Reduction of greenhouse gas emissions in cement and concrete production

International climate goals of the Green Deal, Fit for 55 and Carbon Border Adjustment programs require for the production and use of cement to be climate neutral by 2050.

Climate and environmental protection belongs among the Czech cement industry's top priorities and the industry recognizes itself as a part of the construction and environment chain related to the principles of the Circular Economy.

SVAZ VÝROBCŮ CEMENTU ČR

Introduction

Climate change and the related industrial measures are recognized by the Czech cement industry to be a fundamental challenge. Cement, an energy and environmentally intensive material, is part of the construction-climate chain and as such is ready to aid in the whole construction cycle decarbonization from the raw materials extraction to the used old concrete recycling.

Concrete is still widely used, and cement production emits a considerable amount of one of the greenhouse gases – carbon dioxide CO_2. We will, however, need concrete to build an infrastructure that can cope with climate change and population growth. **The question is - how to reduce the environmental impact of cement and concrete if we still rely on it?**

According to recent statistics, about 7-9% of global CO_2 emissions are emitted in cement production. More than 55% of cement is produced and utilized in China, i.e. about 2.5 billion tons out of the world's production of 4.4 billion tons in 2021. In Europe, we produce and process approximately 0.250 billion tons of cement per year, so approximately one tenth of the production in China. In the Czech Republic, 4.5 million tons of cement are produced annually, which is about 2% of the European production.

The Czech cement industry, although it produces a relatively small volume worldwide, searches intensively for ways to reduce these emissions.

Current decarbonization takes place in the following steps:

1. Treatment of raw material composition through previously decarbonized limestone components, especially waste
   → **continuously fulfilled and ongoing search for other sources**

2. Fundamental transformation of the fuel base using alternative waste fuels and a permanent shift away from fossil fuels
   → **85% and above of usable maximum reached**

3. Supplementing fuel mix with a share of renewable combustible biomass
   → **maintaining current level of 30%**

4. Reduction of the clinker factor in cements and use of composite cements in the production of concrete
   → **current task is being solved in co-operation with the concrete community**

5. Preparation for the introduction of new technologies to capture and store carbon dioxide in deep underground storage
   → **energy and investment wise the most demanding task**

6. In cooperation with the construction industry savings when new materials for the construction of climate-neutral buildings are used
   → **necessary step for the decarbonization of the construction industry**

7. Safe carbonation of concrete and CO_2 absorption in the concrete life cycle
   → **application of the conclusions of the intergovernmental panel for climate change into balanced practice**

8. Use of aggregate from recycled concrete
   → **ecological source of new aggregates within the circular economy**

Decarbonization RoadMap of the Czech cement industry

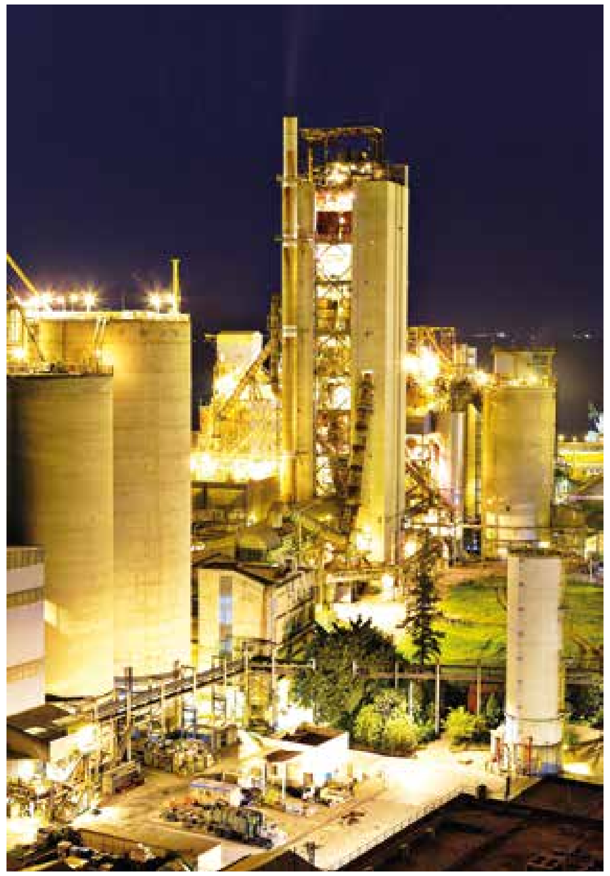
The reduction of greenhouse gas emissions, in particular of fossil fuel and carbonate carbon dioxide originating from the production of electricity and material industrial production, is a significant, contemporary challenge. Prepared legislation of the European Green Deal and the Fit for 55 package creates a strategy for the European society that plans for a climate neutral, innovative and progressive future. Necessary climate change is hereby identified as one from the primary social challenges.

In the energy field, moving on from the burning fossil fuels will be necessary, through a time limited stage of using natural gas and nuclear energy, to fully utilize green energy originating from water, wind, sun, and biomass.

