Research Centre on
ZERO EMISSION
NEIGHBOURHOODS
IN SMART CITIES

ZEN CASE STUDY

Strategies and business models to support the transition to low-carbon concrete

ZEN REPORT No. 23 – 2020

Raymond Andreas Stokke and Ann Kristin Kvellheim | NTNU and SINTEF

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Preface

Acknowledgements

This report has been written within the Research Centre on Zero Emission Neighbourhoods in Smart Cities (FME ZEN). The author gratefully acknowledge the support from the Research Council of Norway, the Norwegian University of Science and Technology (NTNU), SINTEF, the municipalities of Oslo, Bergen, Trondheim, Bodø, Bærum, Elverum and Steinkjer, Trøndelag county, Norwegian Directorate for Public Construction and Property Management, Norwegian Water Resources and Energy Directorate, Norwegian Building Authority, ByBo, Elverum Tomteselskap, TOBB, Snøhetta, Asplan Viak, Multiconsult, Sweco, Civitas, FutureBuilt, Hunton, Moelven, Norcem, Skanska, GK, Caverion, Nord-Trøndelag Elektrisitetsverk - Energi, Smart Grid Services Cluster, Statkraft Varme, Energy Norway, Norsk Fjernvarme and AFRY.

The Research Centre on Zero Emission Neighbourhoods (ZEN) in Smart Cities

The ZEN Research Centre develops solutions for future buildings and neighbourhoods with no greenhouse gas emissions and thereby contributes to a low carbon society.

Researchers, municipalities, industry and governmental organizations work together in the ZEN Research Centre in order to plan, develop and run neighbourhoods with zero greenhouse gas emissions. The ZEN Centre has nine pilot projects spread over all of Norway that encompass an area of more than 1 million m^2 and more than 30 000 inhabitants in total.

In order to achieve its high ambitions, the Centre will, together with its partners:

- Develop neighbourhood design and planning instruments while integrating science-based knowledge on greenhouse gas emissions;
- Create new business models, roles, and services that address the lack of flexibility towards markets and catalyze the development of innovations for a broader public use; This includes studies of political instruments and market design;
- Create cost effective and resource and energy efficient buildings by developing low carbon technologies and construction systems based on lifecycle design strategies;
- Develop technologies and solutions for the design and operation of energy flexible neighbourhoods;
- Develop a decision-support tool for optimizing local energy systems and their interaction with the larger system;
- Create and manage a series of neighbourhood-scale living labs, which will act as innovation hubs and a testing ground for the solutions developed in the ZEN Research Centre. The pilot projects are Furuset in Oslo, Fornebu in Bærum, Sluppen and Campus NTNU in Trondheim, an NRK-site in Steinkjer, Ydalir in Elverum, Campus Evenstad, NyBy Bodø, and Zero Village Bergen.

The ZEN Research Centre will last eight years (2017-2024), and the budget is approximately NOK 380 million, funded by the Research Council of Norway, the research partners NTNU and SINTEF, and the user partners from the private and public sector. The Norwegian University of Science and Technology (NTNU) is the host and leads the Centre together with SINTEF.

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Norwegian summary

Strategier og forretningsmodeller for å støtte overgangen til lavkarbonbetong

Denne rapporten evaluerer forretningsmodeller og markedstiltak for lavkarbonbetong med karbonfangst og lagring (CCS) i Norges største sementprodusent, Norcem. Rapporten er basert på en studie utført som en del av FME ZEN-forskningssenteret der Norcem er partner. Funn har blitt analysert og syntetisert ved bruk av en case studie metodikk, der de viktigste driverne og barrierene for implementering av CCS-teknologier i norsk sementkontekst blir diskutert.

Forskning viser at det er et stort potensial for CCS-kostnadsreduksjon på lang sikt på grunn av produksjonsfordeler og forbedret designintegrasjon. Denne typen kostnadsreduksjoner kan være oppnåelig for Norcem, spesielt med potensialet for andre- og tredje generasjons fangstteknologier. Hovedproblemet som Norcem står overfor knytter seg til byrdefordeling gjennom hele verdikjeden og høye investerings- og driftskostnader. Sammenlignet med fornybare teknologier er CCS heller ikke egnet til å bli installert på en fragmentert måte. For at CCS skal lykkes må det implementeres i full skala.

For tiden delfinansierer og subsidierer den norske regjeringen forskjellige fornybare energiteknologier, men med CCS er en høy finansiell investering en uunngåelig forutsetning. En annen forutsetning er en klar inntektsstrøm basert på en jevn og tilstrekkelig høy karbonpris i nær fremtid. Forutsatt at karbonutslippet øker kontinuerlig, inkludert i sementindustrien, er argumentet for CCS sterkt. Våre funn viser at lagring, sikkerhet og tekniske forhold kan løses av markedet, men de store investeringskostnadene i fangstanlegget vedvarer. Kostnadsbyrden mellom produsent og sluttbruker er også et dilemma. For å løse dette dilemmaet er ambisiøs miljøpolitikk for utslipp, kombinert med markedsdrevne løsninger, nødvendig. For å bane vei for lavkarbonsement i det norske markedet, anbefaler vi følgende virkemiddelpakke for myndigheter og industri:

1) Invester og implementer fullskala CCS ved Norcems Brevik-anlegg som pådriver for det bredere markedet.
2) Utvikle stabile, forutsigbare og langsiktige skattefradrag for fanget CO_2 / per tonn.
3) Utrede et 'grått' sertifikatmarked som en integreringsmekanisme for karbonkostnader.
4) Fokus på å akselerere grønne offentlige anskaffelser og innovasjonspartnerskap.

Våre funn indikerer at sentrale barrierer for lavkarbonsement er både økonomiske og markedsrelaterte. Tidlige pilot- og demonstrasjonsprosjekter viser at CCS er en levedyktig løsning i norsk sementindustri. Problematikken knyttet til pris og prisfastsettelse i hele verdikjeden må adresseres i mer detalj. Policy bør fremme de mest lovende grønne produktene og teknologiene. Beslutningen om å finansiere CCS-teknologier er ikke bare et økonomisk eller politisk spørsmål, men et spørsmål knyttet til miljø og samfunnsansvar. For et tungindustriselskap som Norcem er det i tillegg viktig å finne en konstruktiv tilnærming til byrdefordeling, kombinert med realistiske markedsdrevne løsninger.

English summary

Strategies and business models to support the transition to low-carbon concrete

This report evaluates business models and market measures for transitioning to low-carbon concrete with carbon capture and storage (CCS) in Norway's largest cement producer, Norcem. The findings of this report are based on a study conducted as part of the Research Centre on Zero Emission Neighbourhoods in Smart Cities (FME ZEN), of which Norcem is a partner. Findings are analyzed and synthesized using a case study methodology, and the most significant drivers and barriers for implementing CCS technologies in the Norwegian cement context are discussed.

Research shows that there is great potential for CCS to influence cost reduction in the long term because of economies of manufacturing scale and enhanced design integration. While high upfront costs are expected, operational cost reduction could be attainable for Norcem, especially given the potential for second- and third-generation capture technologies. One of the main problems that Norcem faces pertains to burden-sharing throughout the value chain, as well as high investment cost. Additionally, compared to renewable technologies, CCS is not suitable for fragmented installation; to be successful, it must be deployed full-scale throughout any given industrial site.

Presently, the Norwegian government subsidizes different renewable energy technologies domestically; however, with climate reduction technologies such as CCS, there is an inevitable prerequisite for high initial financial investment. Another prerequisite is a definite income stream based around a steady—and adequately high—carbon price in the near future. Assuming that carbon emissions are perpetually increasing, including in the cement industry, the argument for CCS is strong. Our findings show that storage, safety, and technical matters can be solved; however, the large initial investment costs persist. Burden-sharing between producer and end user is, therefore, a dilemma. To overcome this dilemma, ambitious environmental policies on emissions, coupled with market-driven solutions, are necessary. In creating a pathway for low-carbon cement in the Norwegian market, we recommend the following key measures for government and industry:

1) Invest in and implement full-scale CCS at Norcem's Brevik plant as a catalyst for the wider market.
2) Enact stable, predictable, and long-term tax deductions for captured CO_2 per ton.
3) Explore a 'grey' certificate market as a carbon cost integration mechanism.
4) Focus on accelerating green public procurement and innovation partnerships.

All these measures should be adopted in an interdependent manner. Our findings indicate that key barriers to low-carbon cement are both financial and market related. Early pilot and demonstration projects show that CCS is a viable solution in the Norwegian cement context. Nevertheless, for these to be enacted more broadly, barriers pertaining to cost and pricing throughout the value chain would need to be addressed more effectively. Pertinent policies should act as promoters for the cement industry to continue advancing the most promising green products and technologies. Moreover, the decision to finance CCS technologies poses not only a financial or political query, but also an environmental and social responsibility one. For a company such as Norcem, it is additionally imperative to identify a feasible approach to burden-sharing, coupled with realistic, market-driven solutions.

Contents

1. INTRODUCTION

1.1. The green shift in Norway

The climate of the planet is changing due to man-made greenhouse gas (GHG) emissions. To curb emissions, and thereby reduce the extent of climate change, policies and plans are being made and actions are being taken worldwide. Recently, it was announced that the Norwegian GHG emission reduction target will be strengthened from 40% to 50% by 2030 [1]. So far, however, previous targets have not been met, and the present decade will be critical in terms of actual implementation of policies and plans.

Carbon capture and storage (CCS) is considered an opportunity to facilitate a green shift in Norway, through which emissions are cut and business prospects are created simultaneously. To enable CCS, the Norwegian government is supporting the investigation into and development of two projects, one of which is Norcem's (a HeidelbergCement subsidiary) cement production plant in Brevik. If realized, this project will be the first cement production plant in the world with CCS capabilities. The degree of innovation is vast, and the emission reduction potential and business prospects likewise.[1]

1.2. Zero Emission Neighbourhoods in Smart Cities

Buildings in Europe are responsible for approximately 40% of the continent's total final energy requirements and 36% of its CO_2 emissions [2]. In Norway, which has a high production of hydropower, direct emissions from the building sector are considered low, at only 1.6% [3]. However, direct emissions are only related to the energy consumed in buildings, whereas indirect emissions—for example, from materials—are not included in this figure.

As buildings become increasingly energy efficient, the share of emissions generated by the materials in buildings becomes more significant. Indirect emissions (e.g., from materials) are assigned to the respective industries that produce them. However, buildings are large consumers and could substantially affect emissions from materials through the purchasing power of builders. Challenges in significantly reducing CO_2 emissions include not only energy efficiency and decarbonizing the power system, but also reducing the embodied emissions from materials [4]. These developments are part of an even larger transition towards a low-carbon society.

The Research Centre on Zero Emission Neighbourhoods in Smart Cities (FME ZEN) develops solutions for future buildings and neighbourhoods with no GHG emissions. The Centre has 32 user partners, including producers of building components and materials, such as Norcem.

1.3. The ZEN case: Strategies and business models towards low-carbon concrete

This report is the outcome of a ZEN case study on strategies and business models towards low-carbon concrete. Norcem took the initiative for this case study, and resources from ZEN's research partners and industry partners have been involved, as have those of external actors. The study is largely devoted to strategies and business models toward low-carbon concrete with CCS, thereby exploring various market measures and scenarios toward this outcome in the Norwegian marketplace. However, a brief discussion of other strategies and business models to lower the carbon footprint of concrete is included in one of the latter chapters. In addition, the system boundary has been drawn around the production plant, which

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[1] Note: All financial and market-related estimates are undertaken solely by the original authors of this report.

means that the main focus of the case study and the report is the process of capturing GHG emissions, producing low-carbon cement and market measures, and less on transport- and storage-related issues.

This ZEN case study began with a survey directed towards the ZEN partners. Further, in cooperation with the Norwegian Green Building Council and ZEN partners Norcem, FutureBuilt, and Statsbygg, ZEN arranged a focus group workshop to which members of the Green Building Council and ZEN partners were invited. The main target was to discuss how to reduce the carbon footprint of concrete and to introduce the CCS project and its potential and challenges. The workshop was attended by 44 participants from throughout the value chain: public authorities, builders, and building owners.

2. BACKGROUND

2.1. Low-carbon concrete in the building and construction industry

Dealing with climate change does not only involve measures such as drastically reducing GHG from the energy supply sector. The obligation to reduce carbon emissions also falls on various carbon-intensive industrial processes, such as the production of cement. Norcem is the sole producer of cement in Norway and plays a vital role in the building and construction industry [5]. Research into cement production shows that the costs associated with steep reductions in carbon emissions from the sector will not significantly affect the production costs of new buildings [6], [7]. Production costs for a residential building only increased by 1% when using low-carbon cement with CCS, with larger construction sites and civil engineering works increasing by 7% to 8%. However, for a large cement producer such as Norcem, it is estimated that operational costs will increase between 25% to 50% with CCS implementation [8]. Therefore, there is a need for more even burden-sharing throughout the value chain.

Cement is the most important component of concrete, a substance used virtually all around the globe in construction and civil engineering projects. In this respect, cement and cement production are linked closely to the global economy. Cement production is emission intensive, with carbon released not only from fuel use but from the production process [9]. These emissions are known as process emissions and comprise 60% of the sector’s climate impact. Today, production of one ton of cement emits nearly one ton of carbon [10]. Methods to mitigate carbon emissions from cement production include the use of less carbon-intensive fuels (e.g., biomass, waste), which would reduce overall cement emissions by 18% to 24% [11]. However, for traditional cement production, carbon emissions can only be substantially reduced with CCS.

To limit the effects of climate change, carbon emissions must be reduced in emissions-heavy industries such as the cement industry. Producing cement with a very low climate impact will require additional manufacturing processes; consequently, the production costs are likely to increase. Research estimates that in the future, low-carbon cement production with CCS will be more 50% more expensive than today’s climate-intensive cement [12]. Nevertheless, given that cement and concrete tend to represent only a small fraction of the total production costs of buildings and other civil engineering projects, the final increases for the end users could be small. Assuming a doubling of the cement cost, an average residential building using low-carbon concrete with CCS would add approximately 1% to the final cost. Still, the increased financial burden for producers and suppliers is a perpetual problem.

Zero-emission buildings and neighbourhoods include low-carbon materials and are an important part of a future low-carbon society. With new strategies and business models, Norcem and other cement producers can begin building with construction inputs that have zero GHG emissions over the life cycle of the material.

2.2. Current status and challenges

CCS technology provides a significant opportunity to attain steep CO_2 emission decreases in vital manufacturing processes such as cement production. CCS facilitates novel clean energy paths, while providing the groundwork for other carbon dioxide removal methods. That said, many deployments of CCS are not novel or experimental, and international knowledge of heavy industry–scale CCS plants is increasing. The capture and parting of carbon has been functional in some industries for several decades and is already an essential part of some industrial processes [13].

Around 60% of functional CCS plants are located in North America, with the majority profiting from an income stream for the captured carbon [14]. For some nascent projects, the income from carbon storage has been adequate for profitable CCS operation, whereas more recently, income combined with financial grants have facilitate the closing of the commercial gap and aid funding. Investment opportunities are anticipated to remain a key factor for nascent CCS acceleration and implementation, with increasing international attention, including in Scandinavia. If Norcem implement CCS at their Breivik plant (see Figure 1), they will be the first cement producer in the world to integrate the technology.

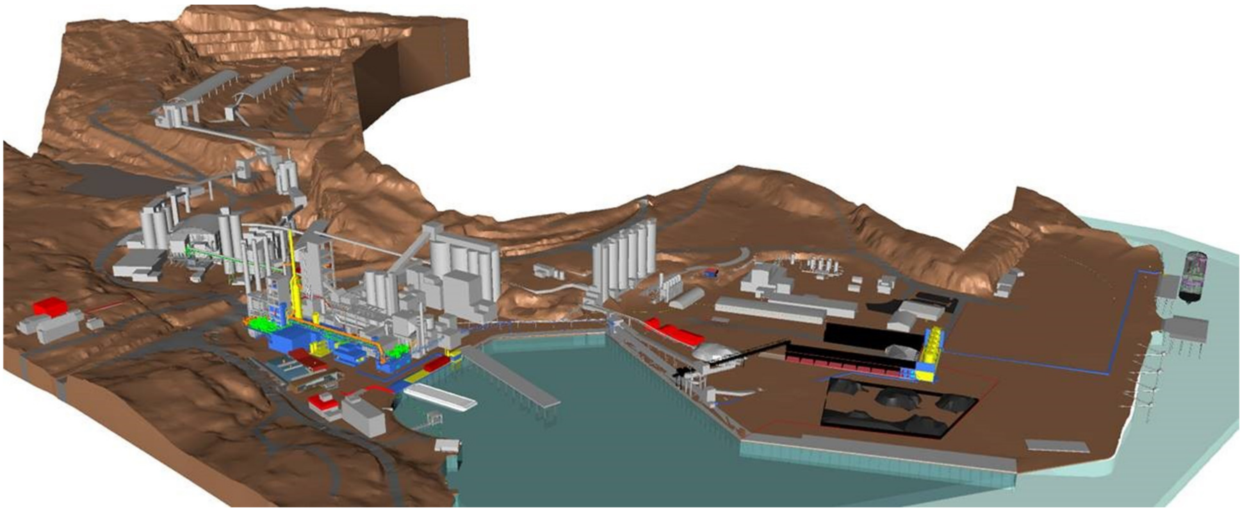


Figure 1. Location of CCS in the Brevik plant (in front of the cement processing facilities) [15].

The commercial argument for investment in CCS services is restricted in the absence of a robust environmental response and targeted policy provisions. In recent years, policy support for CCS has varied, and the amount of public subsidies allocated to comprehensive CCS plants since 2010 is less than 3% of the yearly grants assigned to renewable energy technologies [16]. This inadequate funding has affected CCS ventures and contributed to the termination of numerous planned deployments, with a decline in the development pipeline in the last fifteen years. Nevertheless, there are encouraging signs that the policy and investment environment for CCS technologies is improving [17], [18]. The introduction of tax credits in the United States is expected to trigger significant new CCS investments, and many countries, including Norway, Saudi Arabia, and the United Kingdom, are also pursuing CCS deployment at scale. Such a level of deployment would require a substantial and rapid scale-up of CCS from today's levels, with eighteen projects currently capturing around 33 million tons of carbon each year [19].

There are several critical components to the CCS opportunity. Although there is significant assurance that international storage properties are well in surplus of future needs, even in extremely ambitious circumstances, failure to advance these storage properties in an appropriate way might decelerate CCS deployment. Moreover, there are several overarching issues pertaining to CCS technology development [12], [20], [21]:

- The absence of financial investment in CCS surveying and valuation. Assurance of the accessibility of satisfactory and safe technologies will be a precondition for CCS funding.
- Inadequate commercial justification for carbon infrastructure investment. Developing carbon transport and storage substructures with the singular objective of eliminating carbon emissions is a fairly novel business proposal and is only feasible within the framework of robust environmental policy. This type of financial investment carries added intricacy owing to the characteristics of the substructure that involve engineering risks, long-standing accountability considerations, and the requirement to align carbon supply with storage expansion. Public, private and innovation partnerships have been projected to progress CCS and shape transport capabilities in the initial distribution stages.
- Public acceptance. Societal acceptance might limit the accessibility of CCS properties, mainly for onshore locations. In Norway, public acceptance is deemed high; however, CCS projects in some European countries have been discontinued, partially because of local disapproval.
- Capture facilities and carbon transport infrastructure. The CCS assessment process must identify geotechnical uncertainties related to containment, injectivity and capacity, in addition to considering economic, social, and market factors. Experience has demonstrated that this process can take anywhere from 1 to 15 years, depending on innovation.

