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198 A Path towards Climate neutral Production of Cement in Austria via a new Circular Economy

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Abstract

Mineral resources are a fundamental part of the circular economy. Concrete, for example, can be recycled 100 percent. Along the value chain of cement and concrete, there are several routes for re-use and recycling processes. Concrete mainly consists of natural materials: up to 80 percent of aggregates, like sand, gravel or crushed stone, and water. Cement acts as the binding agent and makes up 10 to 15 percent by volume. Cement itself consists of natural materials as well, mainly limestone and clay. These components are burnt at a temperature of 1,450 °C, thus transform into a substance called clinker. This process is mainly responsible for the CO_2 footprint of concrete: about two thirds of direct CO_2 emissions arise from the chemical process of the decarbonisation of limestone, another third from heating of the rotary kiln. Thanks to improvements in kiln and abatement technologies, emissions have been continuously reduced since 1990. The European cement industry aims at being climate neutral by 2050. The European Cement Association set out this ambition of net zero emissions in its Carbon Neutrality Roadmap, to be reached by measures at each stage along the value chain: clinker, cement, concrete, construction and (re)carbonation. While some of the measures have already been put in place, others are still in the research, development and demonstration phase. The Austrian Cement Industry is currently working on its national roadmap to climate neutrality along the value chain. In Austria, cement clinker is produced in rotary kilns with preheater. This state-of-the-art technology enables the use of waste heat for preheating fuels and raw materials, thus reducing the overall energy consumption for the production of cement. Moreover, several cement companies in Austria supply waste heat for district heating. In addition to energy efficiency, resource efficiency is an important pillar of cement production in Austria: for each tonne of cement produced in Austria, 441 kg of secondary materials are reused. Three main categories for the use of alternative resources in cement production have been identified: first, alternative raw materials provide the chemical

elements required for the formation of clinker minerals. Second, alternative fuels are used at a rate of about 80 percent in Austria, substituting conventional fuels like coal and oil. Via co-processing, the combination of simultaneous material recycling and energy recovery from these alternative fuels, natural raw materials and fossil fuels are replaced. And finally, alternative additives to clinker, like slag or fly ash, contribute to the required properties of the cement types produced. With an emission intensity of 0.54 tonnes CO_2 per tonne of cement produced, the Austrian cement industry is considered a global front runner in terms of CO_2 reduction measures. Compared to the world-wide average, almost 6 million tonnes of CO_2 have been avoided since 2005 in Austria. Already in the near future, breakthrough technologies will make it possible to capture CO_2 and recycle it to hydrocarbons as new raw materials. Details and projects will be shown in the Climate Neutrality Roadmap of the Austrian Cement Industry.

Keywords: Circular Economy, Recycling, Climate Neutrality, Carbon Capture and Use, Carbon Cycle

Introduction

Cement is a mineral-based hydraulic binder. Applied as a binder in concrete, it is the building material with the greatest economic importance worldwide: Currently, 4.1 billion tonnes of cement and 33 billion tonnes of concrete are produced annually worldwide (IEA, 2021; Bhardwaj et al., 2021). In Austria, 5.2 million tonnes of cement were produced in 2020 (Mauschitz, 2021) and approximately 40 million tonnes of concrete (öbv, 2021). Concrete is the most widely used building material in the world because of its strength and durability, among other benefits. Concrete is used in nearly every type of construction, including residential, commercial and public buildings, roads, bridges, airports and subways. The production of cement naturally involves the generation of carbon dioxide (CO_2). In a cement plant, CO_2 is produced directly during the production of the main component of cement, the cement clinker. Around two thirds of the CO_2 is released during the decarbonisation of limestone. Another third results from the combustion of fuels. According to the latest figures from the Netherlands Environmental Assessment Agency, global greenhouse gas emissions amounted to 57.4 billion tonnes CO_{2eq} in 2019, made up by the sum of 74% CO_2, 17% CH_4, 5% N_2O, 3% F-gases, (PBL, 2020). The global cement industry emitted 2.4 billion tonnes CO_{2eq} in the reference year 2019 (IEA, 2021), thus had a share of less than 4.5% of greenhouse gas emissions worldwide. Related to the climate gas CO_2 only the share of the cement industry's emissions was 5.6%, if land use, land-use change and forestry, short LULUCF, are included. Figure 1 shows the global greenhouse gas emissions by sector in 2010, a total amount of 49 Gt CO_{2eq} (IPPC, 2014). The largest sector is electricity and heat production with 25%, followed by deforestation and agriculture with 24%. Cement, with a contribution of less than 4,5%, is part of the sector industry that comprises 21% in total, followed by the sector transportation with 14%.

