



The cement industry still earns a huge amount of money. But it is getting more difficult to make money with cement because of the industry's carbon footprint and the necessity for a transition to a green industry. In this article we strive to provide an overview about the many green challenges for the cement industry and what can be done. Controversial issues are the re-carbonation of concrete and the future financing of carbon capture and storage schemes.

GREEN CHALLENGE

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Green challenges in the cement industry

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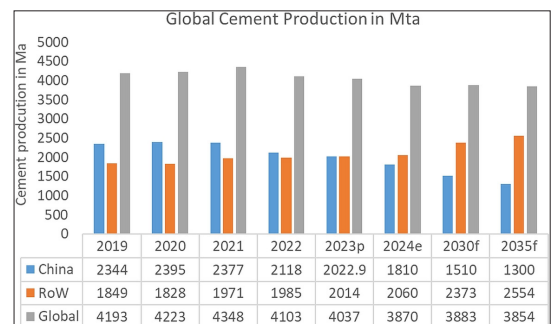
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Ash Grove Foreman Cement plant in the USA

1 Introduction

According to our projection [1], global cement production will not increase any further. On the contrary, cement production will decline from about 4350 million annual tons (Mt/a) in 2021 to 3850 Mt/a by 2025 (Figure 1) and will then mainly stagnate by 2050, because of the major

demand decline in China and because more 'green' cements will be introduced to the market. Such 'green' cements are free of clinker and are therefore not classical cements anymore. But the challenges for the cement industry will continue due to its massive CO₂ emissions and because more and more customers are looking for low-emission cements and concrete [2]. We classify the upcoming challenges into two major segments:



1 Global cement production outlook

- a. The conventional segment: This segment includes the modernisation of cement plants, the continued reduction of the clinker factor and the increase of alternative fuels. These steps will be facilitated in almost all countries by the cement producers, who wish to stay in the market.
- b. The advanced segment: This segment includes decarbonisation measures with so-called CCS/CCUS-projects (carbon capture and storage and carbon capture, utilisation and storage) as well as the development of clinker-free cements and concrete. These projects will be carried out in selected countries, by cement producers who are financially strong enough to proceed with the costly CCS/CCUS-projects, or where new independent producers are developing 'green' cement & concrete. The established cement producers will mainly continue to produce clinker and standard cements, which is their key competence.

The intention of this article is to provide valuable market information that has been collected during many years of working for the cement industry and its equipment suppliers. However, time has changed dramatically, from the moment when it seemed impractical to provide standardized cement plants to the present time, when it has become difficult to operate a cement plant.

2 The conventional segment

2.1 Modernisation of a cement plant

In many countries across the world, the efficiency of cement plants is still poor. This depends on plant

age, the pyro-processing system, grinding mills and many other factors. A very important issue is how smooth a plant is running and how the process can be automated with the help of digitalisation and advanced process control. It is very hard to say how cement producers should start modernizing a plant. If the company has not enough internal expertise, it is probably best to approach an engineering consulting company to make a plant check-up and find ways for debottlenecking and increasing the plant efficiency and availability, while reducing energy costs and emissions. In most cases also the previous supplier of the plant or the supplier of mayor equipment will be ready to provide expertise. Plant modernizations can decrease CO₂ emissions by 30% and more.

It was about ten years ago that we provided a market review about vertical roller mills (VRM) for the cement industry [3]. Not much has changed regarding the advantages of these mills. VRMs achieve comparatively high availability rates (Figure 2), save up to 30% specific grinding energy when compared to ball mills and are more suitable than any other type of mill for the grinding of composite cements [3]. When we look back to about 10 years ago, VRM still needed promoters to get used in cement grinding. Now that is fine, the advantages of VRM are widely accepted as for the grinding of cement raw materials, coal and granulated blast furnace slag (GBFS). However, the situation has changed in cement production. New integrated cement plants are less frequently ordered, while the average size of new integrated plants is increasing, as is the number and size of separate grinding plants.