In the European Union (EU), prices are projected to be €40 per ton of carbon avoided for a 1 Mt-a-year cement plant. The use of alternative solvents and the incorporation of an external power plant could halve this price. Further, the price of CCS at a cement plant is projected to be comparable to the price at a typical coal-fired power plant. Additionally, the amount of oxygen required per ton of carbon captured is approximately three times lower at a cement plant; however, the economies of scale are less advantageous.

2.3. Cement industry

Cement production has few substitutes to CCS when reducing its emissions [12]. Over 60% of emissions from cement production are process emissions, and the absence of viable alternatives to CCS means that the cement industry could absorb a substantial part of the currently available carbon storage capacity. However, presently, the use of CCS in this sector allows for only a fraction (approximately 0.8 Gt carbon) of total emissions to be stored with today's capacity [22].

Cement manufacture consumes 11 exajoules (EJ) (3055.56 TWh) of final energy and releases 2.2 Gt of carbon direct global emissions annually, representing a major industrial carbon source [23], [24]. Cement production involves the disintegration of limestone when creating clinker, representing approximately 60% of the carbon emissions created in the whole procedure, with the rest stemming from the combustion of fuels. Globally, the majority of the thermal energy castoff from produced cement is created from fossil fuels, with coal accounting for over 50% of this. In a Norwegian context, Norcem has emissions and energy levels as presented in Figure 2.

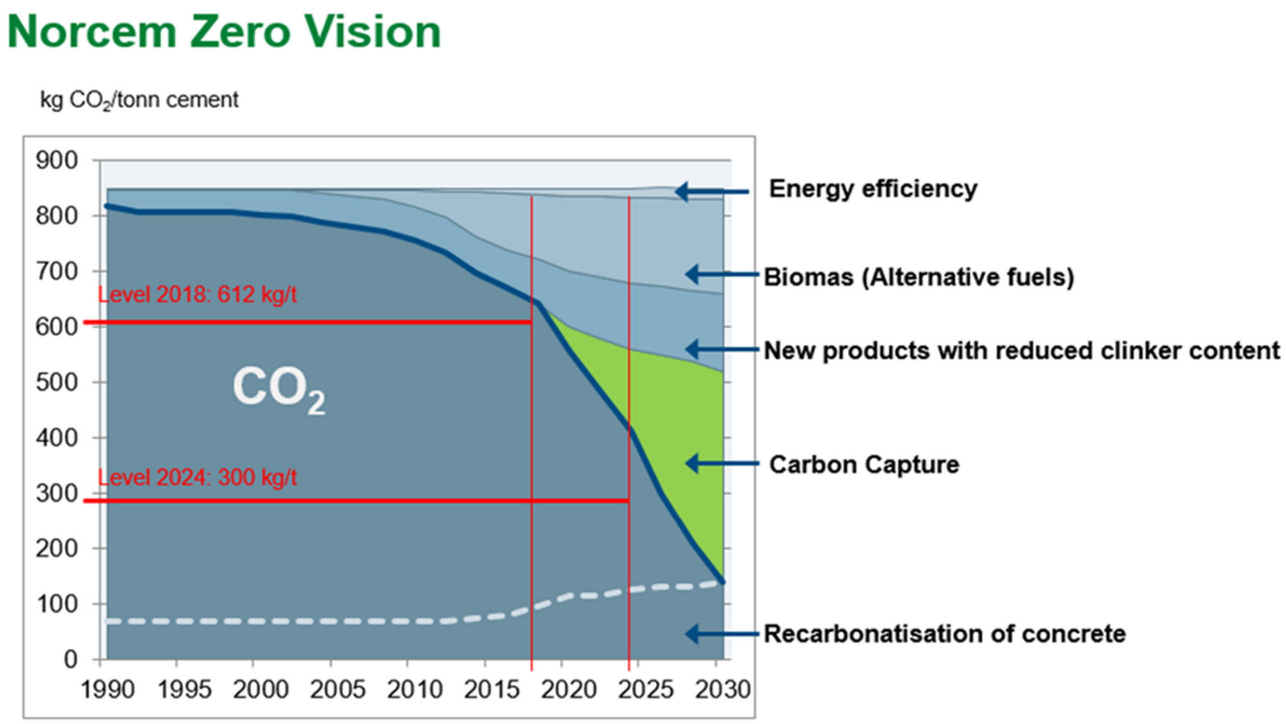


Figure 2. Norcem Zero Vision graph [25].

In 2025, if Norcem implements full-scale CCS at the Brevik plant, 1.3 Mt of CCS cement will be available, with potential expansion to 2.5 Mt if the Slite plant in Sweden is included. As such, the production and emissions in Norway are relatively low in a global context; nevertheless, they are at a stable level over time given Norcem's position in the market.

The key carbon mitigation devices supporting sustainable change in the cement industry are cultivating both energy and material efficacy, converting to alternate fuels (biomass and/or waste), and installing green technologies and products [26]. These measures could render a collective saving of approximately 6.5 Gt of carbon by 2060. The decrease in clinker-to-cement ratio and the incorporation of carbon capture in cement manufacturing are other focal strategies. These would modify energy and process carbon emissions by 30% and 20% of the total reductions, respectively. A total of 5 Gt carbon could realistically be captured and stored internationally by 2060, and in that year the level of stored carbon from cement production would be 20% of the overall emissions created by the industry [10], [12], [27], [28].

If CCS fails, fast-tracking the decrease in the clinker-to-cement ratio and implementing substitute binding materials could become the imperative. It is unlikely, however, that direct carbon emissions could be decoupled from cement production without CCS [29], [30]. Mixed cements with low clinker-to-cement ratios create less carbon emissions when mass-produced, but characteristically depend on industrial derivatives such as pulverized granulated blast incinerator slag and fly ash, which are not readily available. This effect could be more notable in a scenario of limited CCS, since the move from coal-based power could be fast-tracked and there could be a growing burden to reduce primary production. Cement created with widely obtainable raw materials such as ground limestone and calcined clay, utilizing limestone as caulking, can contribute to lowering the clinker-to-cement proportion, aiding the ratio to fall, on average, to 30% by 2040 and 60% by 2060 internationally, notwithstanding the gradually restricted availability of traditional clinker replacements [7].

2.4. Holistic planning and zero emission buildings: From manufacturer to customer

The construction industry is a dynamic and valuable part of any country; however, it has a substantial effect on the environment. Construction sites are one of the main users of energy and material resources, and, as such, are significant polluters. To address these effects, there is increasing agreement between governments regarding eco-friendly performance objectives, stipulating that proper measures are necessary to make building and construction methods more environmentally friendly. A green building methodology has the potential to strongly influence sustainable development. Zero emission buildings are a wide-ranging and intricate concept, but have grown to be one of the foremost topics in the construction sector. The concept of zero emission buildings aims to improve quality of life, consequently permitting people to live in a green environment with sustained social and economic circumstances. A zero emission building project is built, operated, and re-used in an environmentally friendly and supply-efficient way. Therefore, it must meet a variety of goals: energy effectiveness, low carbon emissions, improved indoor air quality, and synchronization with the local environment. A model building should have low building costs, with low maintenance and longevity [6].

The construction industry has started to pay attention to amending the environmental harm caused by their activities. Practitioners involved with the construction process have an opportunity to diminish the environmental impression through the application of low-emission goals in the planning stage of a construction project [31]. Current environmental objectives emphasize strategic international goals, with little micro-level cohesiveness in the decision-making. However, we argue that micro level green solutions must be rendered into real practical win-win solutions, utilizing a integrative methodology to enable decision-making.

Ecolabels like the Building Research Establishment Environmental Assessment Method (BREEAM) and Leadership in Energy and Environmental Design (LEED) are constantly developing and restructuring to match contemporary practices for producing green measures. The shared aim is that constructions be designed to decrease the total effect of building sites on the natural environment. It is projected that in the next four decades, international commerce will reach five times today’s levels, the worldwide population will grow 50%, energy consumption will triple, and industrial activity will increase threefold [17], [32].

Low-emission construction methods are considered an approach through which the construction sector can move toward realizing green development, also accounting for commercial matters [18]. It is also a method to represent the sector’s accountability for protecting the environment. Low-emission construction denotes several approaches in the progression of executing projects that comprise lower levels of damage to the environment—for example, deterrence of surplus waste production, and increased recycling of waste in the manufacturing of building material while being lucrative to the respective business. Low-emission construction begins with the planning phase of a building or neighbourhood and lasts for the entire life cycle, up to the recycling of its resources.

3. CHALLENGES AND POSSIBILITIES

3.1. Strategies and policies

Recognizing the contribution of CCS to reducing emissions across industrial sectors highlights the importance of supporting the accelerated proliferation of CCS technology and substructures [33]. Such support comprises targeted strategies to incentivize (public and private) economic funding, the identification and expansion of lower priced deployment prospects, and reinforced innovation partnerships in fields such as green public procurement. The case study also emphasizes the necessity of a sustained focus on ongoing technology innovation with regard to CCS.

A list of priority measures for supporting CCS deployment in the Norwegian cement industry include [12], [34], [35], [36]:

- Green and innovative public procurement can create business opportunities and support the path to lowering emissions in the cement industry. Green procurement can be specifically targeted at creating markets and diffusing new products, such as low-carbon concrete. Public procurement of low-emission products also has the effect of aggregating demand and thus enhancing economies of scale. In theory, the Norwegian government can earmark funds for low-carbon concrete, thereby creating business revenue.
- Tax deductions can incentivize deployment and large-scale implementation of CCS through provision of a tax credit for dedicated carbon storage. This type of tax measure can also lead to the development of new projects and could generate a large flow of (public and private) carbon capture investment.
- Green banking loans have received increasing interest and can provide a host of green business opportunities. In Norway, eligibility for green loans is usually tied to compliance with technical eligibility criteria (i.e., TEK10). These eligibility standards can be accompanied by typologies listing technologies or products, such as low-carbon concrete, that, in turn, can be considered environmentally friendly without further in-depth assessment.
- Financing the surveyance and evaluation of the whole CCS value chain can help meet the requirements for assurance of safe, protected, and suitable technology for investment in the transport of carbon and carbon capture plants. Despite the fact that international CCS properties are considered superfluous for future needs, substantial evaluation is essential for translating hypothetical carbon storage into real-life commercial storage, wherein volume, injectivity, and monitoring are comprehended.
- Establishing a transparent market and regulatory framework for low-carbon concrete with CCS is also an important measure. Steady and clear market schemes and frameworks that incorporate the main elements, together with lasting monitoring systems and accountability in the marketplace, are essential for ensuring the economic viability of low-carbon concrete with CCS. A ‘grey’ certificate market (see in Sections 3.4 and 3.5), based on the green electricity certificate scheme, could be implemented to facilitate commercial viability.
- Public–private partnerships could have an important role in the planning and development of green networks, including to support appropriate risk-sharing arrangements, facilitated by innovation intermediaries such as FME ZEN.
- Finally, forecasting and investment for large-scale CCS infrastructure should be enabled. The extensive distribution of CCS at scale is based on significant investment in both carbon transport and storage systems that can facilitate numerous plants across geographical locations and the innovation value chain. The expansion of CCS centers or hotspots can

lower unit prices through economies of scale, while simultaneously lowering financial risk by dividing the main elements of the value chain and the technological innovation system, which comprises the pillars of capture, transport, and storage.

Moreover, understanding the green value chain in this sector is imperative. This is especially important with regards to transportation and collaboration with other actors in the CCS value chain (see Figure 3). Globally, pipelines are the most common way of moving large bulks of carbon involved in CCS. Presently, infrastructure exists comprising millions of kilometers of pipelines around the world that transport several gases, including carbon. In Norcem's case, transport by truck and ship is already established. However, if CCS deployment were to be scaled up throughout Norway and Northern Europe, and given the large quantities of carbon that must be captured via CCS in the long term, it is unlikely that truck and ship transport will be adequate across all locations and industries.

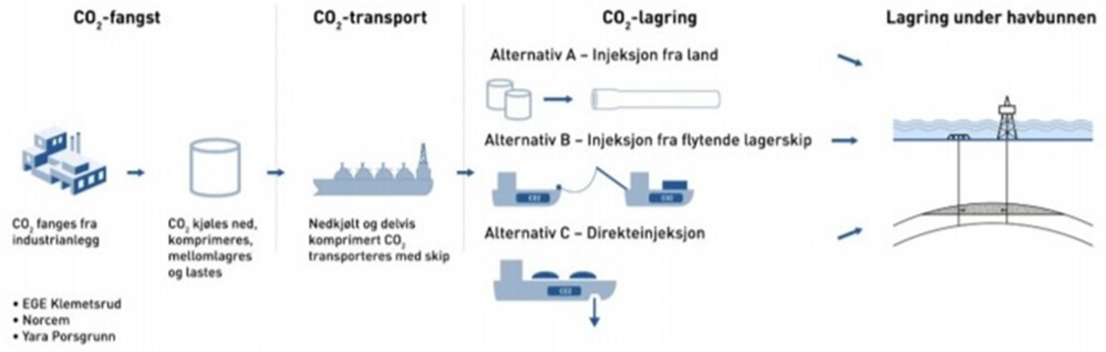


Figure 3. Schematic view of the CCS value chain [15].

Beyond 2050, sustained restrictions on the accessibility of CCS might significantly limit the readiness of many carbon emission technology options [37]. Both private and public funding for green technology innovation ought to be accessible through all phases of the technology development cycle, together with nascent research for disruptive technology, all the way to commercialization [38]. Technology supply strategies can additionally incentivize the best available technologies and accelerate the elimination of less effective developments.

This report advocates an improved integration of policy measures and technology. In addition to requiring greater mitigation efforts and behavioral changes in the building and transport sectors, strong and reliable policies are essential across the value chain to recognize and reply to these interdependencies to sustain effectual and appropriate funding. Policies must also address carbon transport and storage, which is required to service plants across various industries. Innovation system analysis is required that includes end users, combined with market measures that focus on burden-sharing throughout the value chain and support the effective facilitation of resources. Moreover, a carbon price, such as in the Emissions Trading System (ETS), can be an effective measure for broad (in scope and scale) emissions decreases and to encourage policy-making with long-term environmental objectives. In the present system, however, the carbon price increases too slowly compared to the costs of measures such as CCS.

3.2. Alternative scenarios for CCS deployment in the cement industry

This study purposes to explore the financial and technological inferences for Norcem associated with CCS implementation. It accomplishes this by both constraining and expanding the accessibility of CCS. While carbon storing properties are anticipated to be superfluous of those needed internationally, and given very ambitious environmental scenarios, lack of resources for evolving these carbon storage properties might in turn become a hinder for CCS deployment [34], [39].

This case study builds upon and expands past research that has emphasized the role of climate reduction technologies in realizing numerous global goals, including the proliferation of profitable mitigation opportunities [13], [40]. Key factors to the examination is the utilization of scenarios to evaluate the consequences of dissimilar pathways in the advancement of CCS up to 2035. In a central global climate mitigation scenario, cumulative emissions of more than 115 Gt of carbon dioxide are captured for permanent storage (107 Gt carbon) or use (7.8 Gt carbon) across the power generation, industrial, and fuel transformation sectors in the period until 2050 [20], [34].

It is not easy to forecast how sequential stages of technology innovation will work to increase the available CO_2 storage resources; however, the moderately mature storage resource evaluation of the Utsira formation offshore Norway [22] can be used as a factor of this potential. Here, structural trapping of free-phase CO_2 affords approximately 0.8 Gt of storage, while injection up to the natural pressure parameters might allow up to 8.3 Gt of storage. Evaluations of the potential Utsira storage resource when arranging active high-pressure management yielded estimates of between 42 and 50 Gt of storage. Our estimates are conservative compared to this.

Below, different scenarios are adapted for CCS in a Norwegian context (from 2020 to 2035), drawing on empirical literature, industry reports, and the insights gained from the ZEN–Norcem case study [41], [42]. Previous research has strived to create pathways in terms of expanding the quantity of CCS plants [43]. We adopt a similar approach, using the same uncertainty indicators, with different scenarios being analyzed on the basis of Gt of storage. For each uncertainty and assessment indicator, the scenarios are evaluated at five-year time frames to assess the differences between them. These differences are acknowledged as dissimilar pathways between scenarios. Four scenarios aimed at 2035 are presented, which differ widely in the levels of CCS deployed. Overall, these scenarios represent circumstances with a) optimal levels of CCS implementation in a Norwegian industrial context, b) moderate investment and sufficiently developed CCS technology innovation, and c) no government investment or CCS deployment or innovation.

The scenarios are developed to show the importance of investment and policy support in either early or late selection of CCS technologies. These scenarios purposely do not include discussions about specific plant capture techniques:

- CCS Scenario 1: Optimal—A largely effective scenario, with a reasonably high level of CCS deployment. By 2035, CCS has a recognized position as a commercially and technically feasible choice and is inexpensive compared to other technologies and measures.
- CCS Scenario 2: Middle-path—The CCS pilot project is implemented, and it receives additional deployment in various industries up to 2030. In this scenario, CCS is commercially feasible; however, from 2030, it is not commonly an ideal choice for the heavy industries in Norway, due to slow incremental technological innovation.
- CCS Scenario 3: No traction—The CCS pilot project is implemented, with narrow further deployment in other industries up to 2035. While technologically feasible, it has not received the policy support and investment needed for economies of scale in Norway. It is partially commercialized in a few locations.
- CCS Scenario 4: Failure—No CCS proliferation beyond the pilot project.

In the graph in Figure 4, Scenario 1 represents a widely encompassing policy effort with high initial investment in CCS, as opposed to the inadequate and fractional approach of Scenario 4. Scenario 2 branches off in 2030 due to a lack of radical CCS technology innovation, despite receiving policy support and initial investment. This scenario could see the rise of a major technical problem, coupled with the wrong technology being implemented. In Scenario 3, the lack of high-level investment coupled with restrained policy support produces an only moderately effective deployment, which could still lead to partial commercialization in a handful of industries by 2035. This scenario shows that technological path dependency is a real threat for CCS deployment, and that strong initial investment and policy mechanisms are needed long-term for overall success. Scenario 4 illustrates that a lack of investment in initial deployment coupled with immature choices of technology alternatives can have severe repercussions for CCS development as a whole.