In the field of industrial technology, ecological cement production plays a primary role together with the subsequent use in concrete construction technologies. These will aid Europe in minimizing greenhouse gas emissions and maintaining conditions for building a climate-neutral environment which will serve as the foundation for wind-turbines, hydroelectric plants, passive living, and the necessary ecological investment.

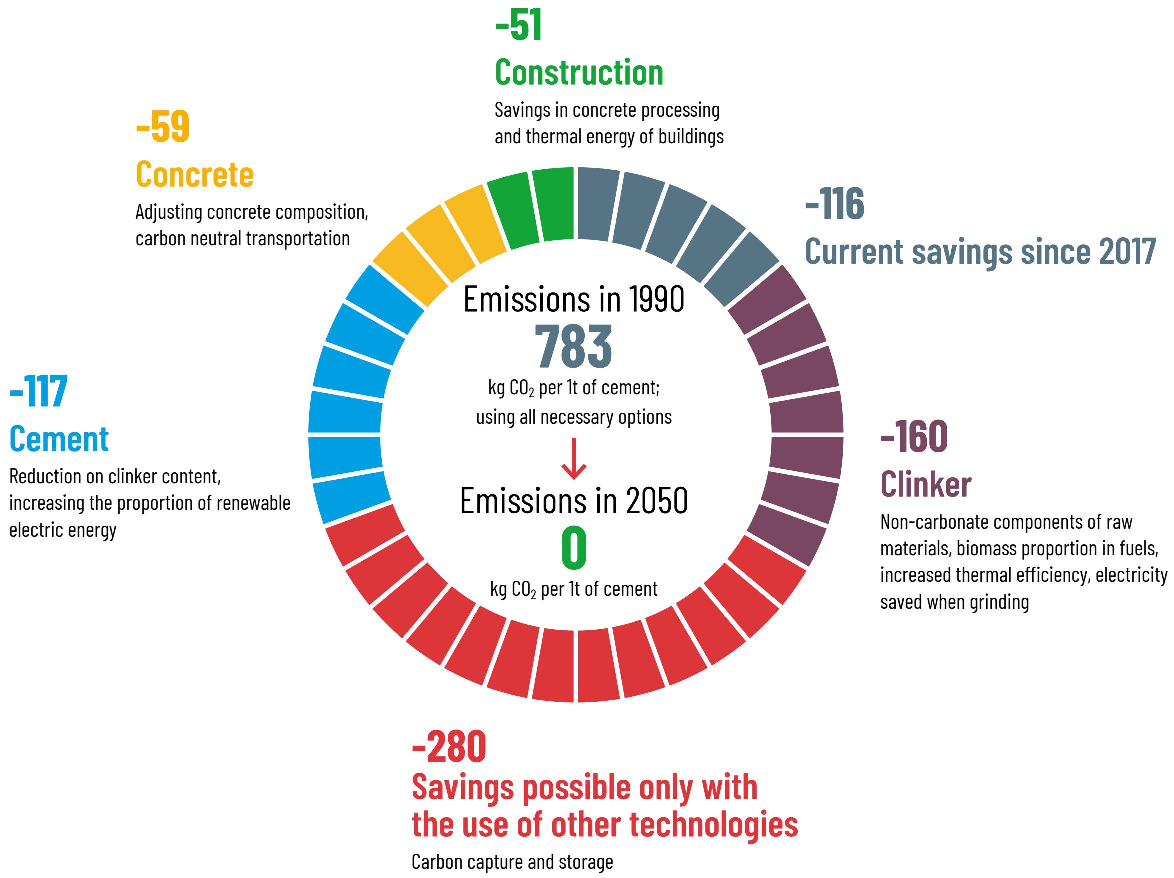
Limestone decomposition naturally produces basic CO_2 procedural emissions, which can be slightly reduced by the addition of suitable recycled raw materials. However, these process emissions, which cannot be influenced further, make up about two thirds of the total CO_2 emissions from cement production.

Long-term scenarios anticipate that the demand for cement in the Czech Republic will stagnate by 2030 at the current level of 4.5 million tons per year. On the other hand, for the fulfilment of the Paris Agreement and to limit global warming, emissions from cement production in the context of the whole life cycle must be climate neutral by 2050.



Cement production belongs to industrial processes, whose emissions can be reduced, but is much more difficult than, for example, energetics. Therefore, environmental scenarios also expect that cement production one of the last economic sectors to be decarbonized.

The way to zero emissions by 2050



Fuel emissions essential for the thermal transformation of raw limestone materials, which are the basis of subsequent cement production – of clinker firing, however, can be influenced with a specific approach. The first, long-term implemented approach is a replacement of the original fossil fuels – coal, fuel, oil and gas – with alternative fuels originating from already unusable, combustible industrial materials with a certain energy value. The second possible approach is a permanent increase in the content of biomass within these waste energy sources.

During cement production, European product standards allow for the production of several types of cement with a graded content of the most climatically and energetically demanding component, i.e. clinker, with other suitable materials – slag, fly ash or limestone, entirely according to the needs of the concrete and construction industry.