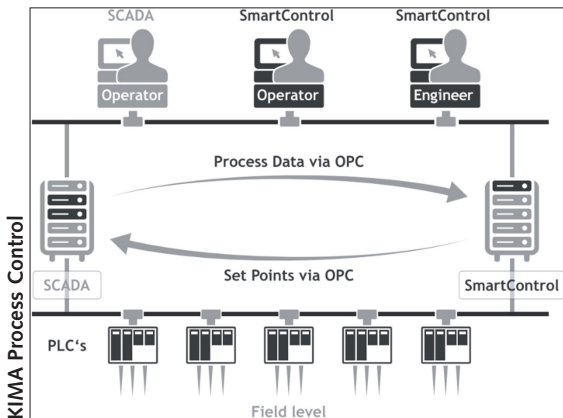


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2 Grinding rollers in a VRM

A second major issue is the automation and digitalization of cement plants [4]. The performance of a modern cement plant depends on a large number of parameters.

An optimization of the plant's throughput need not be the energy optimum or vice versa. For many years now, various expert systems have been on the market, which are specifically designed for cement plants and allow advanced automation and process control. The expert system's approach



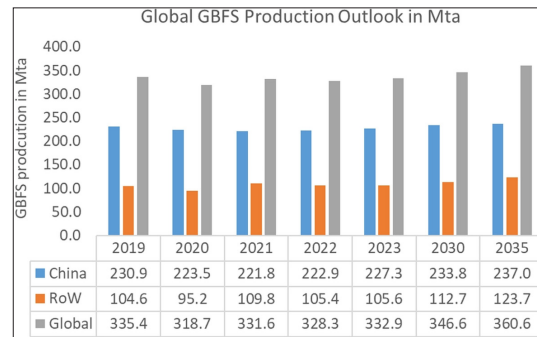
3 Smart control system

2.2 Reduction of the clinker factor

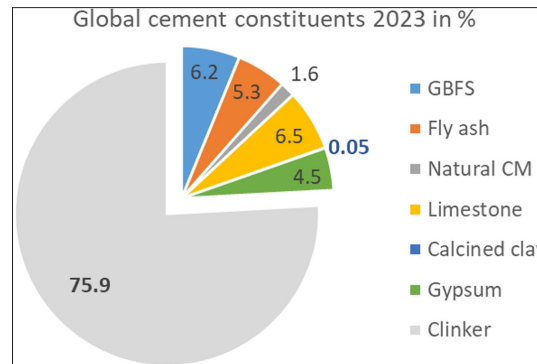
The reduction of the clinker factor (the clinker to cement ratio) is ongoing. A further reduction mainly has to do with the availability of cementitious materials [5], the acceptance of higher proportions of limestone cements for applications which are not highly demanding, such as for C30 concrete [2], and finally, how the market for limestone-calcined clay cements (LC3) will further develop [6]. In the past, the availability projections for fly ash and granulated blast furnace slag (GBFS) saw only declining curves and a significant decrease in these products. However, while the phasing-out of coal-fired power plants has a high priority in Europe and North America, there are regions such as Asia, where new cf-power plants are still being built and a phasing-out will not take place before 2050 to 2060. With GBFS we have two hemispheres in the usage and development of blast furnaces and the transition to a green steel industry. A new report [7] shows that the global availability of GBFS will not decrease, but on the contrary even increase by 2035 (Figure 4).

The International Energy Agency (IEA) projected several years ago [8], how the market for calcined clay will increase to allow a decrease of the clinker factor. We now see a lot of new calcined clay plants in the world, but we are lagging far behind the IEA-projection. At the moment, calcined clay accounts for a production of 2.0 Mta or only a 0.05% market share of the constituents in the cement production (Figure 5). There are many reasons for this. Up to now, new clay calcination plants have an average size of 1000 t/d

is to model the behaviour of the best kiln operators by means of neural networks, advanced sensors and predictive or model control. The solutions today allow the combination of artificial intelligence and predictive advanced control based on a smart-control software (Figure 3). For example, one MillMaster by Kima Process Control can save as much CO₂ as 725 E-Cars (10000 km annual mileage). What is required are innovative sensor systems and a closed-loop process control.