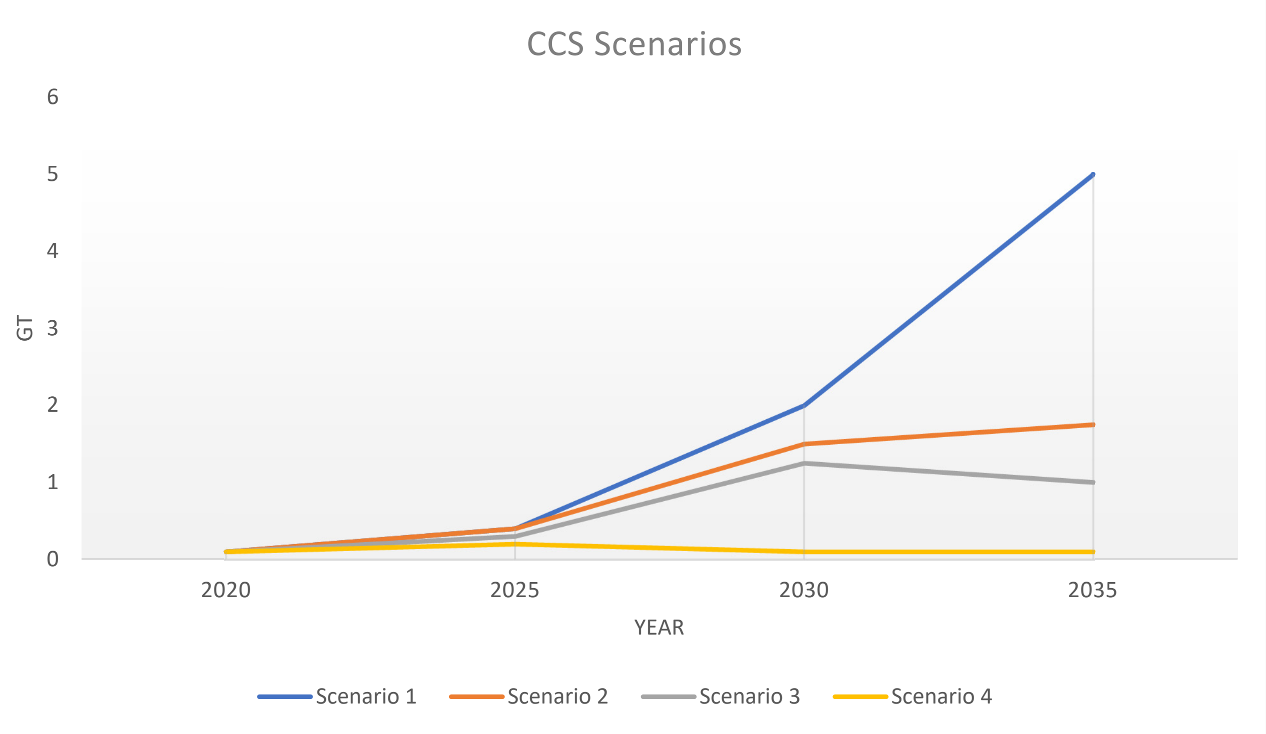
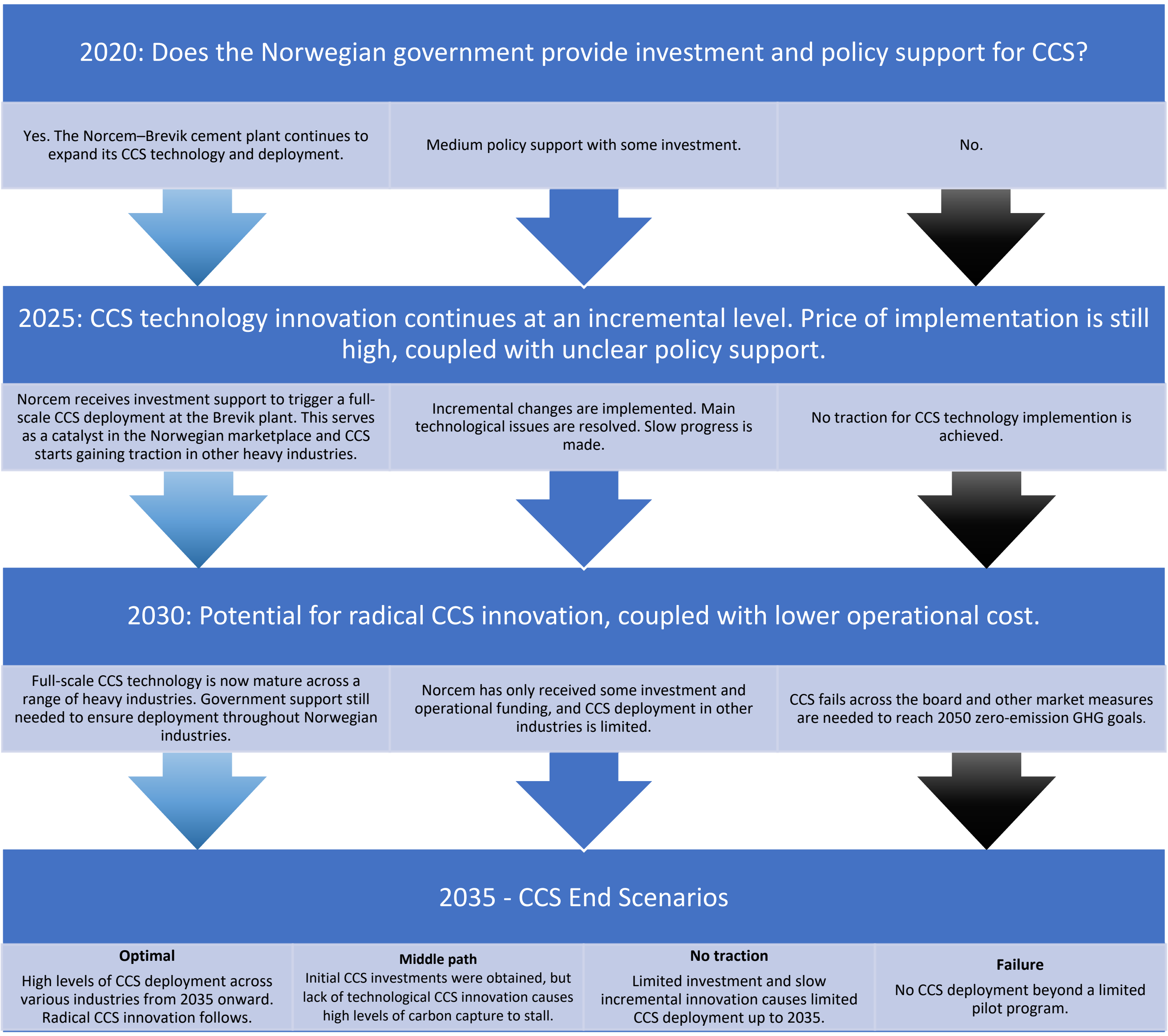


Figure 4. Various CCS scenario pathways in a Norwegian context.

Figure 5 is based on the same scenarios from a policy perspective.



2020: Does the Norwegian government provide investment and policy support for CCS?

Yes. The Norcem–Brevik cement plant continues to expand its CCS technology and deployment.

Medium policy support with some investment.

No.

2025: CCS technology innovation continues at an incremental level. Price of implementation is still high, coupled with unclear policy support.

Norcem receives investment support to trigger a full-scale CCS deployment at the Brevik plant. This serves as a catalyst in the Norwegian marketplace and CCS starts gaining traction in other heavy industries.

Incremental changes are implemented. Main technological issues are resolved. Slow progress is made.

No traction for CCS technology implemention is achieved.

2030: Potential for radical CCS innovation, coupled with lower operational cost.

Full-scale CCS technology is now mature across a range of heavy industries. Government support still needed to ensure deployment throughout Norwegian industries.

Norcem has only received some investment and operational funding, and CCS deployment in other industries is limited.

CCS fails across the board and other market measures are needed to reach 2050 zero-emission GHG goals.

2035 - CCS End Scenarios

Optimal
High levels of CCS deployment across various industries from 2035 onward. Radical CCS innovation follows.

Middle path
Initial CCS investments were obtained, but lack of technological CCS innovation causes high levels of carbon capture to stall.

No traction
Limited investment and slow incremental innovation causes limited CCS deployment up to 2035.

Failure
No CCS deployment beyond a limited pilot program.

Figure 5. CCS Scenario pathways. Left in this figure is the "optimal" scenario wherein CCS develops the strongest traction coupled with uncertainties improving.

Further, if CCS fails to be deployed at scale, there will be an increased reliance on alternative technologies that are currently at earlier stages of technology readiness or commercialization. Enlarging the portfolio of innovation streams and establishing partnerships within the innovation ecosystem for these technologies could maximize the technology options available to support steep emissions reductions in the future and reduce the associated costs and technology risks. In Norcem's case, these potential CCS scenarios should be analyzed, and potentially leveraged, with other market and regulation factors (see Appendices A, B, and C) [7], [26], [43], [44]. Table 1 presents an analysis of the different deployment scenarios.

Table 1. Different CCS deployment scenarios assessed in relation to various market measures.

Scenarios	CCS	Norcem	Market/Regulation	Uncertainty indicators
Scenario 1	Optimal—This is a broadly successful pathway with a plausibly high level of CCS deployment.	A full-scale CCS plant is built in Brevik by 2025. By 2035, CCS has an established position as a technically proven and financially viable option for Norcem, and competitors have followed. Norcem bears little of the financial burden.	In 2025, the government of Norway has invested in full-scale CCS technology at Norcem's Brevik plant. Shortly after 2025, environmental labels include requirements for low-carbon concrete with CCS and technical building code guidelines follow. Green procurement refers to these guidelines and/or environmental labels, which ensures technology-neutral, functionality-based procurement. Simultaneously, tax deductions per ton of stored CO_2 and a 'grey' certification scheme are implemented.	In the first years, integration, transport, and storing issues arise pertaining to plants in Northern Norway. Uncertainty also exists regarding technology development and sunk costs, particularly in terms of storage. Carbon leakage is avoided through safeguarding the CCS value chain (e.g., transportation, storage facilities). This scenario depends on a well-functioning system of transport and storage of CO_2. A strategy to maintain high public acceptance in Norway should be followed.
Scenario 2	Middle-path—Commercial-scale demonstration of CCS goes ahead and is followed quickly by further deployment up to 2030.	By this time, CCS has established itself as technically viable, but from 2030 onwards, it is not generally a preferred option as part of the low-carbon generation mix in the Norwegian marketplace. Financial viability is marginal. Norcem bears some of the financial burden. The financial burden is shared and end users are paying more for low-carbon concrete with CCS.	Government incentives include faster case management and cheaper properties. Regarding tax benefits of using low-emission concrete, the questions arise: where should the burden lie—with the home buyer or the contractor? There must be uncompromising climate requirements to avoid the distortion of competition from those who have made costly investments. It must also be made clear that there is a separate "environmental tax" on the products to highlight the "environment" costs. An Enova program will be implemented with support for end users and/or manufacturers. Incentive schemes should be based on the amount of CO_2 per krone, with benchmarking/stepwise rewarding extra-large measures. Market share of technology variants. Extent of lock-in or the dominance of a particular technology variant. 'Grey' certificates will be introduced.	CCS development is strongly influenced by uncertainties about the extent of political support, as well as the choice and design of policies and regulations. There is uncertainty about whether and how fast CCS technologies can be scaled up and developed to maturity. Cumulative investment and installed capacity. The diversity of technological options represents an uncertainty because early selection might accelerate development, but risks locking in weak technologies. The private sector has greater flexibility in allocating funds (even with the reliance on green loans) than the public sector, which depends on the client's willingness to pay to obtain budget approval.
Scenario 3	No traction—Commercial-scale demonstration of CCS goes ahead, followed by limited further deployment up to 2035. There is relative importance of variants for technology developers.	CCS has established itself as technically viable for Norcem, but it is not generally a preferred option as part of the low-carbon generation mix in Norway. Financial viability remains marginal, with deployment in particular market niches only. Norcem bears most of the financial burden.	Environmental certification must require low-emission materials. This is not the case today for either the Svane or the BREEAM. BREEAM makes demands in 2021. The following are identified functional units: 1) emissions per square meter of building and 2) absolute carbon budgets for buildings under development. There are strict requirements for low carbon if buildings are built with concrete. Though a low grade is a requirement, this is difficult to achieve in some geographies. If it results in a significant increase in risk or cost, it falls away. Green loans must be linked to schemes where low carbon is a minimum requirement; therefore, the minimum requirements	Regarding economic and financial viability, the future cost and financial risk of implementing CCS are very uncertain. The economic and financial uncertainty is heavily dependent on policy. Real additional costs for "low-carbon concrete" are low (less than NOK100), and the market must be informed of this. This is equivalent to 0.1 per million in a normal housing project. Market niches are relatively important. Costs, including assessment of quality of cost data. In terms of construction vs infrastructure, large road projects are usually publicly initiated; the requirements and willingness to pay (ability) must come from the top

Scenarios	CCS	Norcem	Market/Regulation	Uncertainty indicators
			must be incorporated into the BREEAM, the Nordic Ecolabel, CEEQUAL, and so on. Carbon tax.	down, from project owners (state, county, municipality).
Scenario 4	Failure—No CCS deployment occurs beyond a limited pilot program.	By 2035, Norcem stands at risk of other industries—such as wood and concrete, which has replaced most cement with other substances—being prevalent and taking over parts of the market share.	Nature of legal / regulatory framework to share risks / liabilities. Levels of public awareness / acceptance of risks. The government mandates the use of other building materials than cement and concrete. There is a high carbon tax. Most banks mandate green loans for business and clients across the board.	There is uncertainty as to whether geological storage of CO_2 will be secure over long periods, and whether storage risks can be reliably assessed and managed. Availability of storage site data is another concern, including agreed robust estimates of their capacity.

3.3. Norcem CCS SWOT Analysis

The evaluation in Table 1 demonstrates that the situation in terms of lowering Norcem's CO_2 emissions is very complex. However, CCS technology in Norway has a certain foundation for further development; as such, it is considered an effective measure to resolve carbon emissions. Nevertheless, the internal and external challenges regarding the continued development and market conditions necessary to implement large-scale CCS technology are not particularly clear. The SWOT (strengths, weaknesses, opportunities, and threats) analysis in Table 2 is applied to evaluate the potential rewards and obstacles of Norcem's large-scale implementation of CCS technology. We strive to identify the developments and context for CCS technology in Norcem, and based on the empirical literature, examine the variables pertaining to current impediments to present recommendations [7], [12], [26], [27], [28], [44], [45], [46].

Table 2: SWOT analysis.

INTERNAL FACTORS	
STRENGTHS (+)	WEAKNESSES (–)
• Potential broad government support • Developed and tested technology • Currently most plausible option to decarbonize cement production process • Other actors/proponents progressing with CCS • Substantial research and development funding already allocated to address technology and innovation issues • Substantial decrease in cost for future CCS projects and products (after initial investments) • Well-developed storage technology in the Norwegian market • Vast geologic storage potential	• Poor economic feasibility • Initial investment and ongoing maintenance costs too high • Lack of capital source • Overall immature technology • Dangers of locking in immature or incorrect type of CCS technology • Potential for unmet targets and missed deadlines (both short- and long-term) • No unsubsidized commercial projects • Dependency of other actors in the CCS value chain (e.g., co-storage) • Potential lack of government support
EXTERNAL FACTORS	
OPPORTUNITIES (+)	THREATS (–)
• Increasing focus on climate • Dire energy security and environmental situation • Growing international cooperation • Demands for energy, security, and environmental protection are urgent, relying on the government • Implementation of CCS activities is extensive • Potential cooperation with other actors in the innovation system (research institutes, entrepreneurs, enterprises) • Stakeholder agreements • CCS projects are affected by economic and technological factors; national financial support and industrial development of new technologies should be increased, achieving broader public support • Clean energy subsidies • CCS can sustain and create jobs • Competitive advantage—increased market demand specifically for CCS concrete	• Cement producers outside the EU do not have to adhere to the same regulations and climate goals and can gain competitive advantage in the Norwegian market • Foreign actors (e.g., Chinese and Polish enterprises/entrepreneurs) take advantage of current incentives in the Norwegian marketplace • Actors downstream in the value chain (e.g., suppliers/contractors) gain the benefit that Norcem pays for through CCS investments and maintenance • Imperfect policy and laws • Lack of government and public acceptance (internationally) of CCS • EU ETS legal outline emphasizes pipeline transport • Public opinion and market turning against the use of concrete

3.3.1. Strengths: CCS–Norcem

Demand for concrete is expected to remain high in coming years. Subject to Norcem's CCS implementation, carbon capture technologies have high potential for further development. With the increasing climate concern, and to reach the 2050 zero-emission target while ensuring concrete supply, there is a fundamental need to promote the widespread implementation of CCS in cement production.

CCS technologies are recognized as promising technologies for disassociating CO_2 emissions from cement production at scale, and are included in most climate change mitigation strategies for heavy industries [47], [48], [49]. It is estimated that CCS can contribute 19% of the emission reduction needed to constrain a rise in global temperature. The cost of achieving the same emission reduction without CCS would be 70% higher [6], [30]. CCS has been used successfully in oil and gas industries for decades and aggressive global efforts are underway to implement CCS in cement plants. In this global context, Norcem can take advantage of growing financial opportunity, with technology innovation and advancement that will provide a cleaner environment and more sustainable ecology.

Geologic storage grows relatively fast. Geologic storage sites that can be used include oil and gas reservoirs, deep saline aquifers, and multilayered depositional systems [44]. The large underwater basins of the North Sea have been most extensively tested. CO_2 from the Norcem plant is mainly to be distributed in the North Sea by boat, with the relatively short distance from the potential sequestration site implying that CCS implementation can greatly reduce transportation costs.

3.3.2. Weakness: CCS–Norcem

Ongoing CO_2 capture and storage costs are high. Additionally, with the upfront installation costs of CCS equipment, CO_2 capture cost will be higher due to the current limited installation of CCS-related devices in cement production plants. Initial investment is extremely high. CO_2 emissions from the production process of applying CO_2 enhanced recovery can leak into the atmosphere, and equipment work can also have indirect emissions; as such, the economic feasibility remains to be adequately measured.

Further, advances in technology are notoriously unpredictable. It is not possible to predict the cost and storage of carbon 30 years from now [50], [51]. It is equally difficult to predict whether storage tanks underground will be stable. Neither gas hydrates nor deep seams are counted in contemporary resource estimates. There is also the potential for schedule delays associated with the development of a particular element of the CCS chain lagging behind. For example, if the development of a transport and storage grid is delayed, this will also impose significant delays on the capture plant at Brevik.

3.3.3. Opportunities: Norcem–CCS

CCS technology, as it pertains to cement production, is adequately developed, although there remains some uncertainty regarding storage. Low-carbon concrete is therefore a viable option for the infrastructure and construction industry [26]. A pilot building demonstrating CCS in a construction industry dependent on cement is essential to making its deployment probable for decarbonizing the sector.

In addition, developing CCS technologies will create new business opportunities from an industrial standpoint. As for carbon capture processes in concrete production, a whole new approach must be created in the market in both infrastructure and housing. This opportunity offers potential expansion for the applications of emission reduction and technological innovation in various other industries. Demands for green concrete, energy, security, and environmental protection are urgent, relying not only on the government, but potential cooperation with other actors in the innovation system (e.g., research institutes, entrepreneurs, enterprises).

3.3.4. Threats: Norcem–CCS

At present, the EU ETS legal outline emphasizes pipeline transport as the main form of CO_2 transportation; as such, there is a grey area regarding CCS projects that use shipping and mobile transport on roads. Some environmental regulations do not include clear definitions of CCS [12], [27], [28]. However, the London Protocol allows transportation of CO_2 across national borders for storage in geological formations [52]. Moreover, differing emission reduction mechanisms, such as emissions trading and clean development mechanisms, also do not incorporate CCS technology. Developing a clear policy definition of CCS technology will be an imperative agenda in environmental negotiations. Further, the principal challenge for CCS technology at present is the lack of agreement on long-term targets. Short of these clear targets, it is difficult for companies in the cement industry to both obtain investments and implement CCS technology at a large scale.

While CCS is likely the only option for large-scale cement producers, there are numerous different technologies in other sectors that can contribute to lowering emissions from a national perspective. Whether CCS and low-carbon concrete can be a feasible option is contingent on the cost of investment. Given the current state of CCS technology, the operation cost for Norcem could increase substantially after retrofitting with CCS, and their additional operation costs are estimated to increase anywhere between 25% and 50% annually [8].

3.4. Policy and market measures

As discussed previously, the contribution of CCS to reducing emissions across industrial sectors is reliant on pertinent policy and market support to reach accelerated deployment of CCS technologies and infrastructure. This includes targeted policies to incentivize (public and private) investment, the early identification and development of lower-cost deployment opportunities, and well-designed policy measures. Several variables influence CCS implementation speed—most importantly, the price of capturing emissions and the price of emissions (see Figure 6). In the EU, the cost of carbon is projected to increase progressively up to 2050, whereas the cost of CCS technology is projected to decrease with greater innovation, supply, and capacity. The cost of carbon is projected to initiate CCS investments in the next 30 years.