For the remaining part of carbon dioxide, technologies of its capture and use or storage can be utilised, which are currently being developed and planned. But it is necessary to keep in mind their high energy demand.

When processing cement into individual types of concrete it is necessary to take into account which type of concrete construction is used, i.e. the life of the building, resistance to individual exposure influences. We need to ask whether a high-rise building in the middle of a city is being built or whether we need the concrete for durable industrial construction, e.g. water or nuclear power plant or a concrete surface of a new highway.

At the end of its life cycle, concrete can be crushed, sorted and used again as recycled aggregate or a raw material to produce new cement. Cement and concrete are classified as permanently recyclable materials in the Circular Economy area.

Clinker

Although clinker is only an intermediate product in cement production, it is the most chemically perfect component and in terms of the required cement strength and subsequent concrete also its most important component. From an environmental point of view, however, it is the most emission-intensive and problematic constituent. The production, more precisely burning and cooling of clinker, represents a complex process from the perfect preparation and homogenization of the components of the raw material mixture, its burning with mainly alternative fuels and finally rapid cooling into a grey granular form. Looking inside clinker, it projects an array of colours of the individual natural minerals, which are needed for the much-desired properties of cement and concrete and finally for the durability of the construction work.

When preparing the raw material mixture, it is possible to replace the natural carbonate components with decarbonized waste components while adding siliceous, ferrous and aluminate components, originating e.g. from recycled components of construction waste from concrete buildings. The process of limestone decomposition is called calcination. The Czech cement industry is able to replace the primary carbonate components up to 5% of original raw materials.

Emissions of the Czech cement industry
average 2016 – 2020
based on 1t of clinker in t of CO_2

Process emissions of CO_2	0.5371
Fossil fuel emissions of CO_2	0.2382
Biomass fuel emissions of CO_2	0.0890
Total CO_2 emissions	0.7753

Substitution of carbonate components	**5%**
Substitution of fossil fuels	**85%**
Biomass proportion	**30%**

Optimizing the clinker burning process depends on the one hand, in preheating the raw material with waste heat, and on the other hand, in the subsequent burning during which usual fossil fuels are being replaced with alternative waste fuels that can be no longer utilised in any other way within the framework of the Circular Economy. With the current share of alternative fuels and a significant proportion of biomass neutral components, the Czech Republic ranks at the top in the field of climate neutral initiatives in the European Union. Unusable waste fuel materials are used at a rate of more than 85% with a significant proportion of biomass, over 30%. No other industry producing building materials has undergone such a significant fuel change.

Cement

Cement as the subsequent final product after clinker burning offers several other options to reduce CO_2 emissions in its production, for example by reducing the content of clinker in different types of cements for different construction applications.

The intermediate product - clinker belongs to the EU ETS system, i.e. trading with allowances for greenhouse gas emissions within the European Union. For the Green Deal and the Fit for 55 projects, it is a part of the Carbon Border Adjustment Mechanism (CBAM) system, which is based on the principle of a carbon tax - a projection into the import price of non-ecological products. This system will prevent the transfer of the production of energy and emission intensive industrial enterprises from the EU, i.e. from countries which implement higher standards of climate policy, to countries outside the EU, which exercise either much more liberal conditions for greenhouse gas emissions arising in production. This principle is known as carbon leakage.

Basic European standards for cement EN 197-1 and EN 197-5 list more than 30 types of cement, which can be offered to concrete producers and the construction industry for further processing. In addition to clinker, there are a number of other main constituents of cement, e.g. slag, fly ash, limestone, burnt shale and new, possible principal constituents are being verified. In the Czech Republic, 9 types of cement are produced and there is a significant effort to expand this range.