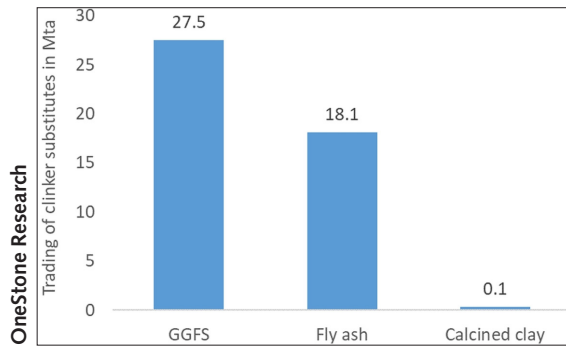
4 Global availability of GBFS



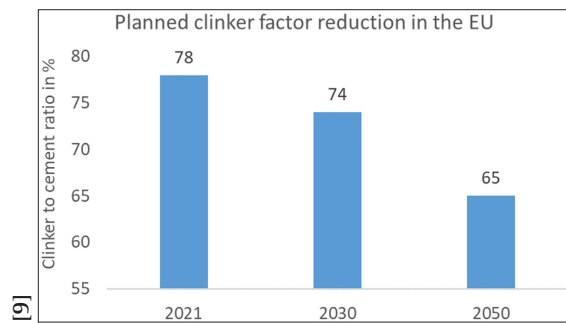
5 Market share of clinker substitutes 2023

and so they are very small when compared to new integrated cement plants, which have an average size of about 7000 t/d. Furthermore, there are booming cement countries such as India, where no full-scale clay calcination plants are operational. Finally, cement companies need to get the mining rights for the mining of clay [2]. This can be a very time-consuming procedure.

A further reduction of the clinker factor in the cement industry can only be achieved if cementitious and other raw materials for producing cement are traded to a much larger extent. Up to now, the global trading of GBFS, fly ash and calcined clay is very limited (Figure 6). These trading figures also include the trade of cementitious products directly to the concrete industry, which does not have an effect on the clinker rate in cement. It can be expected that in the next few years, the consumption of cementitious products in the concrete industry will increase, which has already been happening in Anglo-Saxon countries for several years. Therefore, projections



6 Trading of clinker substitutes 2023



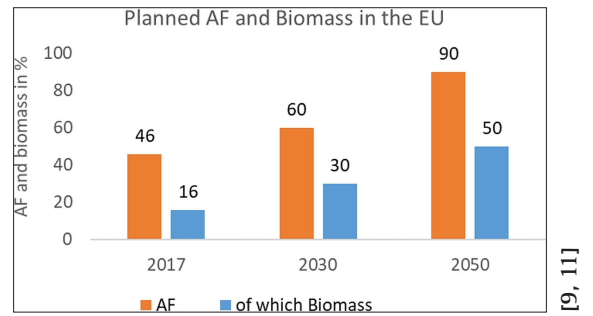
7 Reduction of the clinker factor in the EU

made by cement producer associations about the further reduction potentials might be too optimistic. Cembureau, for example, projects in its net-zero roadmap 2050 [9] that in Europe the clinker factor will be reduced from 78% now to 74% by 2030 and 65% by 2050 (Figure 7).

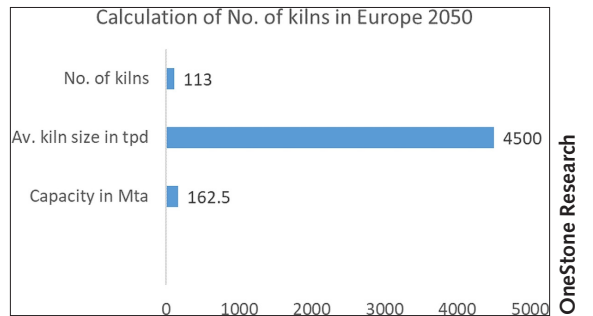
2.3 Increase in alternative fuels

The global population is projected to grow to more than 10 billion by 2084. After this year the population will decline but much more municipal waste will be generated. This municipal solid waste (MSW) can be upgraded to high-quality RDF (refuse derived fuel), which can be used as an alternative fuel in cement kilns instead of conventional fuels, such as coal, pet coke, oil and gas. RDF can also replace other solid recovered fuels (SRF), such as plastic, which can be pyrolyzed for high-quality recycled plastics [10]. Accordingly, if we follow the large RDF-market potential, then the outlook for the cement industry is very positive because of the high temperatures in cement kilns, which are ideal for burning waste. In Europe, there are already cement plants burning up to 100% waste. In 2017, the alternative fuel use represented 46% of the total fuel needs of kilns across Europe, of which 16% was biomass. Cembureau targets in its Roadmap 2050 [12] reaching 60% alternative fuels containing 30% biomass in 2030, and 90% alternative fuels with 50% biomass by 2050 (Figure 8).