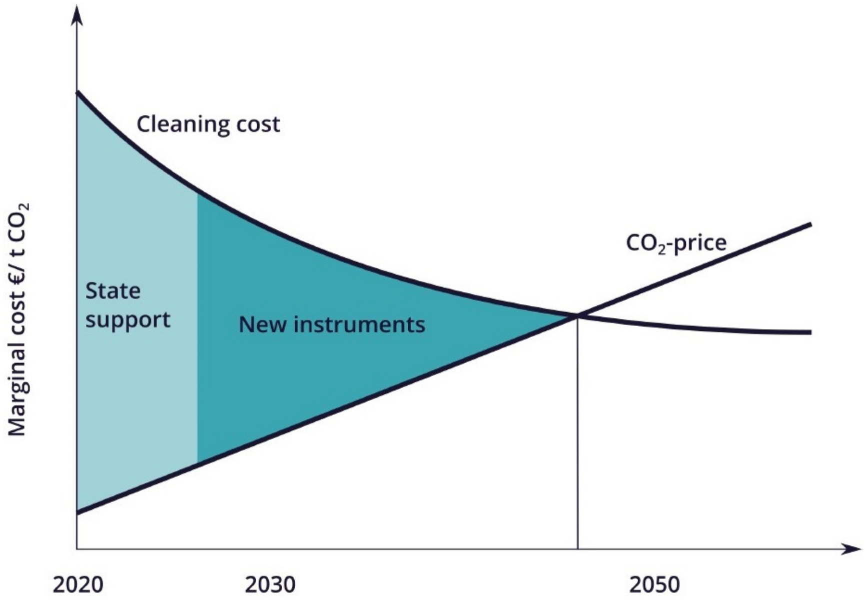


Figure 6. Expected advances for both carbon cost and CCS cost [49].

Further, full-scale CCS would cost Norcem NOK11 MRD to implement, including operational cost, over five years [53]. In a hypothetical scenario, the Norwegian government could cover one-third of the investment cost, Norcem could cover one-third, and various market measures could cover the final third over a five-year period. State aid must align with the regulations controlled by the European Free Trade Association Surveillance Authority. These regulations are implemented to ensure open and fair competition among actors in the European Economic Area. Based on factors presented in the ZERO report (2019) [49], as well as data from our ZEN survey (see Appendix B) and focus group workshop (see Appendix A), Table 3 presents the (financial and non-financial) measures that are deemed relevant.

Table 3. Financial measures.

Measures	2020	2025
Tax deduction per ton of CO_2 stored [15], [54][2]	NOK154 million per year (received by Norcem).	NOK770 million (received by Norcem over a five-year period).
Climate requirements in public buildings and facilities [55][3]	NOK258 million (total annual pot handed out by the Norwegian government for green public procurement).	NOK645 million (in a scenario in which Norcem receives—directly or indirectly over a five-year period—50% of the total annual pot handed out by the Norwegian government for green public procurement). An earmarked sum should be negotiated.
Green banking loans [56][4]	NOK68 MRD eligible green loan portfolio (DNB) (Potentially incorporated into TEK).	NOK91 MRD (includes NOK23 MRD in outstanding green covered bonds).
Grey certificates	Suggested index price of NOK50 per ton of CO_2 stored (price depending on market scarcity and supply and demand).	Based on the green electricity certificate scheme. Payment scheme aimed at reducing costs for the producer by transferring it down the value chain to the end users.
Producer responsibility for carbon [57]	Avoidance costs of NOK1000/tCO_2 to NOK1500/tCO_2. Potential aggregated expenses associated with producer avoidance costs of carbon (per ton) emitted.	Avoidance costs reduced 90% over a five-year period to NOK100/tCO_2 to NOK150/tCO_2.
Climate fee on concrete [58]	NOK500 fee per ton.	NOK0 fee per ton (due to successful financing and implementation of CCS, the climate fee on concrete is not applied to Norcem).

Note: fields in white indicate potential for offsets and increased green revenue, whereas fields in grey indicate a reduction in overall costs/fees.

Tax deductions incentivize the deployment of CCS by providing a tax credit for dedicated carbon storage. For Norcem, 400 000 tons of CO_2 stored on an annual basis provide a substantial incentive for the implementation and use of CCS. One benefit of this type of scheme is that it can improve project

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[2] Note: Based on the calculation that Norcem reaches its goal of 400 000 tons of CO_2 storage with a price of USD50 (NOK385) per ton.

[3] Note: Gjennom Miljødirektoratets Klimasats-ordning kan kommuner og fylkeskommuner få støtte til å dekke merkostnaden ved klimavennlige innkjøp, og til arbeidet med klimakrav i offentlige anskaffelser.

[4] Note: Lending criteria to include building projects with low-carbon cement/concrete.

revenue over time. For example, if Norcem implements full-scale CCS by 2025, and receives a set tax deduction over 15 years, it can substantially leverage initial investment and operational costs.

This type of tax measure can also lead to the development of new projects; however, further policy measures are required for wide-scale deployment. This type of tax scheme could generate the largest flow of carbon capture investment of any policy measure to date, and as an example, in the United States, it is leading to financial investments in the order of USD1 billion in the next five-year period [59]. Other benefits are that it can lead to further funding of exploration and appraisal of potential capture technologies, while absorbing initial value chain risks by providing guarantees for a set level of CCS.

Climate requirements in buildings and facilities are of increasing importance, primarily in public projects. In Norway, one can now receive financial support to establish climate requirements in purchasing. Through the Environment Directorate's Climate Rate Scheme, municipalities and counties can receive support to cover the additional cost of climate-friendly procurement, and to work on climate requirements in public buildings and projects. This climate initiative supports measures under the auspices of municipalities and county municipalities that reduce greenhouse gas emissions or contribute to the transition to a low-emission society. Presently, the most forceful measure is the building regulation, or the building code (TEK). So far, TEK does not regulate emissions from materials directly or through guidelines. This could, however, change in the future.

In 2020 alone, the Environment Directorate will distribute approximately NOK258 million through its climate initiative. This is an opportunity for Norcem to take advantage of, and a chance to work with municipalities and counties to begin climate-friendly procurement, since green purchases are one of several areas covered by the scheme. By emphasizing good climate solutions in procurement, the municipalities can contribute to a major change in their suppliers. Although the suppliers may not provide climate-friendly goods and services upon the first request, it is nevertheless of great value that municipalities demand climate solutions. That said, meeting demand for climate solutions in public projects requires will, expertise, and routines in many parts of the value chain. The Environment Directorate encourages municipalities to seek support for the important process of systematically incorporating climate considerations into their projects. Increased green purchasing is an important area for the Norwegian government, and Norcem, albeit indirectly, can benefit from this targeted policy.

Green banking loans have received increasing interest in recent years [56]. Several banks in Norway are developing broad environmental goals and priorities. These serve as overall frameworks for their considerations of green finance and guide green lending choices. Eligibility for green loans is usually tied to compliance with technical codes and eligibility criteria (e.g., TEK10) [60]. These eligibility standards can be accompanied by typologies listing technologies or products that can be considered environmentally friendly without further in-depth assessment.

Further, specific factors might be defined to measure compliance or performance with regard to certain environmental issues. Delineating what may be considered environmentally friendly is, therefore, imperative. While green loans are targeted predominately towards energy-efficient buildings and projects, the scope of requirements is broadening. This means that more criteria, such as low-carbon cement, will be a part of assessment standards. Green loans could be linked to schemes for which this is a minimum requirement—thus, minimum requirements such as low-carbon concrete must be included in the BREEAM, Swan, and CEEQUAL ecolabels. The private sector has greater flexibility for allocating funds (even with the reliance on green loans) than the public sector, which depends on the willingness of the client to pay for the approved budget (see Appendix A).

Grey certificates as a carbon cost integration mechanism [61] introduce elements of regulatory flexibility by rearranging liability, or parts of liability. This type of 'grey' certificate has many uncertainty factors, but could be explored as a incentive to rearrange and potentially decrease compliance costs while simultaneously deploying low-carbon investments. This can be achieved if one business, which might struggle to reach its environmental obligations because of lack of investment or high operating costs, finds another party willing to ensure compliance at a lower cost. In Norcem`s case, this could be an agreement between them (currently facing high carbon reduction costs) and key actors in the infrastructure and/or construction industry (where a market for low-carbon cement can be formed via a liability transfer). An option in this situation is to instigate a technology-neutral 'grey' certificate market scheme. Such a market scheme could be based on the 'green' certificate model for the electricity sector.

This method could present flexibility for obligated actors in the building industry, comparable to the way that member states have flexibility pertaining to the transfer of part of the yearly emission allocation in the Effort Sharing framework. This type of measure requires having two or more obligated actors in the value chain collaborate to reach low-emission goals. The key principle behind this policy measure is similar to that of a crediting scheme, wherein reduction cost is carried by an obligated actor in return for realization of a market requirement. This kind of scheme can also lead to market creation for low-carbon products, such as CCS cement, given a scenario in which the reduction cost is concentrated in a single effort and not spread out widely in the marketplace.

Producer responsibility for carbon is often calculated as an aggregate avoidance cost. It pertains to all the potential expenses associated with a producer avoiding the costs of carbon (per ton) emitted. It is part of the financial framework implemented to discourage high-carbon options and reduce uncertainty [26], [62], and is often highlighted by actors involved in enabling and implementing low-carbon options. This factor is of particular importance in this case due to the high carbon avoidance cost for Norcem and the cement industry. However, considered in tandem with other measures, this cost can be substantially reduced. This means that a high carbon tax or quota combined with a high level of public financial support is required to compensate for the added costs associated with carbon capture, transport, and storage. While cement is a relatively inexpensive material to produce [63], it has a large climate impact [9]. Therefore, the inclusion of CCS and maintenance costs in the cement production process leads to a potential increase of 50% in production costs, substantially affecting the competitiveness of the cement produced.

This upsurge in cost, which does not account for transport and storage, could exceed Norcem's margin, making CCS cement production unprofitable at the present market price if it is not remunerated. Therefore, if CCS is to be implemented at full scale, public financial support will be required to overcome the additional expenses related to the implementation of CCS and maintenance at the cement plant. As such, the financial support required will depend on the innovativeness, and, consequently, the effectiveness of the capture technology that is implemented.

A climate fee on concrete could be implemented and graded according to carbon emissions in production [58]. Considered alongside CCS implementation, this could provide a zero emissions – zero charge scenario for Norcem. This new fee facility is founded on a "polluter pays" methodology, based on a

Norwegian carbon fee of 500NOK per ton. However, combined with the aforementioned policy measures, the fee could be reduced to 0NOK per ton due to the successful financing and implementation of CCS; in turn, the climate fee on concrete would not be applied to Norcem. This fee is estimated to provide 10% more expensive concrete with contemporary emissions. Such a measure should be considered in relation to an extended producer responsibility whereby manufacturers are required to handle collection costs, taking responsibility for the carbon emissions associated with their product.

In addition to these direct financial market measures, we expand on non-financial issues below, noting that Norcem is the sole producer and major supplier of cement in the Norwegian market.

Green public procurement (see Appendices A and B) [64] is a policy approach that is highly relevant for Norcem and its value chain. Setting standards for carbon efficiency whenever public authorities procure goods creates an immediate inroad for low-carbon products, such as low-carbon concrete. Green public procurement can be defined as a process in which public authorities procure products and services that have less environmental impact from a life cycle perspective than other products and services that have the same function. Examples include the enforcement of public construction projects with embedded low-carbon materials and the use of low-carbon cement.

Public procurement can support the path to lowering emissions in the cement industry at various stages. Green procurement can be specifically targeted at creating markets and diffusing new products and services [65]. In this scenario, green procurement is most pertinent to transforming heavy industries, since it creates precisely the required market-creating impacts for low-carbon products (e.g., CCS cement). Public procurement of low-emissions products also has the effect of aggregating demand and thereby enhancing economies of scale. The EU has introduced a new regulatory framework for green public procurement that is built on the EU's Procurement Directives and is linked with the requirements of the World Trade Organization and other trade agreements safeguarding similar access to procurement for trade partners. In Norway, the National Programme for Supplier Development [66] has been constructed to fast-track innovations in and development of new green solutions through the strategic practices of public procurement, as well as to contribute to new market opportunities for green products such as low-carbon cement.

Public–private partnerships can promote low-carbon cement with CCS through measures such as capacity auctions or contracts for difference, establishing long-term agreements with public counterparties. This would be an explicit methodology for bridging research and development expenses, and the cost gap between traditional cement products and more expensive low-carbon substitutes. In these cases, initial offers and auctions allow for price discovery. The German COORETEC initiative and the GEOTECHNOLOGIEN program are cases of public–private partnerships with research and development activities focused on CCS [67]. Creating long-term contracts between suppliers of low-carbon concrete and public bodies would substantially lower costs associated with CCS.

In this scenario, the main role of the public body is to compensate for the variance between a reference price for traditional concrete and the exercise price for the low-carbon CCS alternative. In Norcem's case, low-carbon CCS cement would be given long-term support through this type of contract, with the exercise price being set via competitive auctions at which suppliers compete for the buyer, rather than the other way around. The main benefit of utilizing contracts for variances, likened to other measures such as per-unit subsidies and government grants to cover investments, is the competitive characteristics in the form of real competition in the marketplace. This scenario could reduce the costs associated with low-carbon cement production. Beyond this cost-effectiveness benefit, it could also increase production, rather than just advancing current production levels; this, in turn, is particularly important if aiming to scale up.

A technology choice mechanism [68] is a measure that could generate a transparent framework and set standards to select which industries—and, more importantly, which low-carbon technologies—would obtain funding to aid deployment. This is an institutional methodology, with government leading and managing pathways and efforts to enhance investments in low-carbon technology such as CCS. In Norway, such a mechanism could be administered by Gassnova. Further, to safeguard competition in the marketplace, any technology company might submit bids and proposals, set against contemporary building codes (e.g., TEK) and environmental standards in Norway (e.g., Swan, BREEAM).

Industrial partnerships are based on long-term cooperation with private actors in the value chain [69]. As discussed previously, long-standing contracts will often be supported by government and other public actors. However, long-term low-carbon contracts with private actors are also relevant. Norcem has already established cooperation with companies such as Yara, EGE, and Equinor in terms of storage and transport; however, there is also potential for this downstream in the value chain. As such, cooperation might be arranged with a private partner, enterprise, or consumer. This can occur when businesses with traditionally high carbon outputs arrange long-term agreements with suppliers of specific types of products. In instances where there is a price discrepancy, it can hypothetically be covered by subsidies or government directives. The advantage of government directives is that they also permit companies that do not have an environmental policy obligation of their own to contribute to environmental goals by safeguarding the demand for low-carbon alternatives.

3.5. Key recommendations

While all the aforementioned measures presented in this report are relevant for reaching low-emissions targets in the cement industry, we focus on a set of measures deemed most suitable in the Norwegian marketplace over a five-year time frame (2020–2025). As discussed previously, there are varying possible CCS deployment scenarios and, as such, CCS technology in and of itself is not sufficient to reach low-emissions target in the cement industry in the next five years. Considering Norcem's size and position in the market, as well as their value chain's high reliance on public actors and projects, the interdependent recommendations Presented in Table 4 are deemed imperative.

Table 4. Key recommendations for measures facilitating a pathway to low-carbon cement in Norway.

LEVEL OF IMPORTANCE	MEASURE	CRITERIA
1	CCS	Obtain external investment in full-scale CCS implementation at Norcem's Brevik plant by 2025. Reach Norcem's goal of 400 000 tons CO_2 captured. Trigger further large-scale CCS deployment in other industries by 2025–2035.
2	Tax deductions	Implement tax deductions per ton CO_2 stored. Norcem receives NOK 150 million+ per year in deductions while reaching its CCS goal. Introduce predictable and long-term tax deduction rates.

LEVEL OF IMPORTANCE	MEASURE	CRITERIA
3	Grey certificates	Explore 'grey' certificates scheme based on the green electricity certificate scheme. Payment scheme is aimed at reducing costs for the producer by transferring them down the value chain to the end users. Suggested index price of NOK50 per ton of CO_2 stored (price depending on market scarcity and supply and demand).
4	Green public procurement	Obtain targeted and earmarked funding for construction and building projects with low-carbon cement. Build innovation partnerships aimed at green purchasing projects. Reduce the environmental impact of public purchasing.

Note: Ranked by level of importance (1 = most important).

1) ***CCS.*** Based on our data, SWOT analysis, and systematic review of the literature, we recommend further investment to reach full-scale CCS deployment at Norcem's Brevik plant. Early demonstrations and pilot testing have been successful, and the size and position of Norcem in the market could trigger further CCS deployment and technology innovation not only in the cement industry, but also in other sectors. Norcem's ambitious goals of 400 000 tons CO_2 captured annually can be realized; however, getting low-carbon cement successfully to the market is dependent on other measures being implemented.

   Demand for cement is expected to remain high in the years to come. Subject to Norcem's CCS implementation, carbon capture technologies show high potential for further development. With increasing climate concerns, and to reach low-emissions targets while ensuring concrete supply, there is a fundamental need to promote the extensive implementation of CCS in cement production. The advantages of CCS in this context are:

   - It is currently the most plausible option to decarbonize the cement production process.
   - Other actors in the Norwegian market are progressing with CCS—there is potential for increased collaboration in the innovation ecosystem.
   - There is a potential decrease in cost for future CCS projects and products (after initial investments).
   - There already exists well-developed storage technology in Norway.

   The potential disadvantages of CCS are:

   - Initial investment and ongoing maintenance costs are too high, and there is a lack of capital source(s).
   - There are dangers of locking in immature or incorrect types of CCS technology.
   - There is potential for unmet targets and missed deadlines (both short- and long-term).
   - There are currently no unsubsidized commercial projects.

2) ***Tax deductions.*** These deductions are directly correlated with Norcem's CCS goals. It is imperative that there are predictable, long-term tax deduction rates that can compensate for Norcem's added operational costs. Tax deductions are beneficial because they incentivize ongoing operations and deployment of CCS by essentially providing a tax credit for dedicated carbon storage.

   In the case of Norcem, the tons of CO_2 stored on a yearly basis provide a considerable incentive for the application and use of CCS. Another beneficial component of this type of scheme is that it can help project profit and loss over a certain time frame. A scenario in which Norcem implements full-scale CCS at their Brevik plant in 2025, and receives a set tax deduction rate (accounting for inflation) over 10–15 years, has the benefits of:

- Markedly leveraging upfront CCS investments and operational costs.
- Creating a stable and predictable long-term financial framework within which to operate.
- Incentivizing continued investments in other clean technologies.

Some of the disadvantages of applying and these types of tax deductions are:

- Large producers and early adopters of full-scale CCS can gain “too much” from first-mover advantage, running the risk of skewing the market and creating a monopoly.
- It is reliant on achieving high, sustained capture levels (dependent on structure of tax index).

3) ***Grey certificates.*** This is a technology-neutral and industry-non-specific certification scheme based on the green electricity certificate system [70]. The payment scheme is aimed at reducing costs for the producer by transferring them down the value chain to the end users. The first phase of this market scheme could pertain to Norway and Sweden, with proliferation to other EU countries over time. The suggested basic index price of NOK50 per ton of CO_2 stored is dependent on market scarcity. The goal of grey certificates in this context is to inject more low-carbon cement into the building and construction market at the expense of traditional cement, which has high carbon emissions. This type of low-carbon cement is too expensive (mainly due to high CCS deployment costs) to enter the market on traditional commercial terms. A significant element of this grey certificate scheme is that low-carbon cement producers receive certificates from the government relative to their production output and carbon stored. The end users can buy a certain quantity of these certificates when they buy the product. Figure 7 illustrates the process for obtaining rights to grey certificates.

Figure 7. Process for obtaining grey certificate rights.

Consequently, a market for low-carbon cement and a market for grey certificates is established. For the producers of cement, this certificate denotes a subsidy, and for the end users, it represents a fee or tax. Both will, in theory, reduce the cement price for the suppliers. Subsidies and taxes are restructured among the suppliers and end users via traditional market effects.