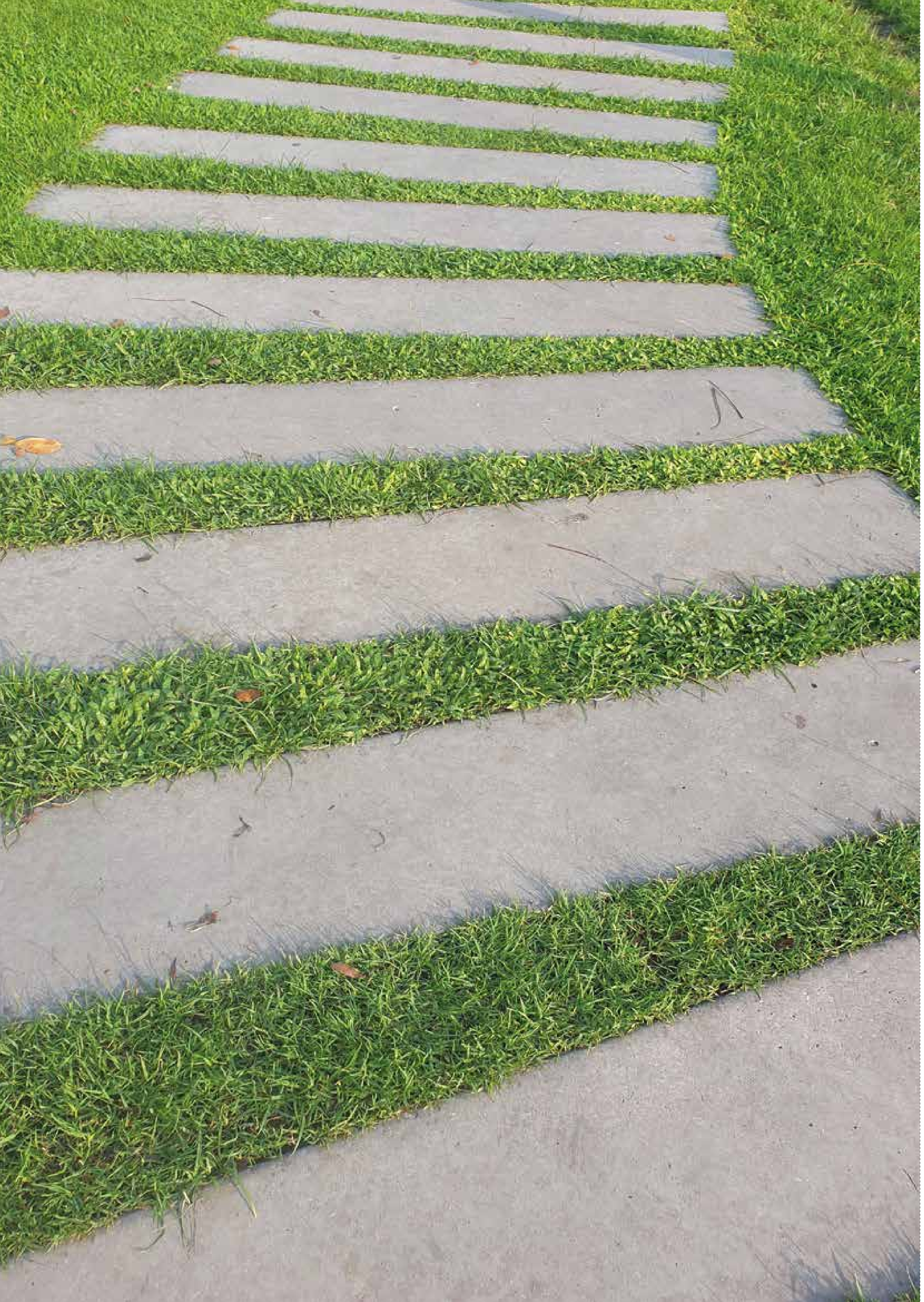
Average clinker content in cements in the ČR in 2020 **78.91%**

Average emission factor of cement in kg CO_2
1t of cement in ČR in 2020

CEM I 52,5 R	740
CEM I 42,5 R	700
CEM II/A-S 42,5 R	590
CEM II/B-S 32,5 R	480
CEM II/A-LL 42,5 R	650
CEM II/B-M (S-LL) 32,5 R	490

Requirements of the Czech construction industry
average 2016 – 2020

CEM I	95% clinker	production share 54%
CEM II with slag, siliceous fly ash, with pozzolana, with burnt shale, with limestone and suitable combinations of above main components	65 – 94% clinker	production share 43%
CEM III with slag	5 – 64% clinker	production share 3%



Concrete

Concrete is a modern, fully recyclable building material with incredible durability. The importance of safe cement and concrete quality is underlined by the fact that the Czech Republic was the first to adopt modern European standards, i.e. ČSN EN 197-1 Cement – Part 1: Composition, specification and conformity criteria for common cements and ČSN EN 206-1 Concrete - Specification, performance, production and conformity specifying requirements on the properties, production and conformity of both. The national specification ČSN 73 2404 is in effect at the same time.

Architects and designers decide its aesthetic form and subsequently also the public reception of concrete buildings. The mostly shamed panel houses with their concrete frame provide, especially after renovations, high-quality housing for a major part of our population. Family homes with concrete foundations resist floods and other influences, safe concrete dam reservoirs have been holding back rainfall as a supply of future drinking water for numerous decades, water is carried at long distances by pipes from concrete. Concrete bridges can be considered as a social link between people. Importantly, we also discuss a natural material which, after completing its mission and life cycle, estimated to be more than a hundred years, is restored safely to nature.

The process of optimizing the composition of new cements and the content of recycled aggregate in concrete needs to be credibly verified and takes time. There are ongoing tests of new cements CEM II/C which provide a possibility of using them in concrete for various exposure classes, i.e. resistance to corrosive effects or freezing and thawing mechanisms. Cements with limited clinker content significantly contribute to environmental protection, both thanks to the economy of their production as well as due to the effectiveness of their use. When using an appropriate combination of the main ingredients, Portland composite cements contribute to the concrete durability for specific applications. The basic strength tests, frost resistance, porosity, carbonation depth and chloride resistance needs to be verified.