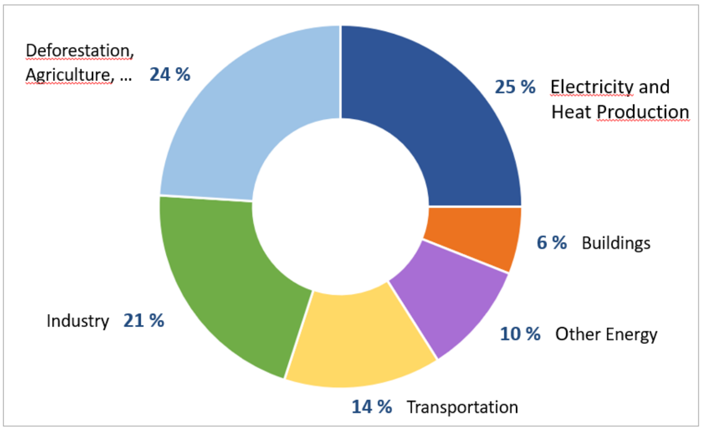

Figure 1. Global Greenhouse gas emission by sector in 2010, the emissions of approx. 4,5% of cement industry are included in the sector industry (IPPC, 2014).

The share of cement industry seems high, but have to be set in relation with the fact that concrete is a ubiquitous material and the second most used material in the world, after water. In fact, the embodied energy [MJ/kg] and the embodied carbon per kg of concrete [CO_2/kg] are rather low compared to other building materials, shown in table 1.

Table 1. Embodied energy and embodied carbon [per kg] of different building materials (Hammond & Jones, 2008a; Hammond & Jones, 2008b; Scrivener, 2019).

Material	MJ/kg	kg CO_2/kg
Cement	4.6	0.83
Concrete	0.95	0.13
Masonry	3.0	0.22
Wood	8.5	0.46
Wood: multilayer	15	0.81
Steel: virgin	35	2.8
Steel: recycled	9.5	0.43
Aluminium: virgin	218	11.46
Aluminium: recycled	28.8	1.69
Glass fibre composites	100	8.1
Glass	15.7	0.85

Figure 2 displays the data of table 1 on a chart, which shows at first glance the specific impact of the different building materials.

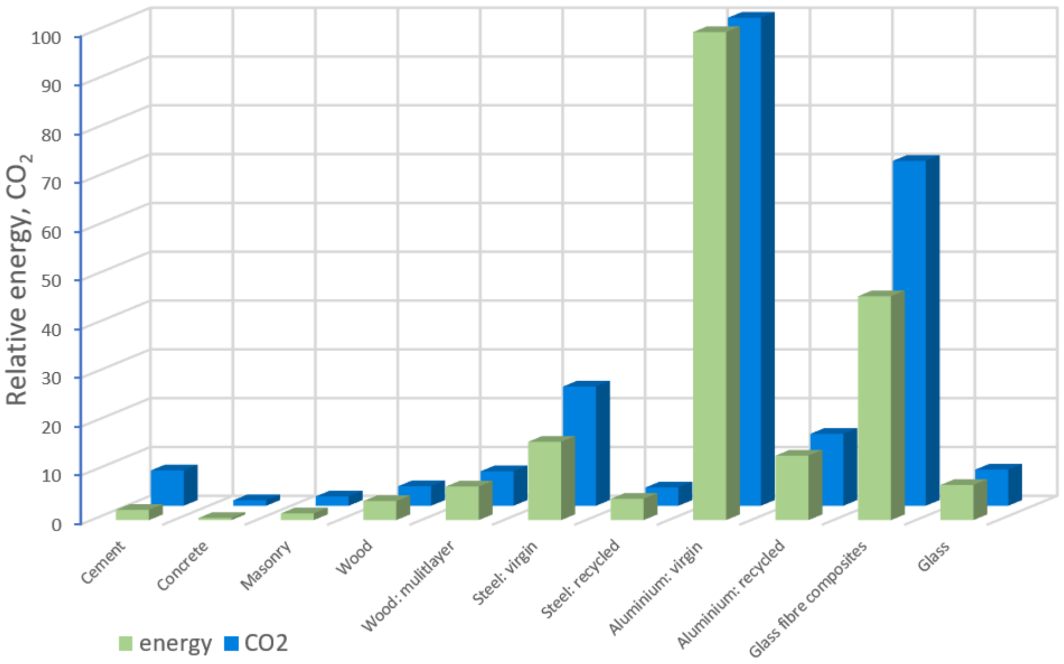

Figure 2. Embodied energy [MJ/kg] and embodied carbon [kg CO_2/kg] of different building materials (Scrivener, 2019)