Achieving these targets will definitely require very great efforts. The main question is, where will the EU get all the biomass from? Finally,



8 Alternative fuels development



9 Required kilns in Europe 2050

the other main questions are, how many cement kilns will still be operational by 2050 and what are the energy requirements for these kilns. If we project a cement production of about 200 Mt/a in Europe by 2050 (excluding Türkiye), a clinker factor of 65% and a utilization rate of 80%, then 162.5 Mt/a of clinker capacity should be available in Europe in 2050. If we calculate the average kiln size in 2050 as being 4500 t/d, then only about 113 kilns will be required in Europe (Germany today still has 46 kilns) (Figure 9). With an average thermal fuel energy requirement of 2700 MJ/t cement in 2050, about 5400 TJ/a will be required in Europe's cement industry. Biofuels have a very different calorific value (3 MJ/kg for sewage sludge, 13 MJ/kg for waste wood, 18 MJ/kg for animal meal). With 50% biomass and an average calorific value of 10 MJ/kg, the cement industry in Europe will require about 27 Mt/a of biomass as a fuel. This will hardly be achieved.

3 The Advanced Segment

3.1 Advanced decarbonization

Do we need CCS/CCUS projects if the cement industry has a powerful tool called natural re-carbonation? Re-carbonation of cement refers to the process that the CO₂ emitted during cement production is re-absorbed in concrete structures by carbonation. The CO₂ uptake in concrete is a relatively slow process that takes place over many years. The basic model (Figure 10) is that the CO₂ uptake in concrete increases with the service life of the concrete, while the annual uptake rate decreases year by year [12]. This is because re-carbonation starts from the surface of the

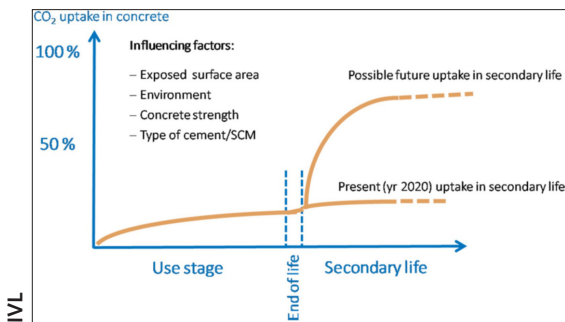
concrete because the CO₂ in the air diffuses into the porous structure and reacts with Ca(OH)₂ and other hydrated phases to form Calcium Carbonate (CaCO₃). There are many parameters influencing this process. The exposed concrete surface can be blocked by paint or by other factors. For large concrete structures, only a small part of the concrete at the outer surface layer will be carbonated during its service life.

Today, we know that re-carbonation of concrete by entrained CO₂ in the air is a function of the permeability of the concrete, the CO₂ concentration, the hydrated phases in the concrete for forming CaCO₃, the water vapour pressure in the concrete and other environmental influences [13]. The permeability of concrete can be measured by standard procedures using the Torrent method and can vary by more than 3 powers of ten, which is a very large range (Figure 11). Without this knowledge, any calculation or estimation of the effect of re-carbonation of CO₂ in concrete, such as provided by the IPCC (Intergovernmental Panel on Climate Change), is useless. Heidelberg Material uses the model provided by the IVL and IPCC for the introduction of their evoZero® cement, produced in Brevik/Norway, stating that 60% of the CO₂ from the plant is captured and arguing that 40% will be re-carbonated during the concrete lifetime. We believe that this is not a paradigm shift but some kind of mislabelling.

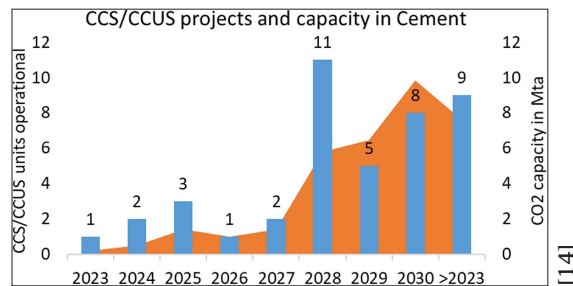
A cement which is not produced carbon-free cannot be a carbon-free cement. You may see this differently, but then any company manufacturing limestone cement or cement that is not used for large concrete structures could argue they produce carbon-free cement. It also makes no sense to

argue with a second service life after the concrete has been demolished and reprocessed. Any carbon credits that are generated from the reprocessing of concrete should be assigned to the reprocessing plant or the operator of the plant and not to the former producer of the cement or concrete. Anyhow, at the moment this is rather theoretical, as the processing of concrete after its first lifetime is only a very small market of the global annual concrete production. Accordingly, to our knowledge, the re-carbonation of all cement in concrete only contributes 2-3% of the annual cement production, which still emits between 1600 and 2600 Mt/a of CO₂ (Global Carbon Atlas and World Economic Forum).