From a practical trading perspective, the following streamlined three-stage process for certifying transactions is applicable.

Stage 1) An industrial plant captures and stores X amount CO_2 a day. This is recorded in the internal accounting system. The data are transferred to a registry provider where the data are recorded and a grey certificate is created.

Stage 2) An intermediary broker an agreement between buyers and sellers of the grey certificates.

Stage 3) A standards agency verifies the acquisition and certifies validity.

Further, because the grey certificates follow a scheme structure, who eventually pays the highest price depends on price elasticities. In a scenario of increasing marginal costs at the supply end, and declining demand curves, the redistribution can be so high that the end users receive cheaper cement than was traditionally offered in the marketplace. Irrespective of whether the end user pays more or less for the cement, the introduction of grey certificates has several potential benefits:

- Transfer of liabilities and creation of fairer burden-sharing in the value chain will occur.
- Demand and production of low-carbon cement will increase.
- The producer price of cement could decline over time.
- Production of traditional cement will decline, except if the supply of traditional cement is entirely price-inelastic.

The disadvantages of such a grey certification scheme are:

- In a quota system, oversupply of low-carbon cement could lead to a sharp decrease in certificate prices, disincentivizing the market.
- Penalty payments would be incurred if certificate quotas are not met.
- Uncertainties pertaining to delineating who administers and participates in the scheme.
- Dilemmas pertaining to an overlap with ETS.

A key feature in this type of scheme is the principle of technology neutrality. As is the case with green certificates; a grey instrument will establish a uniform support system that only marginally distinguishes between technologies. This will generate a level playing field between technological alternatives, with markets and innovation systems determining how best to reduce emissions. As such, technology neutrality can aid the process of driving down prices for clean technology, creating competition and, in turn, innovation in the marketplace. Technological neutrality in this context reduces cost-efficiency dilemmas as they pertain to environmental policy through creating a platform for choices in the market.

4) ***Green public procurement [71].*** This involves the establishment of reliable and long-term innovation partnerships based on green procurement principles. In Norway, public procurement constitutes approximately NOK500 billion annually, or approximately 15% of the overall GDP. Norcem has the potential to provide significant leverage in influencing the market and achieving environmental improvements in the public sector and vice versa. To reduce the environmental impact of public purchasing, it is important to identify and develop green public procurement criteria for products, such as low-carbon cement, that account for a high share of public purchasing and have a significant improvement potential for environmental performance.

Norcem should establish partnerships with key actors in their value chain and use the National Programme for Supplier Development as an intermediary. Successful partnerships and projects such as KlimaGrunn, with entities such as Statens vegvesen, Statsbygg, and Bane NOR, offer a sound blueprint for such a collaboration centered on green procurement. In addition, the Norwegian government earmarks approximately NOK250 million toward projects based on green public procurement annually. This offers a potential not only for partnerships, but also for increased revenue.

The development of green procurement criteria for low-emission concrete in building and construction aims, therefore, to help public authorities ensure that building projects are procured and implemented with higher environmental standards. To identify the areas with substantial environmental improvement potential, it is necessary not only to analyze the overall environmental impacts of cement production, but also to understand the most commonly used procurement processes for building and construction maintenance and to learn from the actors involved in delivering successful projects. A proposal for criteria delivering substantial environmental improvements involves green procurement criteria that can be understood as being part of the procurement process and, therefore, must conform to specific codes and standards. Green procurement criteria [72] will be formulated either as selection criteria, technical specifications, award criteria, or contract performance clauses that are relevant for Norcem's value chain [64]:

- ***Selection criteria.*** When evaluating capability to complete a contract, authorities might consider explicit experience and ability related to environmental characteristics that are pertinent to the subject matter of the contract. Authorities might also reject operators who breach environmental codes or laws in certain instances. For service and works contracts, queries explicitly about operators' ability to apply environmental management procedures will be addressed when processing all aspects of the contract.
- ***Technical specifications.*** These establish minimum compliance requirements that must be met by all tenders. They must be related to the characteristics of the project and the supply acquired, and not to the overall volumes or assets of the operator. It is additionally imperative that they are distinct, understood by all operators in the same manner, and able to be verified.
- ***Award criteria.*** These can be used to stimulate additional environmental performance without being mandatory and, therefore, without foreclosing the market for products that do not reach the proposed level of performance.
- ***Contract performance clauses.*** These stipulate procedures for how a contract must be accepted by the parties. For supply contracts, the main context for the utilization of environmental clauses is often the specification of how the goods will be delivered.

For each set of criteria, there is a choice between two desired levels:

- The core criteria are intended to permit easy implementation of green procurement, converging crucial areas of the environmental performance of goods and keeping administrative expenses for entities low.
- The comprehensive criteria consider more characteristics and stages of environmental performance, and are intended for use by authorities that want to drive support for environmental objectives and innovation partnerships.

Based on these green procurement criteria, targeted and earmarked funding for constructions and buildings with low-carbon concrete could be achieved. Moreover, innovation partnerships aimed at green purchasing projects can help reduce the environmental impact of public purchasing.

These interdependent green measures above should all be incorporated into new environmentally focused business models aimed at reducing emissions. The effects on the market could be substantial and aid the transition to low-carbon cement. This is illustrated in Figure 8, a revised cleaning cost graph for the Norwegian market adapted from the ZERO (2019) [49] report.

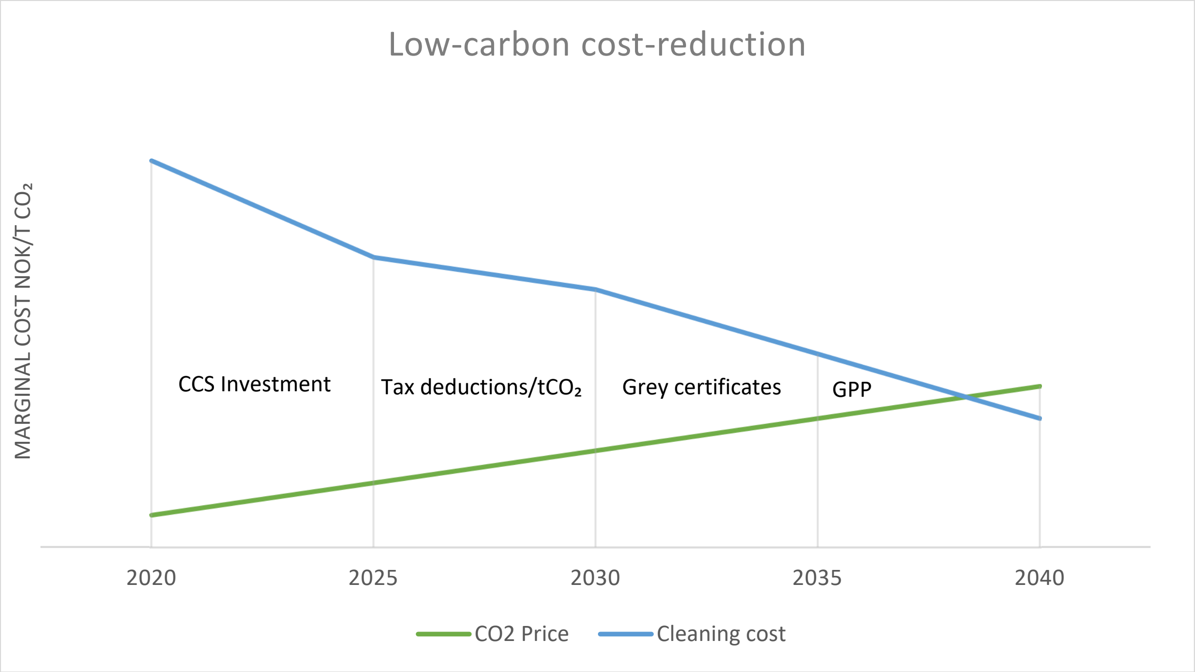


Figure 8. CO_2 price and cleaning costs mediated by CCS investments, tax deductions (tCO_2), grey certificates, and green public procurement (GPP).

In summary, the aforementioned measures should be implemented as a bundle and would be most effective working interdependently. Different measures would account for and mediate different aspects of the market and value chain.

3.6. Business models for reducing the carbon footprint of concrete

Developing new business models for the green shift is a challenging task. New ways of approaching the market, coupled with technological innovation through open value chains, are required to reach high levels of low-carbon concrete in the marketplace. As addressed in this report, Norcem's value chain and industrial partners are heavily affected by the zero-emission goals. The business model presented in Figure 9 provides a holistic view of Norcem's shift toward low-carbon concrete.

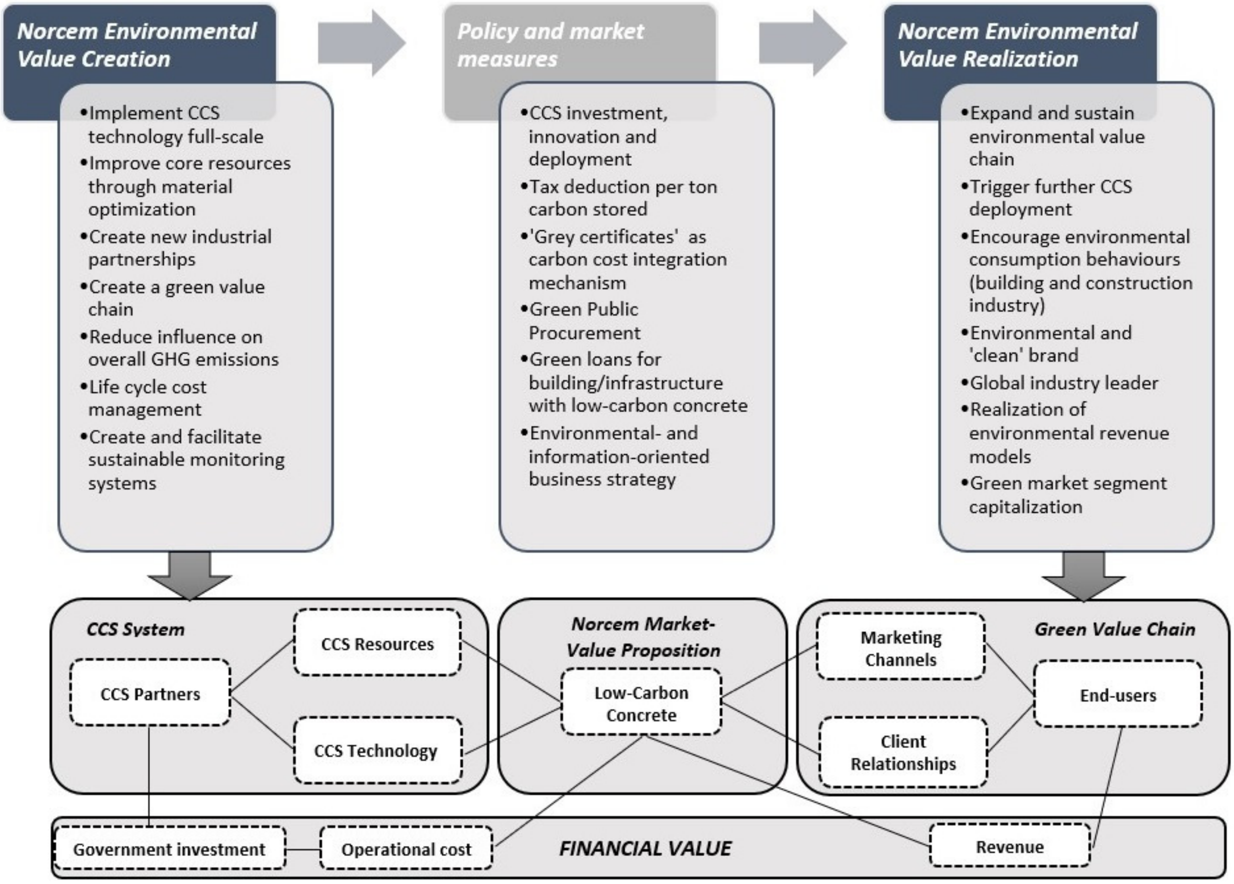


Figure 9. Norcem: A conceptual low-emission business model.

This business model illustrates how Norcem can move from initiating environmental value creation to achieving value realization. The main objective for Norcem in this regard is to implement CCS technology at full scale and ultimately become a leader in providing low-carbon concrete to end users. However, investment support for CCS alone will not necessarily be sufficient to reach this goal. Several market and policy measures, coupled with government investment, are therefore sought. Green public procurement, tax deductions, and green loans are all a part of a new business model for transitioning to low-emission products. To reach their potential for creating a low-emission product with CCS for the Norwegian marketplace, Norcem must expand their green value chain, and capitalize on a new, environmentally oriented business strategy. Initial steps have been undertaken to reach these goals; however, as illustrated in this model, a more systemic approach to tackling these issues is required.

In addition to the CCS option, there are a number of alternative options and strategies for reducing the carbon footprint from concrete. Even though CCS has significant potential if successfully implemented, this is not an argument for shunning other measures. A primary strategy for reducing emissions in buildings and infrastructure developments is material optimization. Using the right material, for the right function, and in the right amount is pivotal to GHG emission reductions. Further, building robust solutions—meaning durable structures and flexible solutions—are meaningful actions from a climate perspective. Sometimes, for various reasons, material substitution can be the result of a life cycle analysis of materials in a project. This can be due to different qualities of materials or different project requirements (e.g., strength, weight, aesthetics, or environmental considerations). GHG emissions are one important measure when planning and designing building projects, but they are not the only consideration that must be made.

Numerous research projects are currently underway, investigating how to replace a share of the clinker in cement with other, more sustainable inputs, such as has already been achieved with the use of fly ash. One such project is DARE2C [73], which aims to replace around 50% of the clinker with blue clay. The project has yielded some promising results, succeeding in developing an armored concrete with lightweight aluminum [74].

A major trend in construction is circular economy. This incorporates several different solutions, including waste and general resource reduction, re-use of materials and building components, recycling, and sharing alternatives. Concrete has been both down-cycled and up-cycled, and is able to be re-used in the same function as before. However, re-use of materials requires a tested and approved system to ensure that re-use will not compromise life and health issues. There is reason to believe that such systems will be developed over the next few years. For the cement and concrete industry, this could imply new market opportunities, and one option would be to team up with strategic partners to be positioned for a new market.

4. SUMMARY AND KEY RECOMMENDATIONS

The progression of CCS deployment in the Norwegian cement market is expected to be far from linear and stepwise. It is also our assumption that CCS alone is not sufficient to implement the transition to low-carbon concrete in the marketplace. Based on evidence from this case study, we make the following key recommendations for government, business, and policy-makers:

1) Invest and implement full-scale CCS at Norcem's Brevik plant as a catalyst for the wider market.
2) Enact stable, predictable, and long-term tax deductions for captured CO_2 per ton.
3) Explore a "grey" certificate market as a carbon cost integration mechanism.
4) Focus on accelerating green public procurement and innovation partnerships.

A wide variety of choices are available for governments when facilitating the transition to low-carbon concrete. The aforementioned measures are designed to work interdependently, focusing on not only creating a market for low-carbon cement, but creating even burden-sharing between producers, suppliers, and end users. However, government policies will only be effective if CCS technology and innovation is adequately advanced and some of the financial burden can be transferred to end users. The Norwegian government should continue to focus on the need for pilot projects proving the viability of CCS technologies long term. Government support should be focused on driving high performance in these pilots. As discussed previously, support for CCS should be packaged with the market measures illustrated in Figure 10.

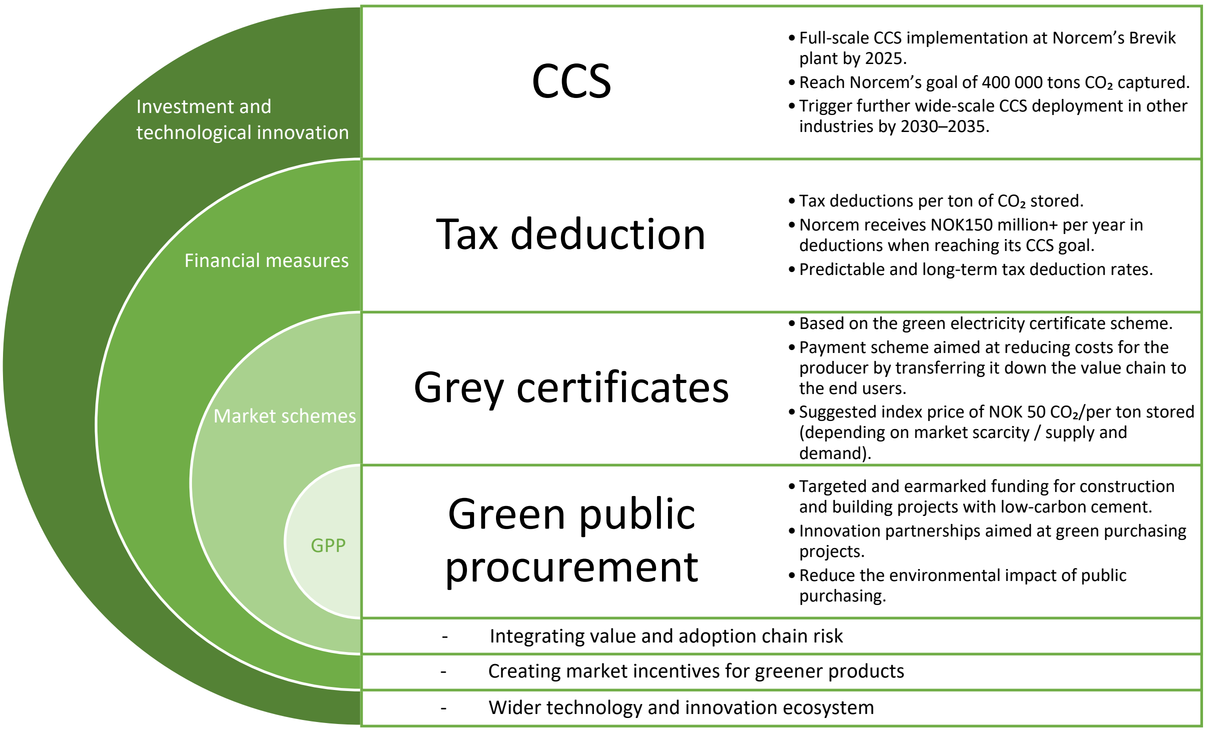


Figure 10. An interrelated model of the key measures recommended in this case study.

Tax deductions to incentivize deployment and large-scale implementation of CCS, by providing a tax credit for dedicated carbon storage. This type of tax measure can also lead to the development of new projects and could generate a large flow of (public and private) carbon capture investment.

Grey certificates based on the green electricity certificate scheme. This payment scheme is aimed at reducing costs for the producer by transferring them down the value chain to the end users. We suggest an index price of NOK50 per ton of CO_2 stored (depending on market scarcity and supply and demand). However, such a scheme has many uncertainties and needs to be further explored.

Green and innovative public procurement can particularly create business opportunities and support the path to lowering emissions in the cement industry. Green procurement can be specifically targeted at creating markets and diffusing new products, such as low-carbon concrete. Public procurement of low-emission products also has the effect of aggregating demand and thus enhancing economies of scale. In theory, the Norwegian government can earmark funds for low-carbon concrete, thereby create business revenue for Norcem.

Carbon cost integration mechanisms facilitate elements of regulatory flexibility by rearranging liability. The incentive to rearrange liabilities is to decrease compliance costs while simultaneously deploying low-carbon investments. This can be achieved if one business that is struggling to reach its environmental obligations because of lack of investment or high operating costs finds another willing party to ensure compliance at a lower cost. This could be an agreement between Norcem and key actors in the infrastructure and construction industries. Our recommendation is therefore that a new, technology-neutral grey certificate scheme be explored further to potentially facilitate this liability rearrangement.