Although being the binder in concrete Portland cement is displayed at the very left, next to concrete. CO_2 emissions and the often-stressed climate impact of concrete and cement are due to the fact that the use of concrete amounts to approximately 33 billion tonnes or 14.5 billion m³ per year worldwide. A comparison with the global yearly sawn wood production of 0,45 billion m³ and the wood panel production with 0,41 billion m³ makes clear that concrete cannot be replaced by alternative building materials (FAO, 2019). These are reasons why we need to decarbonize cement and concrete.

The cement production process offers excellent opportunities to make use of alternative materials and provides the potential to contribute considerably to a circular economy. During the production process of cement there are several steps where alternative resources are used. Concrete itself is an artificial stone and is 100% recyclable. The production of cement leads to considerable CO_2 emissions, in Austria of about 2.7 Million tonnes per year. Consequently, strategies for the decarbonization of cement are crucial. The European Cement Association has published its way to carbon neutrality till 2050 (CEMBUREAU, 2019). This European Roadmap highlights how CO_2 emissions can be reduced by acting at all different stages of the value chain – clinker, cement, concrete, construction and (re)carbonation (5C approach). Goal is to achieve zero net emissions by 2050. The roadmap quantifies different technologies in reaching CO_2 emission savings, by technical and political recommendations to support this objective (CEMBUREAU, 2019). The Austrian Cement Industry will publish its roadmap towards a climate neutral production of cement in autumn 2021.

Methods

The Austrian cement industry has attained many years of extensive experience in the use of alternative fuels, raw materials and additives. Alternative resources in cement production require high level know-how, inputs in quality management systems and significant investments. In addition, several environmental protection technologies were used for the first time in Austrian plants. These include the world's first regenerative thermal post-combustion, the development of catalyst technology to reduce nitrogen oxide emissions, and the testing of mercury separation technologies. (Spaun and Papsch, 2016). The following sections give an overview of methods that have already been implemented in the Austrian cement industry since the 1980s, of methods that will be part of the 5C concept of the roadmap in the upcoming years, comprising clinker, cement, concrete, construction and (re-)carbonation, and of breakthrough technologies in the cement industry.

Current Measures

In Austria, 100% of cement is produced by advanced five-stage preheater kilns which is the state-of-the-art technology. The waste heat generated at all production steps is recovered and used to preheat raw materials and to dry the fuels. Energy is used and reused the most efficient way. In addition, waste heat for district heating is being decoupled at several cement plants. Furthermore, resource efficiency is an additional important pillar of cement production in Austria: for each tonne of cement produced in Austria 2020, 441 kg of secondary materials have been reused (Mauschitz, 2021; VÖZ 2021). Three main categories for the use of alternative resources in cement production have been identified:

- First, the use of alternative raw materials provides chemical elements required for the formation of clinker minerals. In cement production, 15% of the raw materials is already delivered by alternative raw materials. Today, 798,000 tonnes mostly residual demolition and construction waste are recycled (Mauschitz, 2021).
- Second, alternative fuels substitute conventional fuels like coal, oil and gas. Alternative fuels are used at a rate of about 80 percent in Austria, the highest share worldwide, as shown in Figure 3. Alternative fuels provide the necessary thermal energy for clinker production, and moreover some of them, e.g. paper fibre residues, used tyres or sewage sludge, also contribute main elements which are required for the formation of clinker minerals, such as calcium or iron (Spaun and Papsch, 2016). This combination of simultaneous material recycling and energy recovery is called “co-processing”, it is listed as good practice in the “European Circular Economy Stakeholder Platform” (2014):