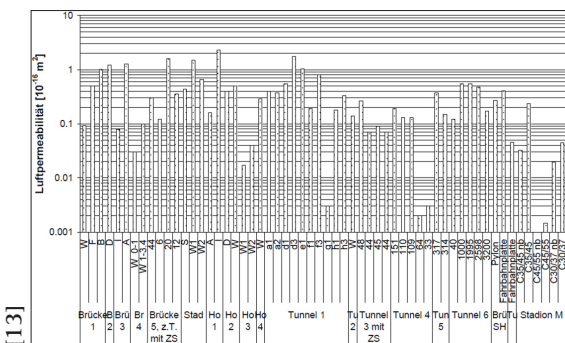
The answer is 'Yes', we need CCS/CCUS projects on the way to a carbon-zero cement production. At the first global cemCCUS carbon capture, utilisation and storage conference in Oslo in May this year [14], I gave an overview of cement and lime CCS/CCUS projects in Europe and worldwide. We identified 42 full-scale CCS/CCUS projects in the cement industry (status 04/2024), with a capacity of 34.3 Mt/a CO₂ capture and storage or utilisation. The projects are by 15 cement companies in about 21 different countries. 31 projects (74%) with 24.0 Mt/a (70%) capacity are in Europe, 6 projects with 9.05 Mt/a capacity are in North America, 5 projects with 1.2 Mt/a capacity are in Asia/Oceania (Figure 12). Projects include the amazing GOCO2-project in Airvault cement plant in France by Ciments Calcia (Figure 13) and the Carbon2Business CCUS in Lägerdorf, Germany by Holcim (Figure 14).



10 Basic model on CO₂ uptake in concrete



12 CCS/CCUS full-scale projects in cement



11 Air permeability of measured concrete structures



13 CCS project in the Airvault cement plant

Heidelberg Materials



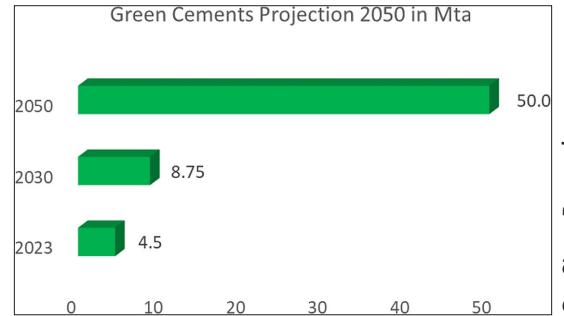
14 CCUS project in the Lägerdorf cement plant

However, the cement industry is far behind the net-zero emission (NZE) goal to be achieved by 2050. According to the IEA, the cement emissions intensity has remained relatively stable since 2018 at just under 0.6 t CO₂ per t of cement produced, following several years of modest increase largely due to an increasing clinker-to-cement ratio in China. To get on track with the NZE Scenario 2050, emissions must fall by an average of 3% annually through to 2030. Energy and material efficiency improvements, adoption of low-carbon fuels, clinker substitution and innovative near zero emissions production routes will be key to achieving this objective. But the NZE goal for 2050 can only be achieved with CCS/CCUS-projects and here the cement industry is far behind other industries. While 50.5 Mta of CO₂ capture technology is already globally available (2023), cement just contributes to a very small proportion.

It is not a question of the carbon capture technologies that are available on the market. The cement industry has just not chosen from the wide portfolio, but this can be expected to happen in the next 3-5 years. The main question is, does the cement industry have the financial power to develop many more CCS/CCUS projects. CCS-projects will also depend on the infrastructure of pipelines from the cement plants to the sea ports, from where the liquid CO₂ will be transported by ship to underground reservoirs in the sea [15]. The VDZ study estimates the investment required to build the identified German CO₂ pipeline network with a length of 4800 km at around € 14 billion. This results in calculated costs for pipeline transport of € 25 to 35/t CO₂. Up to now, about 80% of the European CCS/CCUS projects were funded to almost 50% by EU Innovation Funds and similar sources from the EU ETS carbon permits. The future of these funds is completely unknown as yet.