While initial investments, robust policies, and schemes are essential for low-carbon cement with CCS, there are uncertainties related to fast-tracked innovation and implementation. With high levels of progress comes a higher risk of "locking in" substandard CCS technology. There is still ambiguity related to factors such as full-scale technological integration and the potential for decreased operational cost.

Emerging environmental technologies are often developed in the long term. Price points and expenses cannot be expected to drop in the first year of implementation. Whereas radical technology innovation can reduce expenses significantly, expenses could increase in the long term if CCS technology is scaled up and integrated full-scale at other industrial sites. Public–private partnerships are required to monitor sustainability and innovation to apprise government investment strategies. As addressed in this report, scenarios of incremental innovation and lack of investment lead to "failure" in the long term. As such, other measures and instruments are pertinent.

5. CONCLUSIONS AND FURTHER RESEARCH

This case study of Norcem and the cement market has illustrated how obligations associated with low-carbon cement and CCS are multifaceted. For Norcem and the Norwegian government, burden-sharing between limiting ongoing financial liabilities and covering initial investments is essential. Cooperation on key obligations and how these obligations should be divided is of paramount importance. Further research should focus on the interdependency between market measures and how to practically implement these. There are many factors which could influence the development and implementation of measures such as 'grey' certificates and these need to be researched further, both from a theoretical and practical viewpoint.

Key issues that should be monitored are burden-sharing between producer and end user, ongoing responsibility for covering cost associated with financial liabilities, and additional problems with ongoing technology and operations management. While both public–private and innovation partnerships can solve some of these problems, clear market measures and frameworks should be enacted to create a clearer pathway forward.

6. References

[1] Regjeringen.no. (2020). *Klimaendringer og norsk klimapolitikk*. Retrieved from https://www.regjeringen.no/no/tema/klima-og-miljo/innsiktsartikler-klima-miljo/klimaendringer-og-norsk-klimapolitikk/id2636812/

[2] European Commission. (2019). *New rules for greener and smarter buildings will increase quality of life for all Europeans*. Retrieved from https://ec.europa.eu/info/news/new-rules-greener-and-smarter-buildings-will-increase-quality-life-all-europeans-2019-apr-15_en

[3] Miljøstatus. (2019). *Klimagassutslipp fra oppvarming av bygg*. Retrieved from https://miljostatus.miljodirektoratet.no/tema/klima/norske-utslipp-av-klimagasser/klimagassutslipp-fra-oppvarming-av-bygg/

[4] Ibn-Mohammed, T., Greenough, R., Taylor, S., Ozawa-Meida, L., & Acquaye, C. (2013). Operational vs. empodied emissions in buildings—A review of current trends. *Energy and Buildings, 66*, 232–245. https://doi.org/10.1016/j.enbuild.2013.07.026

[5] Norcem. (2020). *About us*. Retrieved from https://www.norcem.no/en/about_us

[6] Rodriguez, N., Murillo, R., & Abanades, J.C. (2012). CO_2 capture from cement plants using oxyfired precalcination and/or calcium looping. *Environmental Science and Technology, 46*, 2460–2466.

[7] Romeo, L. M., Catalina, D., Lisbona, P., Lara, Y., & Martínez, A. (2011). Reduction of greenhouse gas emissions by integration of cement plants: Power plants and CO_2 capture systems. *Greenhouse Gases: Science and Technology, 1*(1), 72–82.

[8] Gardarsdottir, S. O., De Lena, E., Romano, M., Roussanaly, S., Voldsund, M., Pérez-Calvo, J. F., … Cinti, G. (2019). Comparison of technologies for CO_2 capture from cement production—Part 2: Cost analysis. *Energies 12*(3), 542. https://doi.org/10.3390/en12030542

[9] Vatopoulos, K., & Tzimas, E. (2012). Assessment of CO_2 capture technologies in cement manufacturing process. *Journal of Cleaner Production, 32*, 251–261.

[10] Zheng, L., Hills, T. P., & Fennell, P. (2016). Phase evolution, characterisation, and performance of cement prepared in an oxy-fuel atmosphere. *Faraday Discussions, 192*, 113–124.

[11] Rubenstein, M. (2012). *Mitigating Emissions from Cement*. Columbia Climate Center. Retrieved from http://climate.columbia.edu/files/2012/04/GNCS-Cement-Factsheet.pdf

[12] Barker, D. J., Turner, S. A., Napier-Moore, P. A., Clark, M., & Davidson, J. E. (2009). CO_2 capture in the cement industry. *Energy Procedia 1*(1), 87–94. https://doi.org/10.1016/j.egypro.2009.01.014

[13] Brown, T., Gambhir, A., Florin, N., & Fennell, P. (2012). *Reducing CO_2 emissions from heavy industry: A review of technologies and considerations for policy makers* (Briefing Paper No. 7). Grantham Institute for Climate Change, Imperial College London.

[14] Davies, L. L., Uchitel, K., & Ruple, J. (2013). Understanding barriers to commercial-scale carbon capture and sequestration in the United States: An empirical assessment. *Energy Policy, 59*, 745–761.

[15] Olje- og energidepartementet. (2017). *Mulighetsstudier av fullskala CO_2-håndtering i Norge*. Retrieved from https://www.regjeringen.no/globalassets/departementene/oed/pdf/mulighetsstudien.pdf

[16] Birshan, M., Czigler, T., Siddharth, P., & Schulze, P. (2015). *The cement industry at a turning point: A path toward value creation*. McKinsey & Company. Retrieved from https://www.mckinsey.com/industries/chemicals/our-insights/the-cement-industry-at-a-turning-point-a-path-toward-value-creation

[17] Damodaran, A. (2017). *Margins by sector (US)*. NYU Stern. Retrieved from http://pages.stern.nyu.edu/~adamodar/New_Home_Page/datafile/margin.html

[18] Fennell, P. S., Florin, N., Napp, T., & Hills, T. (2012). CCS from industrial sources. *Sustainable Technologies, Systems and Policies, 2012*(Carbon Capture and Storage Workshop, Texas A & M University, Qatar).

[19] Berge, U., Gjerset, M., Kristoffersen, B., Lindberg, M., Palm, T., Risberg, T., & Svendsen Skriung, C. (n.d.). *Carbon capture and storage.* Zero Emission Resource Organization. Retrieved from https://zero.no/wp-content/uploads/2016/06/carbon-capture-and-storage.pdf

[20] Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Minx, J. C. Farahani, E., Kadner, S., … Zwickel, T. (Eds.). (2014). *Climate change 2014: Mitigation of climate change. Working group III contribution to the fifth assessment report of the Intergovernmental Panel on Climate Change*. New York, NY: Cambridge University Press.

[21] Kjärstad, J., Ramdani, R., Gomes, P. M., Rootzén, J., & Johnsson, F. (2011). Establishing an integrated CCS transport infrastructure in northern Europe—Challenges and possibilities. *Energy Procedia 4*, 2417–2424.

[22] Ringrose, P. S., & Meckel, T. A. (2019). Maturing global CO_2 storage resources on offshore continental margins to achieve 2DS emissions reductions. *Scientific Reports 9*.

[23] Kermeli, K., van Ruijven, B., Graus, W. C., Edelenbosch, O., Worrel, E., & van Vuuren, D. (2016). Enhancing the representation of energy demand developments in IAM models—A modeling guide for the cement industry (ADVANCE-WP2). Amsterdam, Netherlands: Utrecht University.

[24] Energy Transitions Commission. (2019). *Mission Possible: Reading net-zero carbon emissions from harder-to-abate sectors by mid-century*. Retrieved from http://www.energy-transitions.org/sites/default/files/ETC%20sectoral%20focus%20-%20Cement_final.pdf

[25] Norcem. (2020). *Norcem—Cement from Norway*. Retrieved from www.norcem.no

[26] IEAGHG. (2013). *Deployment of CCS in the cement industry*. Retrieved from https://ieaghg.org/docs/General_Docs/Reports/2013-19.pdf

[27] IEA. (2012). *Energy technology perspectives 2012*. Paris: International Energy Agency.

[28] IEA. (2011). *Technology roadmap—Carbon capture and storage in industrial applications*. Paris: International Energy Agency.

[29] Kuramochi, T., Ramírez, A., Turkenburg, W., & Faaij, A. (2012). Comparative assessment of CO_2 capture technologies for carbon-intensive industrial processes. *Progress in Energy and Combustion Science, 38*(1), 87–112.

[30] LEILAC. (2017). *Low emissions intensity lime and cement*. Retrieved from https://www.project-leilac.eu/

[31] van Straelen, J., Geuzebroek, F., Goodchild, N., Protopapas, G., & Mahoney, L. (2010). *CO_2 capture for refineries: A practical approach*. *International Journal of Greenhouse Gas Control, 4*(2), 316–320.

[32] Bombourg, N. (2012). *Global iron and steel industry 2012–2017: Trend, profit, and forecast analysis*. PR Newswire.

[33] Birat, J. P. (2010). *Sectoral assessment for the iron and steel sector*. Vienna, Austria: United Nations Industrial Development Organisation.

[34] IEA. (2010). *Carbon capture and storage: Model regulatory framework* (Working Paper). Paris: International Energy Agency.

[35] ISO. (2016). ISO *14040:2006. Environmental management—Life cycle assessment—Principles and framework*. Geneva, Switzerland: International Organization for Standardization.

[36] Arasto, A., Onarheim, K., Tsupari, T., & Kärki, J. (2014). Bio-CCS: Feasibility comparison of large scale carbon-negative solutions. *Energy Procedia, 63*, 6756–6769.

[37] Ministry of Employment and the Economy. (2014). *Energy and climate roadmap 2050*. Report of the Parliamentary Committee on Energy and Climate Issues, 16th October 2014. Helsinki: Ministry of Employment and the Economy.

[38] Melien, T., Brown-Roijen, S. (2009). Economics in carbon dioxide capture for storage in deep geologic formation. In L. I. Eide (Ed.), *Advances in CO_2 capture and storage technology results* (Vol. 3).

[39] Zakkour, P., & Cook, G. (2010). *CCS roadmap for industries: High-purity CO_2 sources sectoral assessment*. Report prepared by Carbon Counts for the UNIDO in support of the CCS Technology Roadmap for Industry.

[40] European Commission. (2014). *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. A policy framework for climate and energy in the period from 2020 to 2030*. COM (2014)15 Final/2.

[41] Melien, T. (2005). Economic and cost analysis for CO_2 capture costs in the CO_2 capture project scenarios. In D. C. Thomas (Ed.), *Carbon dioxide capture for storage in deep geologic formations—Results from the CO_2 Capture Project* (pp. 47–87). Elsevier.

[42] Ramirez, A., Hoogwijk, M., Hendriks, C., & Faaji, A. (2008). Using a participatory approach to develop a sustainability framework for carbon capture and storage systems in the Netherlands. *International Journal of Greenhouse Gas Control, 2*, 136–154.

[43] Chalmers, H., Gibbins, J., Gross, R., Haszeldine, S., Heptonstall, P., Kern, F., … Winskel, M. (2013). Analysing uncertainties for CCS: From historical analogues to future deployment pathways in the UK. *Energy Procedia 37*, 7668–7679.

[44] Ringrose, P. S. (2018). The CCS hub in Norway: Some insights from 22 years of saline aquifer storage. *Energy Procedia, 146*,166–172.

[45] IEA. (2013). *Technology roadmap—Carbon capture and storage 2013*. Paris: International Energy Agency.

[46] IEAGHG. (2013). *Iron and steel CCS study (Techno-economics integrated steel mill).* IEAGHG.

[47] IPCC. (2018). *Special report: Global warming of 1.5°C*. Intergovernmental Panel on Climate Change.

[48] IEA. (2011). *Summing the parts. Combining policy instruments for least-cost climate mitigation strategies*. Paris: International Energy Agency.

[49] ZERO. (2019). *Nye forretningsmodeller for karbonfangst- og lagring*. Zero Emission Resource Organization.

[50] Al-Juaied, M., & Whitmore A. (2009). *Realistic costs of carbon capture*. Cambridge, MA: Energy Technology Innovation Policy, Harvard University.

[51] Arasto, A., Tsupari, E., Kärki, J., Sihvonen, M., & Lilja, J. (2013). Costs and potential of carbon capture and storage at an integrated steel mill. *Energy Procedia, 37*, 7117–7124.

[52] IMO allows trans-boundary carbon capture and storage. (2019). *The Maritime Executive*. Retrieved from https://www.maritime-executive.com/article/imo-allows-trans-boundary-carbon-capture-and-storage

[53] Refjeringon.no. (2019). *Statsbudsjettet 2020: Fortsatt stor satsing på fangst og lagring av CO_2*. Retrieved from https://www.regjeringen.no/no/aktuelt/fortsatt-stor-satsing-pa-fangst-og-lagring-av-CO_2/id2671041/

[54] Setså, A. R. (2019). *Ønsker kull med nullutslipp*. geoforskning.no. Retrieved from https://www.geoforskning.no/nyheter/klima-og-CO_2/1991-onsker-kull-med-nullutslipp

[55] Anskaffelser.no. (2019). *Du kan nå få økonomisk støtte til å stille klimakrav i innkjøp.* Anskaffelser.no. Retrieved from https://www.anskaffelser.no/nyhet/2019/11/du-kan-na-fa-okonomisk-stotte-til-stille-klimakrav-i-innkjop

[56] DNB Boligkredditt. (2019). *Green Covered Bonds*. Retrieved from https://www.ir.dnb.no/sites/default/files/191024%20DNB%20Green%20Covered%20Bond%20Presentation.pdf

[57] Jakobsen, J., Roussanaly, S., & Anantharaman, R. (2017). A techno-economic case study of CO_2 capture, transport and storage chain from a cement plant in Norway. *Journal of Cleaner Production, 144*, 523–539.

[58] Svendsen Skriung, C. (2019). *Hva, hvorfor og hvordan CCS*. Retrieved from https://energi.tekna.no/wp-content/uploads/2019/05/CCS-presentasjon-mai-2019-generell-fokus-p%C3%A5-virkemidler.pdf

[59] Bennet, S., & Stanley, T. (2018). *Commentary: US budget bill may help carbon capture get back on track*. International Energy Agency. Retrieved from https://www.iea.org/commentaries/us-budget-bill-may-help-carbon-capture-get-back-on-track

[60] Multiconsult. (2018). *DNB Green Covered Bond*. Retrieved from https://www.ir.dnb.no/sites/default/files/Multiconsult%20Report%20(final).pdf

[61] United Nations. (2016). *The social and economic value of carbon and the promotion of efficient public transport and energy efficiency of vehicles*. United Nations Framework Convention on Climate Change. Retrieved from https://unfccc.int/resource/climateaction2020/media/1267/161010_mitigation_tp_final.pdf

[62] BCG. (2012). *Key arguments justifying the European cement industry's application for state aid to balance offshoring risk caused by the increase of electricity prices due to EU-ETS*.

[63] The Environmental Literacy Council. (n.d.). *Cement*. Retrieved from https://enviroliteracy.org/environment-society/materials-use/cement/

[64] European Commission. (2016). *Buying green! A handbook on green public procurement* (3rd ed). European Union.

[65] Baron, R. (2016). *The role of public procurement in low-carbon innovation* (OECD Background Paper). Chair of the Round Table on Sustainable Development at the Organisation for Economic Co-operation and Development. Retrieved from https://www.oecd.org/sd-roundtable/papersandpublications/The%20Role%20of%20Public%20Procurement%20in%20Low-carbon%20Innovation.pdf

[66] Innovative anskaffelser. (2020). Retrieved from https://innovativeanskaffelser.no/?s=green

[67] Jürgen-Friedrich, H., Hubert, H., Schenk, O., & Jochen, S. (2009). CCS for Germany: Policy, R&D and demonstration activities. *Energy Procedia 1*, 3917–3925.

[68] Zachman, G. (2015). *Making low-carbon technology support smarter* (Policy Brief). Bruegel. Retrieved from https://www.bruegel.org/2015/08/making-low-carbon-technology-support-smarter/

[69] Jansen, J. (2017). *Does the EU renewable energy sector still need a guarantees of origin market?* (CEPS Policy Insight No. 2017-27/July 2017). Brussels: CEPS.

[70] Schusser, S., & Jaraite, J. (2018). Explaining the interplay of three markets: Green certificates, carbon emissions and electricity. *Energy Economics, 71*, 1–13.

[71] Testa, F., Annunziata, E., Iraldo, F., & Frey, M. (2016). Drawbacks and opportunities of green public procurement: An effective tool for sustainable production. *Journal of Cleaner Production, 112*, 1893–1900.

[72] Palmujoki, A., Parikka Alhola, K., & Ekroos, A. (2010). Green public procurement: Analysis on the use of environmental criteria in contracts. *RECIEL, 19*, 250–262.

[73] Justnes, H. (2020). *DARE2C*. Sintef. Retrieved from https://www.sintef.no/prosjekter/dare2c/

[74] Justnes, H. (2017). *Durable aluminium reinforced environmentally-friendly concrete construction—DARE2C*. Nordic Concrete Research. Retrieved from https://sintef.brage.unit.no/sintef-xmlui/bitstream/handle/11250/2463869/Pages+from+NCR-Nr.-56-web-30juni17.pdf?sequence=2

Appendix A: Summary of focus group workshop

Referat etter materialforum 29. november 2019 Hvordan oppnå redusert klimafotavtrykk fra betong?

Fredag 29. november 2019 arrangerte Grønn Byggallianse og Byggevareindustriens forening materialforum for sine medlemmer. Møtet ble arrangert sammen med forskningssenteret FME ZEN, FutureBuilt, Statsbygg og Norcem. Tema for dagen var produksjon av betong med lavt klimafotavtrykk og forskningsprosjektet for karbonfangst og -lagring ved sementproduksjonsanlegget til Norcem i Brevik.

Etter presentasjoner fra Katharina Bramslev om Grønn Byggallianses arbeid, Ann Kristin Kvellheim om strategier og forretningsmodeller for redusert klimafotavtrykk fra betong, og Kjell Skjeggerud om Betongbransjens arbeid for å redusere klimafotavtrykk ble det gjennomført en gruppeworkshop for de oppmøtte.

Konklusjonen fra gruppeoppgavene er flertydige, men det er noen hovedpunkter som går igjen. For at sluttbrukeren skal være villig til å betale deler av de økte kostnadene for lavkarbonbetong med CCS, og andre materialer må det etableres reguleringer fra myndighetene med minstekrav som løfter hele sektoren og unngår konkurransevridning hvor enkelte ambisiøse aktører gjennomfører investeringer alene. Markedet vil etterspørre materialer med lave utslipp, og 75 prosent av de spurte i undersøkelse fra FME ZEN svarer at de er villige til å betale mer for materialer med lavere klimafotavtrykk. I eiendomssektorens veikart mot 2050 estimeres det med økte reelle merkostnader for en 100 m^2 i en betongblokk på mellom 7000,- og 8000,- For anleggs- og infrastrukturprosjekter som er typisk mer betongintensive vil kostnadene være høyere. Kostnadene er uansett mindre relevante når dette blir et krav fra myndighetene, bankene og markedet. Finansnæringen stiller stadig strengere krav til grønne bygg, og fremtidige krav til CO_2-utslipp vil sette fart på etterspørselen og dermed redusere prisene. Betongindustrien forbereder seg på å levere.

Forskere ved NTNU har tidligere sett på ulike entrepriseformer og samarbeidsmetoder med mer fokus på kvalitet og funksjon, i stedet for bare pris slik det er ved bruk av totalentrepriser. Deltakerne på forumsmøtet har mange ulike forslag til hvordan man gjennom entrepriser kan løfte frem gode løsninger. Bonusordninger for leveranser på økt reduksjon ut over kravet nevnes som et potensielt insentiv til byggeprosjektene som til nå kun har satt helhetlige prosjektkrav til CO_2-utslipp.