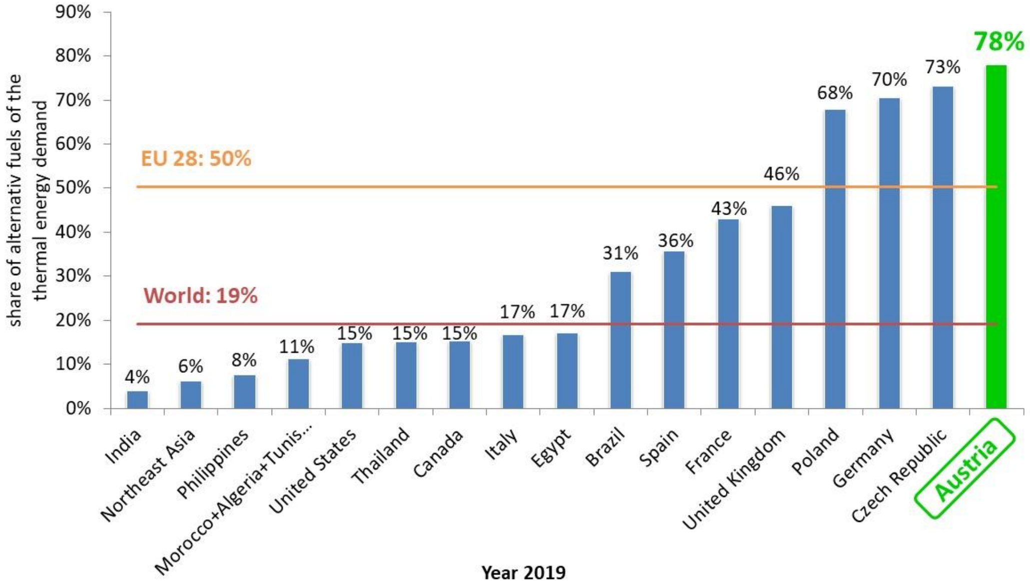

Figure 3. Use of alternative fuels in cement Industry. Diagram by VÖZ based on GCCA data (GCCA, 2020).

- Third, alternative additives to clinker, e.g. industrial by-products such as slag or fly ash, contribute to the required properties of the cement types produced. The increased use of supplementary cementitious materials, e.g. blast furnace slag, has reduced the average clinker content in cement to about 69%. As a result, less clinker has to be produced for the same quantity of cement, while maintaining the high quality of the product. Total CO_2 emissions are significantly reduced.

5C Measures Road Map 2050 and Current Research Projects

Clinker / cement: The Association of the Austrian Cement Industry is working together with the research partner Smart Minerals on a family of climate-friendly cements. With the publication of the new Cement Standard EN 197-5 (CEN/TC 51, 2021) new cement types, namely CEM II/C and CEM VI, are being developed and will enter the market soon. These new cement types will enable higher amounts of supplementary cementitious materials while reducing the clinker content. The aim is to produce “new cements” on a large scale without compromising usage quality, like workability, performance, durability etc. Traditional additives are slag and fly ash, their availability will be limited in the future. Therefore, in addition to reducing the clinker content in new cements, the suitability of other additives such as calcined clays is under investigation. Clays are available in Austria in sufficient quantities and, after calcination, they can replace a significant proportion of clinker in cement. Figure 4 shows the availability of different additives according to a study on eco-efficient cement (Scrivener et al., 2018).

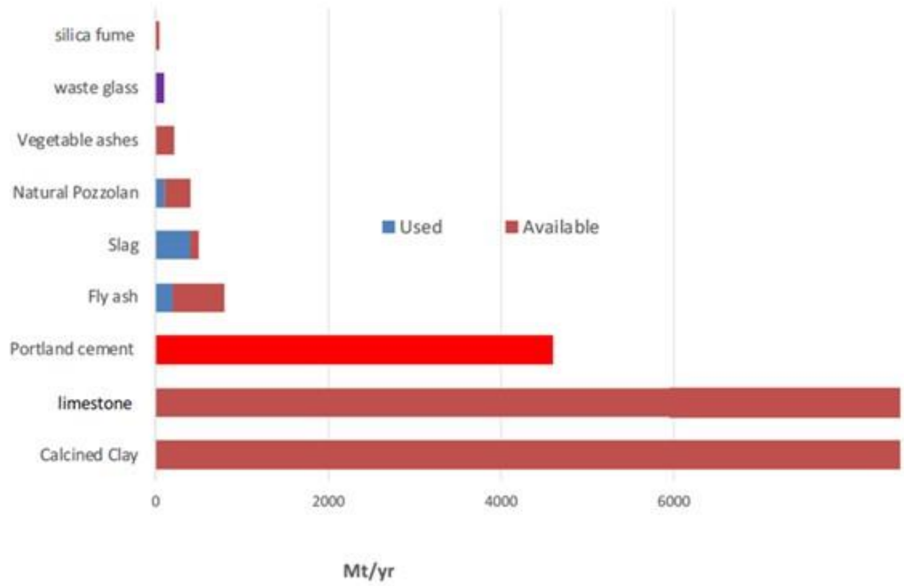

Figure 4. Use and availability of possible cement additives (Scrivener 2019)

Calcination of clays is reached by heating to a certain temperature. This process is not as energy-intensive as burning clinker since temperatures are significantly lower. The first step of the ongoing research project is to identify available domestic clay pits with adequate chemical and mineralogical composition. Furthermore, the calcination process will be optimised to achieve maximum properties like reactivity and strength contribution. Based on these findings, high performing cement mixtures will be developed. In the end, this new cement composition will be tested in concrete with a special focus on performance and durability.

