **increases the cost of production of a tonne of cement by 40 to 60% depending on the type of plant**, because of the added investment in capture and purification for the CCS technology (CAPEX) and the associated operating expenses, in particular additional energy consumption linked to the energy penalty of the capture technology (Figure 10). In the case of the "dry process without precalciner" and "semi-dry process" plants, this technological route with CCS illustrates a major issue concerning the funding: the earlier the *upgrading* operation is completed and the faster it is amortised, the less the cumulative cost at the time of the CCS implementation in 2035 will have to be borne by the production cost over a long time.

The sooner the plants that remain to be renovated are identified as strategic for the future, because potentially eligible for CCS, and the earlier the decision on *upgrading* is made, the more economically feasible the transition will be for the sector at the time of CCS implementation.

[12] Best Available Techniques (BATs) identified in the European BREF documents: https://aida.ineris.fr/sites/default/files/directive_ied/CLM_BREF_042013.pdf
[13] Estimate based on INSEE data: https://www.insee.fr/fr/statistiques/4226063?sommaire=4226092
[14] The methodological aspects associated with the reference plants are detailed in the appendices.

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Abbreviations and acronyms

ADEME - French Agency for ecological transition
IEA - International Energy Agency
BAU - Business As Usual
BTP - Construction and public works
CAPEX - Capital expenditure
CCS - Carbon capture and storage
CSR - Solid recovered fuel
CIW - Common Industrial Waste
ECRA - European Cement Research Academy
BATs - Best Available Techniques
PTS - Sectoral Transition Plan
SNBC - Stratégie Nationale Bas Carbone (French national low-carbon strategy)
VRD - Voirie et Réseaux Divers (Roads and other networks)

ADEME IN BRIEF

At ADEME - the Agency for Ecological Transition - we are firmly committed to combating climate change and degradation of resources.

On all fronts, we mobilise citizens, economic players, and regions, empowering them to move towards a resource-efficient, carbon-free, fairer, and more harmonious society.

In all areas - energy, air, circular economy, food, waste, soils, etc., we advise, facilitate and help finance many projects, from research through to solution-sharing.

At all levels, we put our expertise and prospective capabilities at the service of public policy.

ADEME is a public establishment under the joint oversight of the French Ministry for the Ecological Transition and the French Ministry of Higher Education, Research and Innovation.

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EXPERTISE

CEMENT

First technical-economic results

The cement industry faces major technological and economic challenges in order to achieve the decarbonisation targets set under the National low-carbon strategy (SNBC) - an 81% reduction in greenhouse gas emissions in 2050 compared with 2015 for French industry as a whole. The cement manufacturing process is energy intensive and produces greenhouse gas emissions that are difficult to cut. With the modelling carried out, and on the basis of the technologies identified, a 54% reduction in greenhouse gas emissions can be achieved at best. Other solutions must therefore emerge if the sector is to meet the 81% decarbonisation target set under the SNBC for industry, especially for the period 2030-2050. Decarbonisation will require massive investments in the production tool, innovation and regional infrastructure. To maintain a decarbonisation trajectory in line with the Paris agreements, regulations must accompany the changes in the production plants and provide a medium-term strategy to ensure the sustainability of longer-term investments and augment participation by financial institutions.

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