For at man skal komme i gang med produksjon av lavkarbonbetong med CCS må utbyggere stille tydelige og strenge krav både på prosjektnivå og til enkeltmaterialer. Samtidig må miljøsertifiseringsordningene stille tydelige og absolutte krav. Grønn Byggallianse oppfordres til stille strenge utslippskrav i BREEAM-NOR 2021. Markedet og myndighetene må identifisere funksjonelle enheter for utslipp per kvadratmeter og absolutte karbonbudsjett for bygg ved utbygging.

Gjennom etterspørsel både nasjonalt og internasjonalt vil norske produsenter og leverandører trolig ha et konkurransefortrinn når resten av verden nå vil etterspørre lavutslippsmaterialer.

Grønn Byggallianse oppfordres til å fortsette dialogen med norske myndigheter for å støtte CCS-prosjektet til Norcem og andre tiltak som kan få ned klimafotavtrykket fra materialer. CCS prosjektet til Norcem kan ses på som en politisk gullgruve og kan gi Norge en mer betydningsfull rolle i det grønne skiftet dersom markedet ikke er villig til å betale selv.

Appendix B: ZEN survey

ZEN-Case

Survey Title: ZEN-Case: Klimafotavtrykk og betong

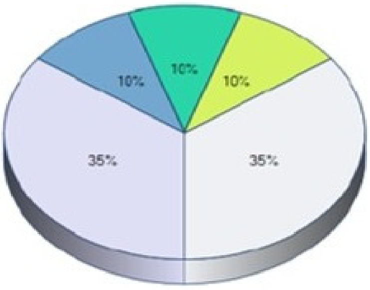
Survey Properties:

Survey Status: Open

Launched Date: N/A

Responses By Question Analysis:

1. Hvem representerer du (kryss av):



	Response Total	Response Percent
☐ Byggherre	7	35%
🟦 Arkitekt/rådgiver	2	10%
🟩 Entreprenør	2	10%
🟨 Betongprodusent/leverandør	2	10%
☐ Andre, vennligst spesifiser	7	35%
Total Respondents	**20**	

kommune

Kommune

Sement

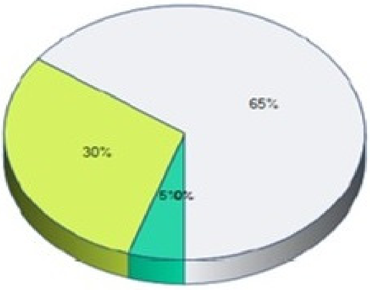
FutureBuilt - innovasjonsprogram i byggenæringen

Offentlig sektor

Forbildeprogram

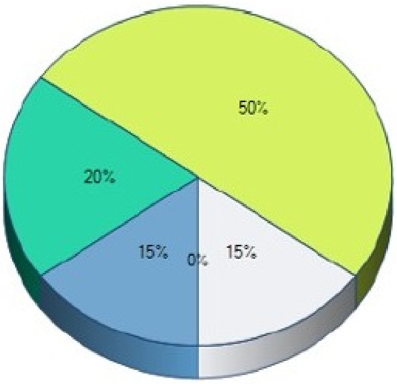
Byggevare produsent

2. I hvilken grad er lavere klimafotavtrykk viktig for dere?



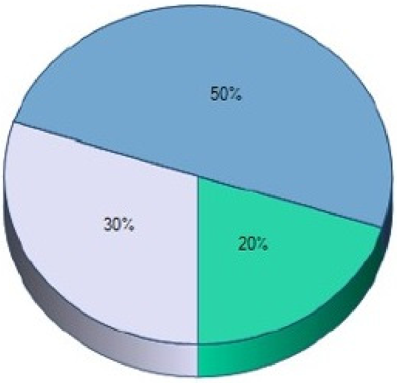
	Response Total	Response Percent
☐ Lite viktig	0	0%
🟦 Noe viktig	0	0%
🟩 Ganske viktig	1	5%
🟨 Viktig	6	30%
☐ Svært viktig	13	65%
Total Respondents	**20**	

3. I hvilken grad er lavere klimafotavtrykk viktig for deres kunder?



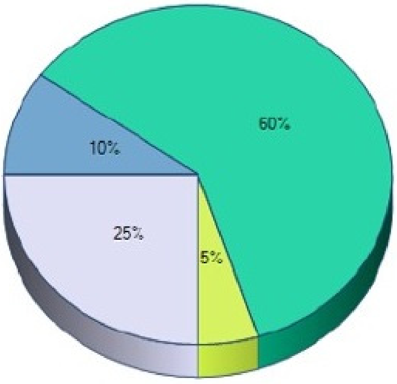
	Response Total	Response Percent
⬜ Lite viktig	**0**	**0%**
🟦 Noe viktig	**3**	**15%**
🟩 Ganske viktig	**4**	**20%**
🟨 Viktig	**10**	**50%**
⬜ Svært viktig	**3**	**15%**
Total Respondents		**20**

4. I hvilken grad er dere bekymret for redusert markedstilgang som følge av manglende fokus på klimafotavtrykk?



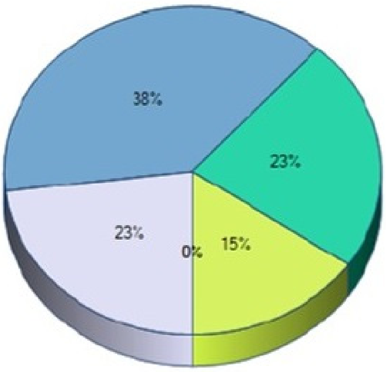
	Response Total	Response Percent
⬜ I liten grad	**6**	**30%**
🟦 I noen grad	**10**	**50%**
🟩 I stor grad	**4**	**20%**
Total Respondents		**20**

5. Er deres kunder villig til å betale en øket pris på leveransene for å oppnå lave klimafotavtrykk?



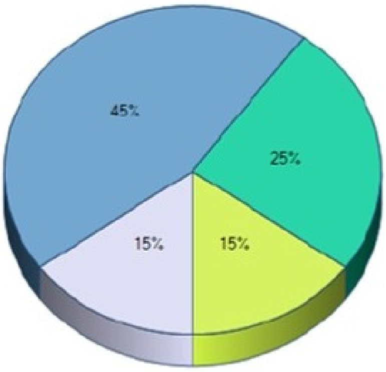
	Response Total	Response Percent
⬜ Ja	**5**	**25%**
🟦 Nei	**2**	**10%**
🟩 Kanskje	**12**	**60%**
🟨 Vet ikke	**1**	**5%**
Total Respondents		**20**

6. I tilfelle ja; hvor mye?



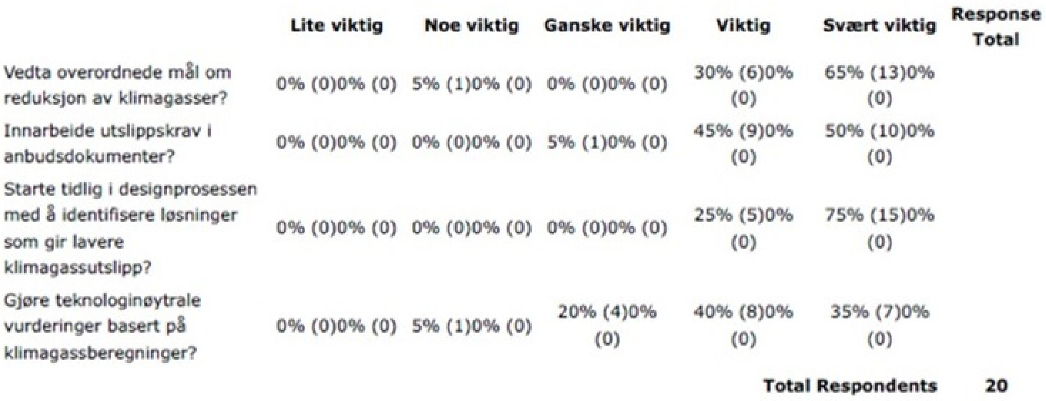
	Response Total	Response Percent
☐ <2%	3	23%
🟦 fra 2-5%	5	38%
🟩 fra 5-10%	3	23%
🟨 fra 10-15%	2	15%
☐ fra 15-20%	0	0%
🟧 over 20%	0	0%
Total Respondents		13
(skipped this question)		7

7. Hvilke kunder har høyest betalingsvilje for bedre klimafotavtrykk?

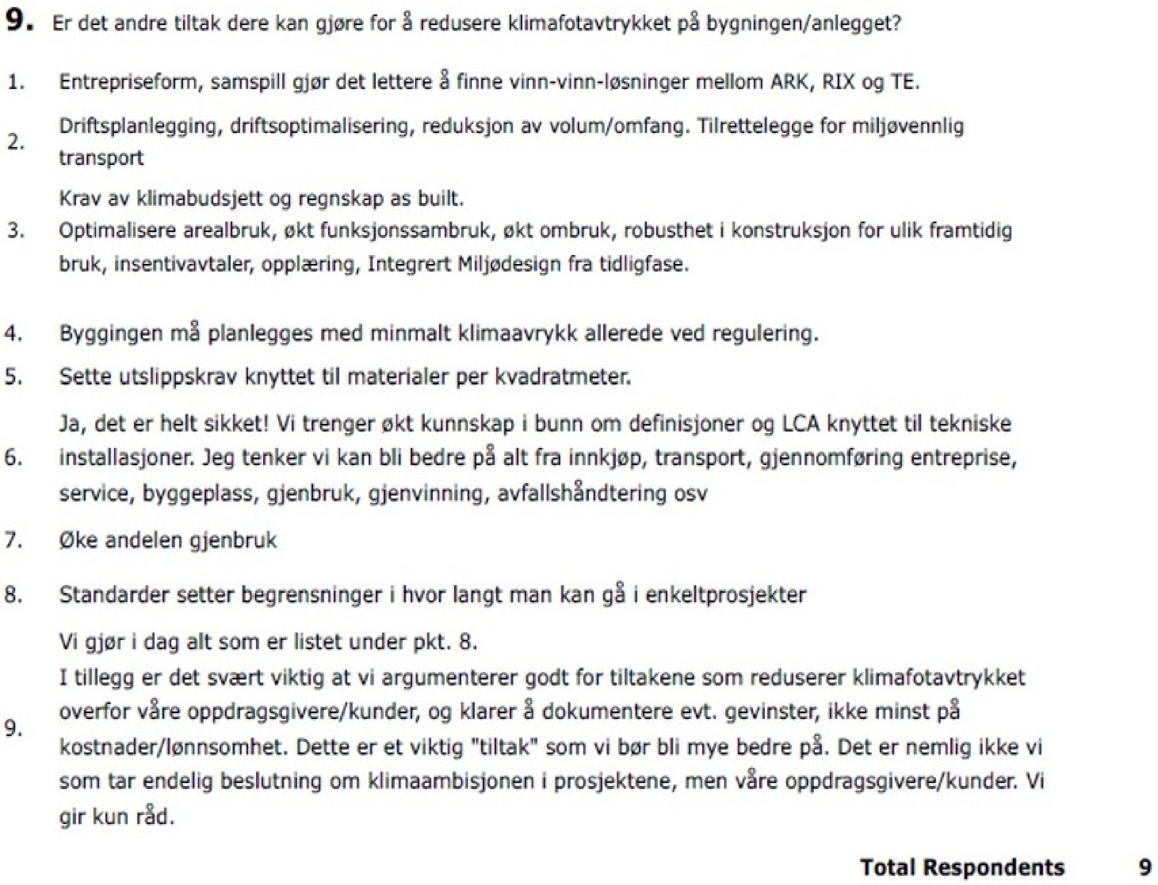


	Response Total	Response Percent
☐ Privat	3	15%
🟦 Offentlig	9	45%
🟩 Ingen forskjell	5	25%
🟨 Ikke aktuelt	3	15%
Total Respondents		20

8. Hvor viktig er følgende tiltak for å redusere klimafotavtrykket på den endelige bygningen/anlegget?



	Lite viktig	Noe viktig	Ganske viktig	Viktig	Svært viktig	Response Total
Vedta overordnede mål om reduksjon av klimagasser?	0% (0)0% (0)	5% (1)0% (0)	0% (0)0% (0)	30% (6)0% (0)	65% (13)0% (0)	
Innarbeide utslippskrav i anbudsdokumenter?	0% (0)0% (0)	0% (0)0% (0)	5% (1)0% (0)	45% (9)0% (0)	50% (10)0% (0)	
Starte tidlig i designprosessen med å identifisere løsninger som gir lavere klimagassutslipp?	0% (0)0% (0)	0% (0)0% (0)	0% (0)0% (0)	25% (5)0% (0)	75% (15)0% (0)	
Gjøre teknologinøytrale vurderinger basert på klimagassberegninger?	0% (0)0% (0)	5% (1)0% (0)	20% (4)0% (0)	40% (8)0% (0)	35% (7)0% (0)	
					Total Respondents	20

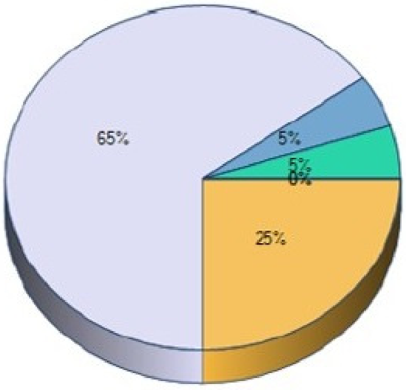


9. Er det andre tiltak dere kan gjøre for å redusere klimafotavtrykket på bygningen/anlegget?

1. Entrepriseform, samspill gjør det lettere å finne vinn-vinn-løsninger mellom ARK, RIX og TE.
2. Driftsplanlegging, driftsoptimalisering, reduksjon av volum/omfang. Tilrettelegge for miljøvennlig transport
3. Krav av klimabudsjett og regnskap as built.
Optimalisere arealbruk, økt funksjonssambruk, økt ombruk, robusthet i konstruksjon for ulik framtidig bruk, insentivavtaler, opplæring, Integrert Miljødesign fra tidligfase.
4. Byggingen må planlegges med minmalt klimaavrykk allerede ved regulering.
5. Sette utslippskrav knyttet til materialer per kvadratmeter.
6. Ja, det er helt sikket! Vi trenger økt kunnskap i bunn om definisjoner og LCA knyttet til tekniske installasjoner. Jeg tenker vi kan bli bedre på alt fra innkjøp, transport, gjennomføring entreprise, service, byggeplass, gjenbruk, gjenvinning, avfallshåndtering osv
7. Øke andelen gjenbruk
8. Standarder setter begrensninger i hvor langt man kan gå i enkeltprosjekter
9. Vi gjør i dag alt som er listet under pkt. 8.
I tillegg er det svært viktig at vi argumenterer godt for tiltakene som reduserer klimafotavtrykket overfor våre oppdragsgivere/kunder, og klarer å dokumentere evt. gevinster, ikke minst på kostnader/lønnsomhet. Dette er et viktig "tiltak" som vi bør bli mye bedre på. Det er nemlig ikke vi som tar endelig beslutning om klimaambisjonen i prosjektene, men våre oppdragsgivere/kunder. Vi gir kun råd.

Total Respondents **9**

10. Hvilke tiltak tror dere kan bidra til å øke viljen til å betale for bedre klimafotavtrykk?



		Response Total	Response Percent
🟪	Krav i lover eller forskrifter	13	65%
🟦	Statlig CO2 avgift	1	5%
🟩	Utnytte anskaffelsesregelverket aktivt	1	5%
🟨	Merkeordninger for produkter/løsninger/bygg med lavere klimafotavtrykk	0	0%
⬜	Vet ikke	0	0%
🟧	Annet, spesifiser	5	25%
		Total Respondents	**20**

Tror mer på gulrøtter her, det vil si at man får goder ved å bygge/investere i lavere klimafotavtrykk

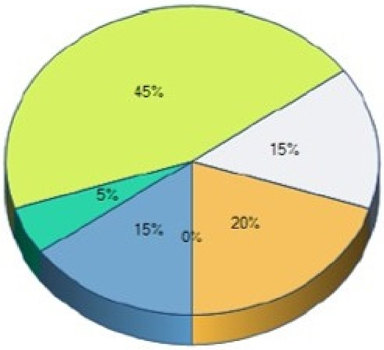
Mange tiltak - f.eks TEK som åpner for gjenbruk av utstyr mellom bygg

Her burde det være mulig å velge flere alternativer. Alle er relevante

Flere av disse, men kunne bare velge ett alternativ

Her kunne det bare krysses av på ett punkt. Krav i lover og forskrifter er selvfølgelig veldig viktig. Statlig CO2 avgift vil sikkert være veldig nyttig. Utnytte anskaffelsesregelverket er så klart veldig relevant og viktig, likeledes merkeordninger - mao er alle disse tiltakene viktige

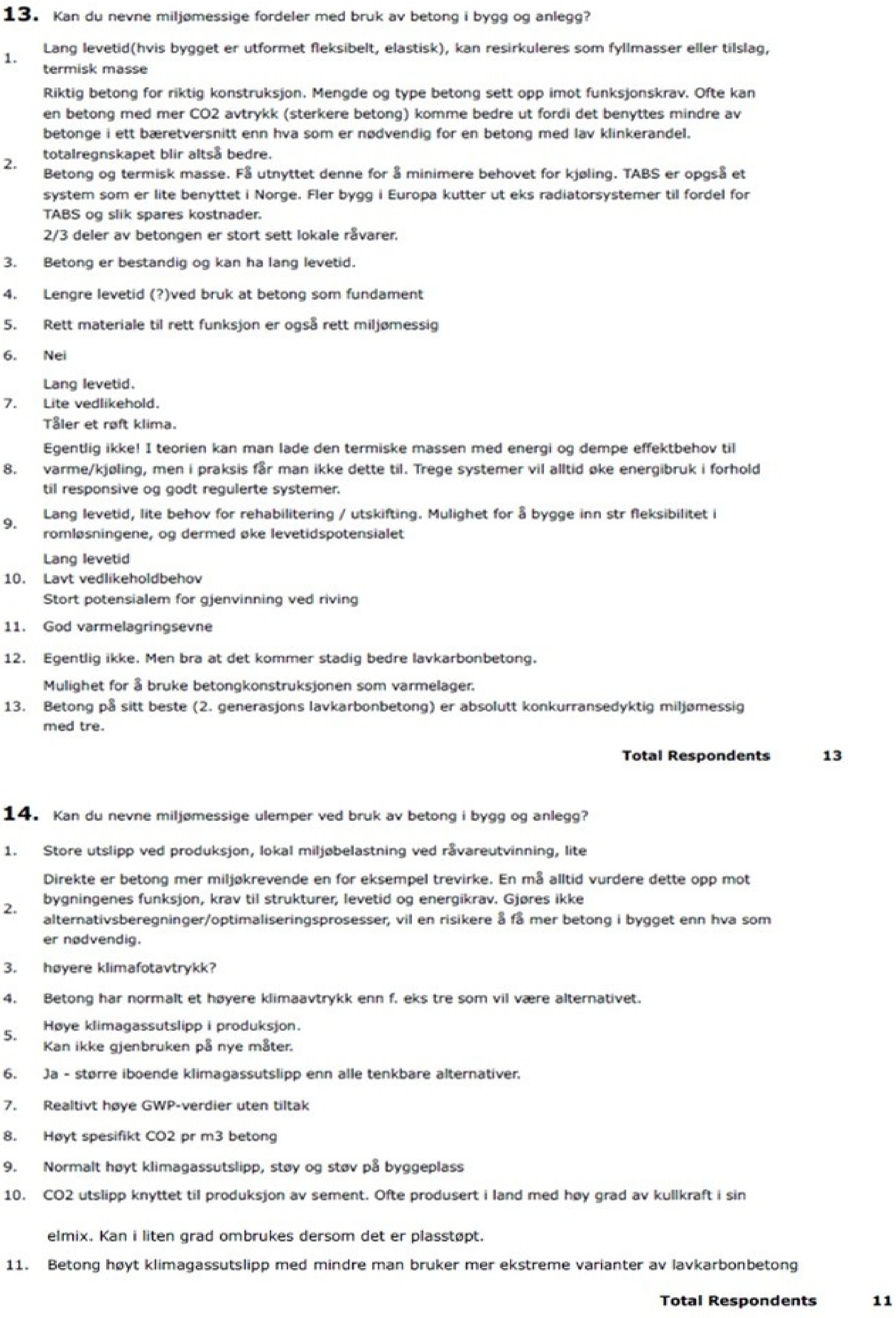
11. Carbon Capture and Storage (CCS) er en metode for å bremse global oppvarming ved å fange karbondioksid (CO2) og lagre det i stedet for å slippe det ut i atmosfæren. Dette jobber man med i forbindelse med sementproduksjon. Hvor viktig er CCS for å redusere klimafotavtrykket på bygg/anlegg?