Europe anticipates reduction of the emission load from concrete production

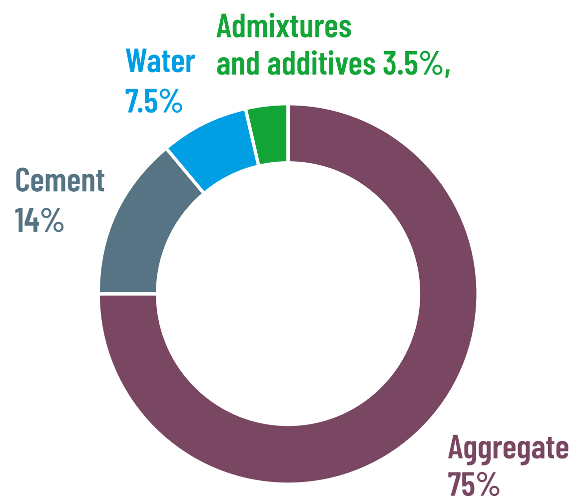
722 kg of CO_2 / 1t of clinker

540 kg of CO_2 / 1t of cement

76 kg of CO_2 / 1t of concrete

The content of cement in concrete is specified according to its purpose, depending on the exposure classes, even over 400 kg of cement in 1m^3 of concrete, however, the average composition of concrete is, depending on the type, 75% aggregate, 14% cement, 7.5% water and 3.5% admixtures and additives.

Composition of concrete in wt. %



Construction industry

Modern ecological technologies in the construction industry offer an opportunity to use affordable, cost-effective procedures to reduce emissions. This can be achieved especially by the following approaches, which are significant in buildings with zero carbon emissions:

decarbonization, electrification, efficiency and digitization.

What exactly does carbon neutral construction entail? What are the specifics of carbon neutral buildings?

Passive design is a method that considers the climate of the area. Thanks to this method of design, the building uses natural energy such as sunlight or air flow to help with heating and cooling.

Building envelope is key for any carbon neutral building. One of the main ways these buildings reduce energy consumption is the prevention of heat gain and loss during hot and cold periods. Types of perimeter cladding for buildings allow for the application of perfect insulation, which prevents any air leaks. Carbon neutral buildings also require effective ventilation systems that ensure the recovery of air without gaining or losing heat.

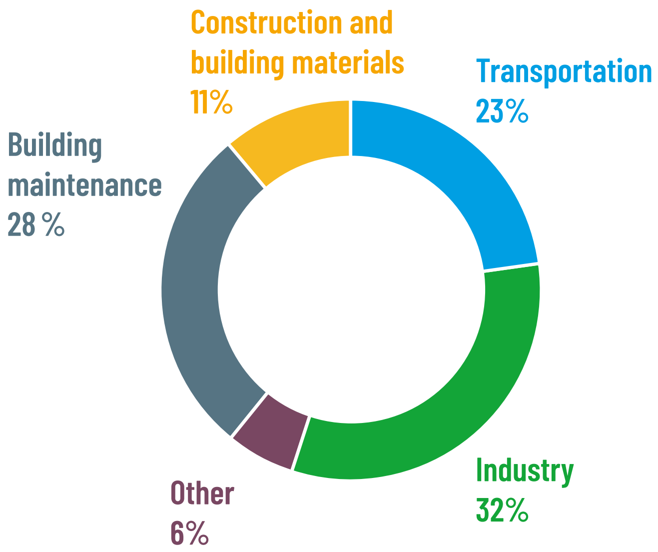
Energy efficient systems are another basic principle of carbon neutral buildings. Houses still need heating systems, ventilation, air conditioning and lighting. Heat pumps are becoming a much more suitable alternative to air conditioning units and as technology advances, they become an appropriate option in areas that experience extreme heat and cold.