3.2 Green cements

Green cements are an alternative. We estimate that the global amount of green clinker-free cements at the moment is not more than 4-5 Mt/a. This is only about one per thousand of the global cement production. But we see many, many companies operating in this market segment including



15 Market potential of 'green' cement

Ecocem, Hoffmann Green Cement, Cemvision, Sublime Systems, and BrimeStone, to name a few. The name 'green cement' has not been protected and therefore almost all cement producers use the name to improve their product marketing. These cement producers actually supply conventional cement where the clinker ratio has been reduced. Instead of this definition, we are referring to a green clinker-free cement. Worldwide, there are many projects, where 'green' cement is being introduced. Worldwide, we calculate that the real 'green' cement market has the potential to grow by about 10% p.a. from 2023 to 2030 to 8.75 Mt/a and by 9.1% p.a. to 50 Mt/a by 2050 or about 1.3% of the global cement production (Figure 15).

4 Outlook

Our fear is whether the net-zero emission (NZE) goals of the cement industry by 2050 can be achieved. CO₂ will still be produced in 2050 by the cement industry (we are only thinking about the scope 1 emissions). By the way, the cement industry is also still far behind the definitions of scope 1-3 CO₂ emissions. Other sectors such as mining are far more advanced here [16]. Net-zero emissions (carbon neutrality) can only be achieved if not more CO₂ is emitted than is absorbed by all available carbon sinks, such as trees, the biosphere, oceans, land and concrete. Here starts the real problem, as we are permanently destroying most of our most valuable carbon sinks. Let us take the oceans as one example. The warmer and saltier the oceans are or become, the less carbon dioxide can be absorbed or stored, and the more is released into the atmosphere. Oceans cover 70% of the globe, hold 60% of all CO₂.

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REFERENCES

- [1] OneStone Consulting: CCF2Up – Cement Country Focus Market Report, 3rd Edition April 2024, 2 updates per year by OneStone Consulting Ltd., Varna, Bulgaria
- [2] Ian Riley, Personal communication, 07.08.2024; Ian Riley, CEO of the World Cement Association (WCA), London, Great Britain, UK
- [3] Harder, J.: Market trends in vertical mills for the cement industry. ZKG International, 1-2/2024, pp. 42 - 52
- [4] Harder, J.: Digital transformation of the cement industry. ZKG International, 4/2023, pp. 27 - 36

- [5] Harder, J.: Availability of cement raw materials. ZKG International, 8/2022, pp. 32 - 40
- [6] Harder, J.: Latest trends in clay activation. ZKG International, 6/2021, pp. 23 – 32
- [7] OneStone Consulting: GBFS Market Outlook 2035, Published June 2024 by OneStone Consulting Ltd., Varna, Bulgaria
- [8] IEA (International Energy Agency): Technology Roadmap, Low-Carbon Transition in the Cement Industry. International Energy Agency, April 2018, Paris/France
- [9] Cembureau: Cementing the European Green Deal, Reaching Climate Neutrality along the Cement and Concrete Value Chain by 2050. Cembureau – The European Cement Association, 12.05.2020, Brussels/Belgium
- [10] Harder, J.: Latest trends in alternative fuels. ZKG International, 5/2017, pp. 53 – 59
- [11] Cembureau: From Ambition to Deployment – Our 2050 Roadmap. Cembureau – The European Cement Association, May 2024, Brussels/Belgium
- [12] IVL (Svenska Miljöinstitutet): Calculation of CO₂ uptake in concrete structures by carbonation. IVL Svenska Miljöinstitutet AB. Stockholm, Sweden
- [13] Jacobs, F.: Air permeability as characteristic parameter for the quality of cover concrete of concrete structures. TFB, Technische Forschung und Beratung für Zement und Beton, Wildegg F. Jacobs, Dr. sc. techn., Dipl.-Geol. BDG/SIA; Forschungsauftrag AGB 2002/003 auf Antrag der Arbeitsgruppe Brückenforschung (AGB), September 2006
- [14] Harder, J.: Overview of cement and lime CCS/CCUS projects in Europe and worldwide. Presentation at 1st CemCCUS Conference at 14.-15.05.2024, Oslo, Norway
- [15] VDZ: Environmental Data of the German Cement Industry 2022. Published 2023, Düsseldorf, Germany.
- [16] Harder, J.: Reducing CO₂ emissions - Pathways for decarbonization in mining. AT Minerals Processing 05/2024, pp. 46 - 56.