	Response Total	Response Percent
☐ Lite viktig	0	0%
🟦 Noe viktig	3	15%
🟩 Ganske viktig	1	5%
🟩 Viktig	9	45%
☐ Svært viktig	3	15%
🟧 Vet ikke	4	20%
Total Respondents		**20**

12. Hvilke andre teknologier, metoder eller virkemidler er viktige for å redusere klimafotavtrykk på bygg/anlegg?

1. Energistyring, effektstyring, bæresystemer i tre, redusere byggefeil/prosjekteringsfeil, arealeffektifisering, ombruk/gjenbruk av bygg, bæresystemer og komponenter.
2. Helhetlig design med klimamål (funksjonskrav) og ikke spesifikke materialvalg som utelukker andre mer miljøvennlige løsninger. Hva som skal velges bør tas stilling til i en lca-analyse i detaljprosjektet. Forprosjektet er som regel for tidlig da de som gjennomfører dette ikke er oppmerksomme på alle løsninger som finnes.
   Øke perspektivet på LCA analyser til eks 100 år eller mer.
3. Tilskuddsordninger til klimatiltak ut over krav i lover og forskrifter vil bidra til en økt vilje til å redusere klimafotavtrykk. Dagens tilskuddsordninger premierer stort sett de som er i først i rekke i forhold til nyvinninger. NR 2 og alle andre nyter ikke samme fordeler. Dette motiverer ikke bredt nok.
4. Lav brutto/netto (færre bygde m2)
   Generelt materialer med lave utslipp
   Utslippsfri byggeplass
   Lokalprodusert energi
5. Krav til anleggsmaskiner, valg av varme og belysning, transport osv..
6. Så lenge det ikke er innarbeidet i Plan- og Bygningsloven samt at metoder og løsninger ikke har markedsgjennombrudd vil støtteordninger vær avgjørende for å reduaere kostnader og risiko. Som boligbygger får man ikke betalt for tiltak ut over PBL.
7. Ikke glemme, og slutte å underkommunisere fotosyntesen, og derved i særlig grad god skogforvaltning som den absolutt mest effektive og lønnsomme CCS-løsning kombinert med å lagre karbon ved å bygge i tre. Teknologien for moderne og effektivt trebyggeri finnes og er på frammarsj, det skorter fortsatt på kompetanse på en del fronter både på innkjøp, planlegging og bygging.
8. LCC, LCA, lover og forskrifter, sertifiseringer, merkeordninger, standarder.
9. Gjenbruk av kanalnett ved oppgradering, gjenbruk av kanaler i annet bygg (demontere og remontere i annet bygg), Smart service (færre reparasjoner og færre servicebesøk), fleksible innstallasjoner (mindre ombygging/rehab), innkjøp/lager/logistikk som gir mindre transport, kanalproduksjon på byggeplass, krav til gjenbruk, bruk av mer miljøvennlige materialer, miljøriktig emballasje, el-biler også i distriktene...
10. Design med lavt totalt materialforbruk per m2 bruksareal. Arkitekter og prosjektutviklere må ta større ansvar for å begrense utslipp.
11. Optimalisering av materialbruk i prosjekterings- og byggefasen
    Bygge for lang levetid med minimalt vedlikeholdsbehov
12. Gjenbruk og sirkulær design
13. Ny NS 3720 for klimagassberegninger i bygg og One Click LCA. Bør tas i bruk av de fleste aktørene.
14. Fokus på bærekraft og samfunnsansvar. Omdømme.
15. Få fart på sirkulær materialbruk markedet
16. Benytte trebaserte produkter og særlig isolasjon (mye volum)



13. Kan du nevne miljømessige fordeler med bruk av betong i bygg og anlegg?

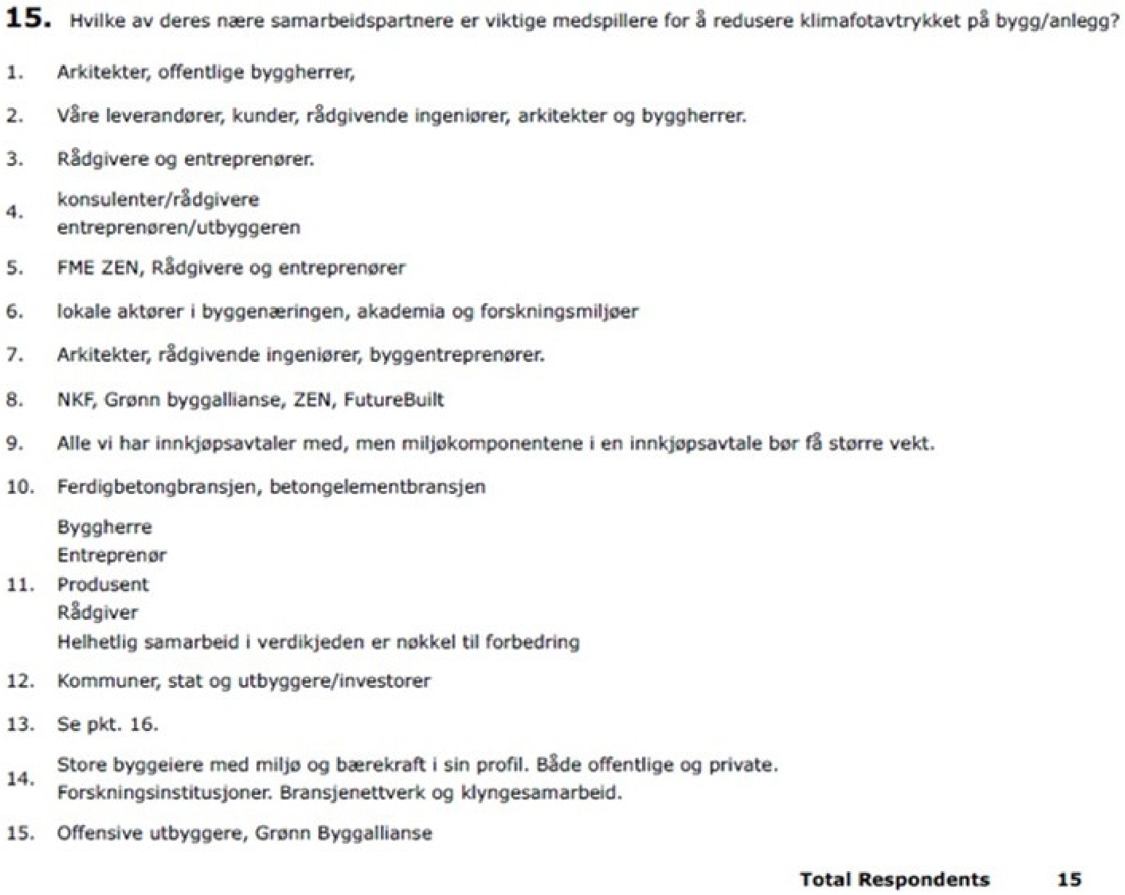
1. Lang levetid(hvis bygget er utformet fleksibelt, elastisk), kan resirkuleres som fyllmasser eller tilslag, termisk masse
2. Riktig betong for riktig konstruksjon. Mengde og type betong sett opp imot funksjonskrav. Ofte kan en betong med mer CO2 avtrykk (sterkere betong) komme bedre ut fordi det benyttes mindre av betonge i ett bæretversnitt enn hva som er nødvendig for en betong med lav klinkerandel. totalregnskapet blir altså bedre.
   Betong og termisk masse. Få utnyttet denne for å minimere behovet for kjøling. TABS er opgså et system som er lite benyttet i Norge. Fler bygg i Europa kutter ut eks radiatorsystemer til fordel for TABS og slik spares kostnader.
   2/3 deler av betongen er stort sett lokale råvarer.
3. Betong er bestandig og kan ha lang levetid.
4. Lengre levetid (?)ved bruk at betong som fundament
5. Rett materiale til rett funksjon er også rett miljømessig
6. Nei
7. Lang levetid.
   Lite vedlikehold.
   Tåler et røft klima.
8. Egentlig ikke! I teorien kan man lade den termiske massen med energi og dempe effektbehov til varme/kjøling, men i praksis får man ikke dette til. Trege systemer vil alltid øke energibruk i forhold til responsive og godt regulerte systemer.
9. Lang levetid, lite behov for rehabilitering / utskifting. Mulighet for å bygge inn str fleksibilitet i romløsningene, og dermed øke levetidspotensialet
10. Lang levetid
    Lavt vedlikeholdbehov
    Stort potensialem for gjenvinning ved riving
11. God varmelagringsevne
12. Egentlig ikke. Men bra at det kommer stadig bedre lavkarbonbetong.
13. Mulighet for å bruke betongkonstruksjonen som varmelager.
    Betong på sitt beste (2. generasjons lavkarbonbetong) er absolutt konkurransedyktig miljømessig med tre.

Total Respondents **13**

14. Kan du nevne miljømessige ulemper ved bruk av betong i bygg og anlegg?

1. Store utslipp ved produksjon, lokal miljøbelastning ved råvareutvinning, lite
2. Direkte er betong mer miljøkrevende en for eksempel trevirke. En må alltid vurdere dette opp mot bygningenes funksjon, krav til strukturer, levetid og energikrav. Gjøres ikke alternativsberegninger/optimaliseringsprosesser, vil en risikere å få mer betong i bygget enn hva som er nødvendig.
3. høyere klimafotavtrykk?
4. Betong har normalt et høyere klimaavtrykk enn f. eks tre som vil være alternativet.
5. Høye klimagassutslipp i produksjon.
   Kan ikke gjenbruken på nye måter.
6. Ja - større iboende klimagassutslipp enn alle tenkbare alternativer.
7. Realtivt høye GWP-verdier uten tiltak
8. Høyt spesifikt CO2 pr m3 betong
9. Normalt høyt klimagassutslipp, støy og støv på byggeplass
10. CO2 utslipp knyttet til produksjon av sement. Ofte produsert i land med høy grad av kullkraft i sin elmix. Kan i liten grad ombrukes dersom det er plasstøpt.
11. Betong høyt klimagassutslipp med mindre man bruker mer ekstreme varianter av lavkarbonbetong

Total Respondents **11**

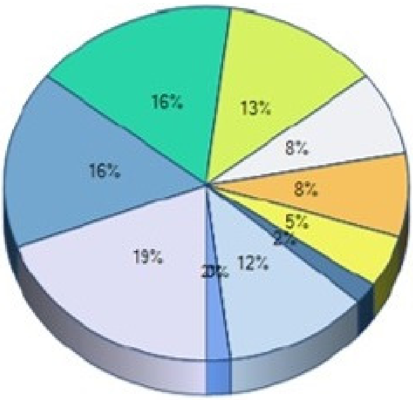


15. Hvilke av deres nære samarbeidspartnere er viktige medspillere for å redusere klimafotavtrykket på bygg/anlegg?

1. Arkitekter, offentlige byggherrer,
2. Våre leverandører, kunder, rådgivende ingeniører, arkitekter og byggherrer.
3. Rådgivere og entreprenører.
4. konsulenter/rådgivere
   entreprenøren/utbyggeren
5. FME ZEN, Rådgivere og entreprenører
6. lokale aktører i byggenæringen, akademia og forskningsmiljøer
7. Arkitekter, rådgivende ingeniører, byggentreprenører.
8. NKF, Grønn byggallianse, ZEN, FutureBuilt
9. Alle vi har innkjøpsavtaler med, men miljøkomponentene i en innkjøpsavtale bør få større vekt.
10. Ferdigbetongbransjen, betongelementbransjen
11. Byggherre
    Entreprenør
    Produsent
    Rådgiver
    Helhetlig samarbeid i verdikjeden er nøkkel til forbedring
12. Kommuner, stat og utbyggere/investorer
13. Se pkt. 16.
14. Store byggeiere med miljø og bærekraft i sin profil. Både offentlige og private.
    Forskningsinstitusjoner. Bransjenettverk og klyngesamarbeid.
15. Offensive utbyggere, Grønn Byggallianse

Total Respondents **15**

16. Er det andre aktører i innovasjons-økosystemet som er/kan bli viktige medspillere for å redusere klimafotavtrykket på bygg/anlegg? (flere kryss er mulig)

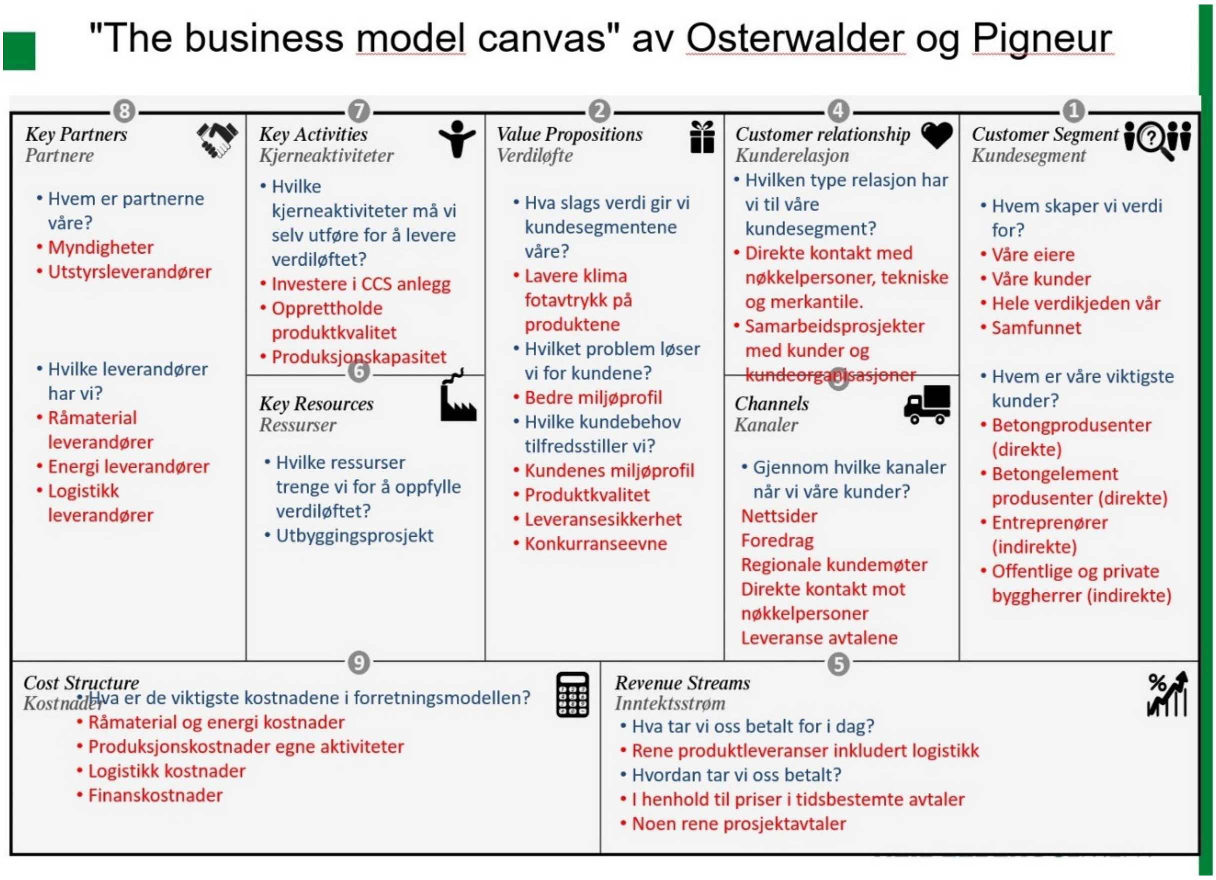


	Response Total	Response Percent
■ Offentlige aktører	20	100%
■ Forskningsinstitusjoner	17	85%
■ Rådgivningsselskaper	17	85%
■ Grønne gründere/entreprenører	13	65%
■ Grønne ildsjeler	8	40%
■ Risikoinvestorer	8	40%
■ Aktører innen infrastruktur	5	25%
■ Inkubatorer	2	10%
■ ZEN-partnere	12	60%
■ Ikke aktuelt	0	0%
■ Andre, vennligst spesifiser	2	10%
Total Respondents		**20**

Politikk

Alle aktører har en rolle å spille, og må ta den!

Appendix C: Norcem business model canvas



"The business model canvas" av Osterwalder og Pigneur

⑧ *Key Partners*
Partnere

- Hvem er partnerne våre?
- Myndigheter
- Utstyrsleverandører
- Hvilke leverandører har vi?
- Råmaterial leverandører
- Energi leverandører
- Logistikk leverandører

⑦ *Key Activities*
Kjerneaktiviteter

- Hvilke kjerneaktiviteter må vi selv utføre for å levere verdiløftet?
- Investere i CCS anlegg
- Opprettholde produktkvalitet
- Produksjonskapasitet

⑥ *Key Resources*
Ressurser

- Hvilke ressurser trenge vi for å oppfylle verdiløftet?
- Utbyggingsprosjekt

② *Value Propositions*
Verdiløfte

- Hva slags verdi gir vi kundesegmentene våre?
- Lavere klima fotavtrykk på produktene
- Hvilket problem løser vi for kundene?
- Bedre miljøprofil
- Hvilke kundebehov tilfredsstiller vi?
- Kundenes miljøprofil
- Produktkvalitet
- Leveransesikkerhet
- Konkurranseevne

④ *Customer relationship*
Kunderelasjon

- Hvilken type relasjon har vi til våre kundesegment?
- Direkte kontakt med nøkkelpersoner, tekniske og merkantile.
- Samarbeidsprosjekter med kunder og kundeorganisasjoner

Channels
Kanaler

- Gjennom hvilke kanaler når vi våre kunder?

Nettsider
Foredrag
Regionale kundemøter
Direkte kontakt mot nøkkelpersoner
Leveranse avtalene

① *Customer Segment*
Kundesegment

- Hvem skaper vi verdi for?
- Våre eiere
- Våre kunder
- Hele verdikjeden vår
- Samfunnet
- Hvem er våre viktigste kunder?
- Betongprodusenter (direkte)
- Betongelement produsenter (direkte)
- Entreprenører (indirekte)
- Offentlige og private byggherrer (indirekte)

⑨ *Cost Structure*
Kostnader

- Hva er de viktigste kostnadene i forretningsmodellen?
- Råmaterial og energi kostnader
- Produksjonskostnader egne aktiviteter
- Logistikk kostnader
- Finanskostnader

⑤ *Revenue Streams*
Inntektsstrøm

- Hva tar vi oss betalt for i dag?
- Rene produktleveranser inkludert logistikk
- Hvordan tar vi oss betalt?
- I henhold til priser i tidsbestemte avtaler
- Noen rene prosjektavtaler

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Research Centre on
ZERO EMISSION
NEIGHBOURHOODS
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CENTRE FOR
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