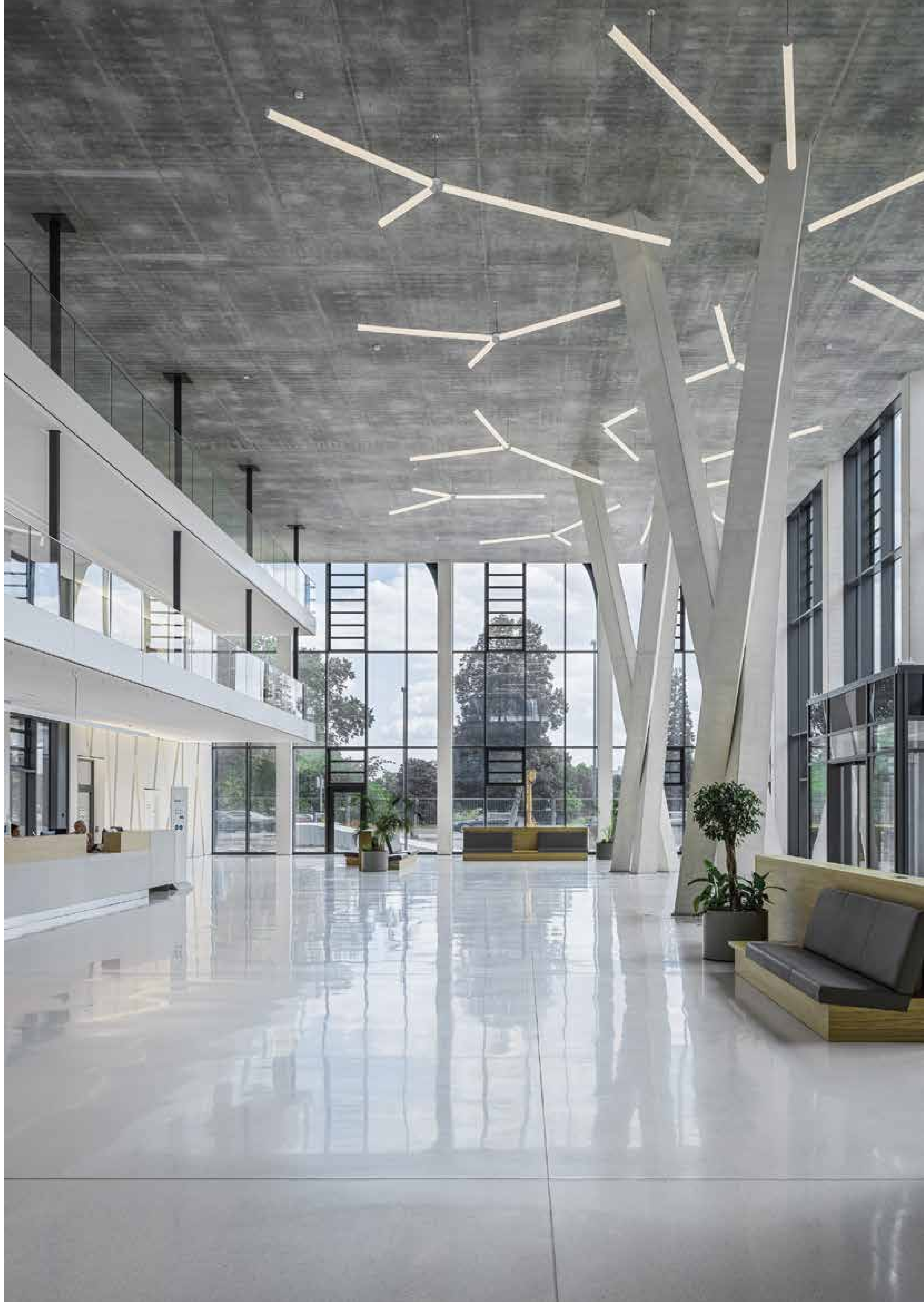
Contribution of the construction industry and buildings on total CO_2 emissions

Construction and building materials	11%
Building maintenance	28%

Renewable energy is a big part of the carbon neutral formula. If a building that produces little or no carbon is to be built, it must be designed so that it consumes as little power as possible with the addition of renewable systems, which provide as much energy as possible to meet the building‘s requirements. In practice, this often means solar power in large cities and the use of hydro and wind energy in areas where possible.

Origin of anthropogenic CO_2 emissions





Carbonation

A very important process in the concrete life cycle takes place outside of cement production. During carbonation, limestone is formed from hydration products containing calcium in a hardened concrete cement paste. Concrete, in turn, binds carbon dioxide back from the air. The Intergovernmental Panel on Climate Change (IPCC), in its report in August 2021, recognized and quantified the carbonation of cement building materials as a process of carbon reabsorption for the first time.

Model equation of concrete carbonation and CO_2 absorption

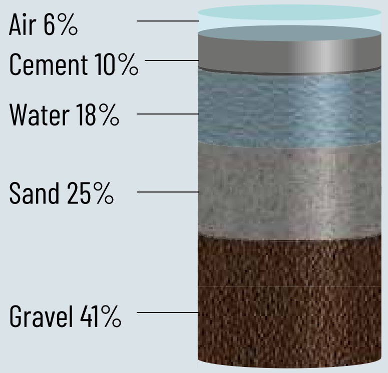
$$X_c = \sqrt{\frac{2D_{CO_2}(t, RH) * C_{CO_2} * t}{a}} \left(\frac{t_r}{t}\right)^{n_m}$$

$$cf\ .\ D_{CO_2}(t) = D\, t^{-nd}$$

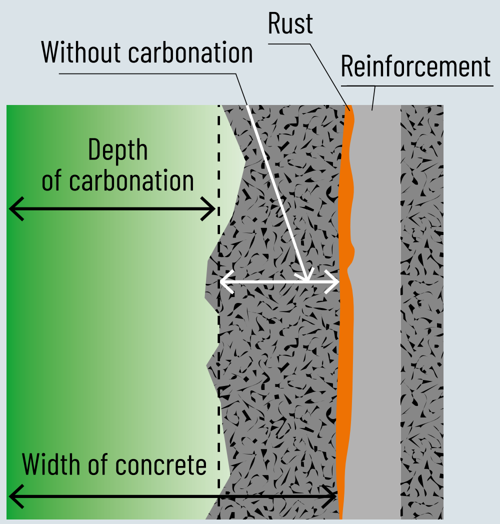
$$a = 0{,}75\, C_e * CaO * a_H \frac{M_{CO_2}}{M_{CaO}}$$

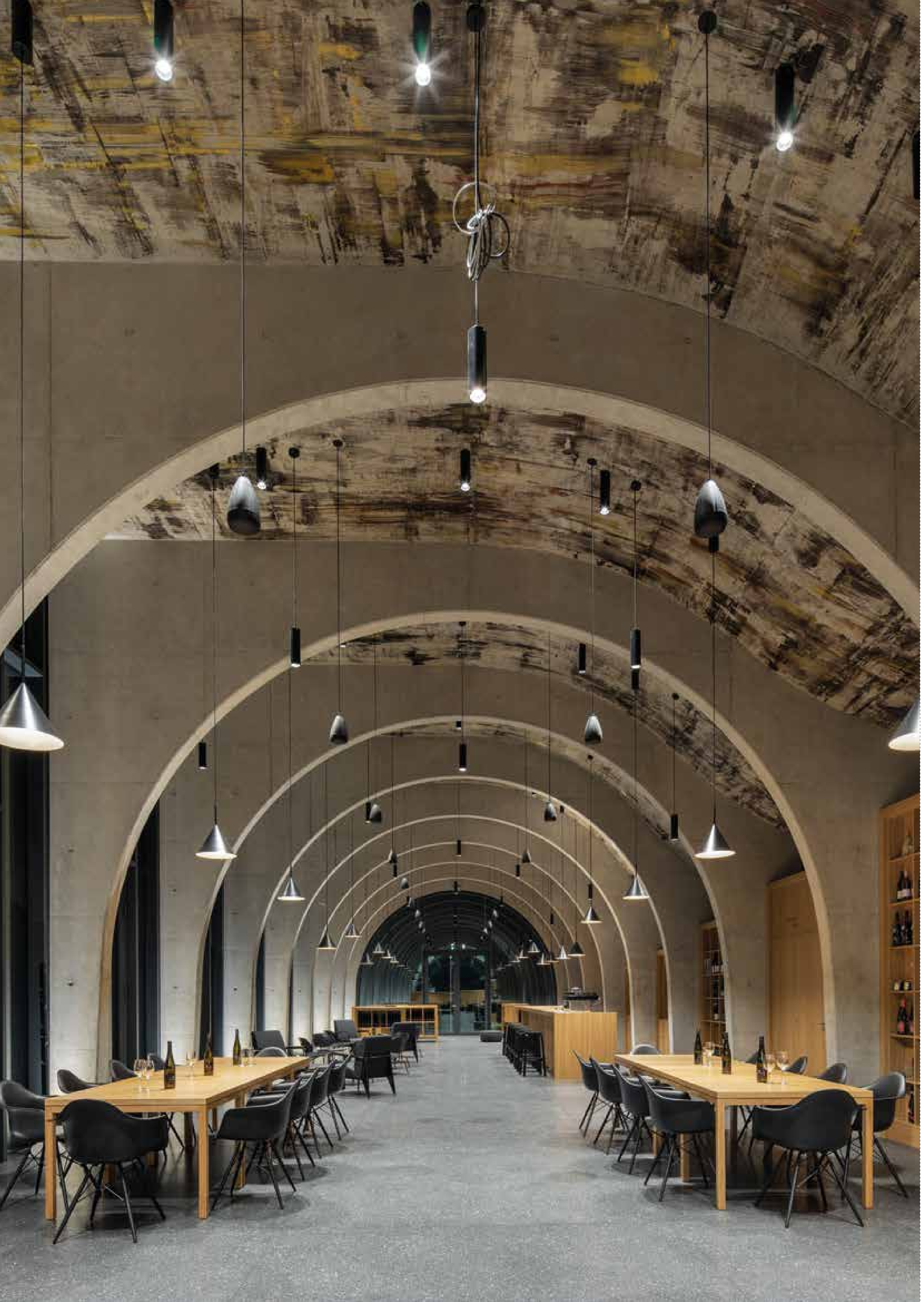
An important aspect is the degree of carbonation. How fast can carbonation take place and what are the processes determining its speed? The carbonation rate depends on factors such as humidity, temperature, porosity, CO_2 concentration in the surrounding air, etc. For convenience, this is often determined by measuring the depth of carbonation as a function of time. The depth is proportional to the second square root of time. The carbonation rate then can be expressed as a constant. These reactions are relatively fast and cannot be considered as reactions determining speed. However, there are several other factors that can slow down the rate of carbon dioxide absorption. A common aspect of these factors is the access to hydration products and their transportation through concrete. As carbonation progresses, an increasing amount of limestone precipitates in the concrete mass, which can reduce its permeability. This limits the access of CO_2 to the interior of the concrete, the dissolution of $Ca(OH)_2$ slows down and consequently, the rate of carbonation is reduced.

Composition of fresh concrete in vol. %



Carbonation process





Recycling

When it comes to concrete, we always mean the natural material that is returned to be reused after the end of its life cycle, which is estimated to be more than a hundred years. It is recognized that concrete and the cement and other components in it, which are types of transformed natural stone, are not only close to nature, but importantly after the termination of concrete's life cycle, which is incidentally one of the longest, are safely returned as utilised stone to the natural environment for their next application.

Since 1991, no new stone or sand quarries have been opened in the Czech Republic and there are no plans for them in the near future. More than half of those currently active stone and sand quarries will probably stop mining in the next 10 years. What makes the situation more complicated is that to open a new mining area, or to extend and expand an existing mining deposit, is a very complicated process which can, in some cases, take up to 10 years.

For a wider application of recycled aggregate in construction, however, current standards for the use of recycled material in concrete need to be modified. Enabling the production of concrete with recycled aggregate according to the standards for concrete production could lead to a better faith of developers and designers in the offered material and subsequently to greater demand. When using concrete with recycled aggregate for a specific construction it is necessary to proceed with caution and to be aware of its weak points - especially its lower elastic modulus and bulk density.

Usable components of construction waste

Carbon footprint and labelling of ecological cements

The cement production in the Czech Republic and cement as a product have been going for more than 10 years through the environmental life cycle assessment in the Life Cycle Assessment (LCA) system, and for more than 10 years, they have carried a rating according to the Environmental Product Declaration (EPD).

Based on this assessment, five years ago Czech cements were labelled as

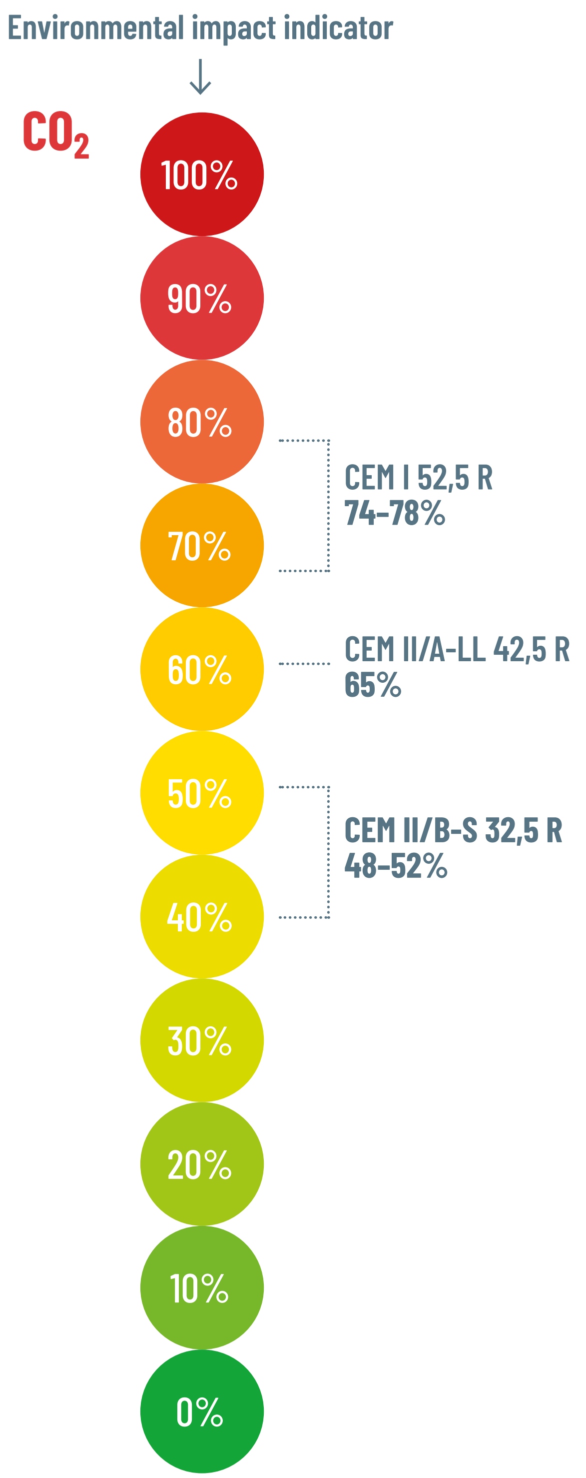
ČESKÝ CEMENT

This logo is now being supplemented based on an environmental evaluation of the product carbon footprint – cement with a green eco mark

ČESKÝ EKO CEMENT

Prepared environmental logo

What exactly is a Product Carbon Footprint? This score is a measure of the total amount of greenhouse gas emissions that are released during a product's life cycle. Carbon footprint is the amount of emitted greenhouse gases expressed in CO_2 equivalents. This product information is used to select products whose production offers the least possible effect on the environment. Due to there not being a unified evaluation for construction products in Europe, cement manufacturers inform their customers in separate materials. In the case of cements, however, the carbonation value, which can lower the result further, is not included in the data.



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https://www.cembureau.eu/;
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June 2022

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