Concrete / construction: Applied as a construction material, concrete allows for savings of CO_2 emissions. An example is the infrastructure for renewable energy: wind power plants or hydropower plants could not be built without using concrete. Concrete is also the material of choice for the public mass transit transport or the construction of railways and subways. Bridges or tunnels shorten road stretches and thus help reducing emissions. The European Concrete Paving Association EU PAVE analyses environmental, economic and societal aspects of concrete pavements. An infographic with the title “Concrete pavements make roads more sustainable” gives an overview of different benefits, like 100% recyclability, less global warming potential because of reduced fuel consumption especially of heavy trucks and a higher albedo, higher resilience to climate change and to extreme meteorological events and a contribution to sustainable water management, e.g. by the means of possible infiltration (EU PAVE 2020). Such savings are usually not taken in account when talking about the CO_2 balance of concrete. About one third of the concrete in Austria is used in civil engineering, approximately two thirds for structural engineering (öbv, 2021). Considerable savings are being achieved during the use phase of concrete buildings thanks to their thermal mass. Thermal mass refers to the ability of heavyweight materials to store energy, which is later released. Thanks to its high material density and good thermal conductivity, concrete can be turned into an energy storage by means of thermal component activation: Pipes are laid in solid building components through which water flows as a heating or cooling medium, resulting in a surface heating or cooling system, a schematic view is shown in figure 5. The activated building components emit heat over their entire surface or absorb it again – depending on whether heating or cooling is needed.

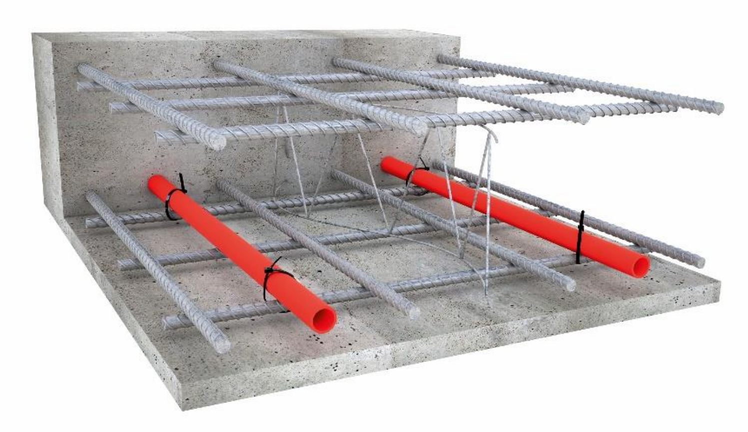

Figure 5. Functional schematic design of thermal component activation: the water-carrying pipes in concrete slabs, walls or floors turn concrete into an energy storage.

Due to the large surface, system temperatures can be kept very low, with a temperature difference between surface and room air of approx. 1 to 6 °K. The high efficiency reduces the overall energy consumption and facilitates the use of renewable energy instead of fossil energy. In regard to a 100% supply with renewable energy, storage capacity has become increasingly important (Klima- und Energiefonds, 2020). The vast amount of concrete structures provides large reserves that can be used for energy storage. Thus, thermal component activation can contribute considerably to achieving climate goals. The roadmap of the Austrian Cement Industry will focus on reducing emissions from its own sector. Nevertheless, with regard to life cycle calculation, the offsetting of emissions versus savings, especially for societal benefits, need to be considered in some way as well.

Carbonation is a process that occurs naturally per se in the cement paste. During cement production, CO_2 is released from limestone in the calcination process; carbonation is the reversal of this process, i.e. the cement stone absorbs CO_2 again from the ambient air. This CO_2, in combination with the calcium hydroxide and water present in the cement paste, becomes limestone. The durability of the concrete is improved by this process, it turns denser and stronger. Steel reinforcement has to be protected from corrosion by an appropriate concrete cover. Carbonation is a relevant parameter for the global CO_2 cycle. The Global Carbon Project (2020), an international scientific network, compiles and updates the global CO_2 balance annually. The CO_2 balance 2020 addresses "cement carbonation" for the first time: between 1840 and

2019, cement paste is assumed to have absorbed approximately 40% of the geogenic CO_2 process emissions back from the atmosphere, also shown in figure 6.

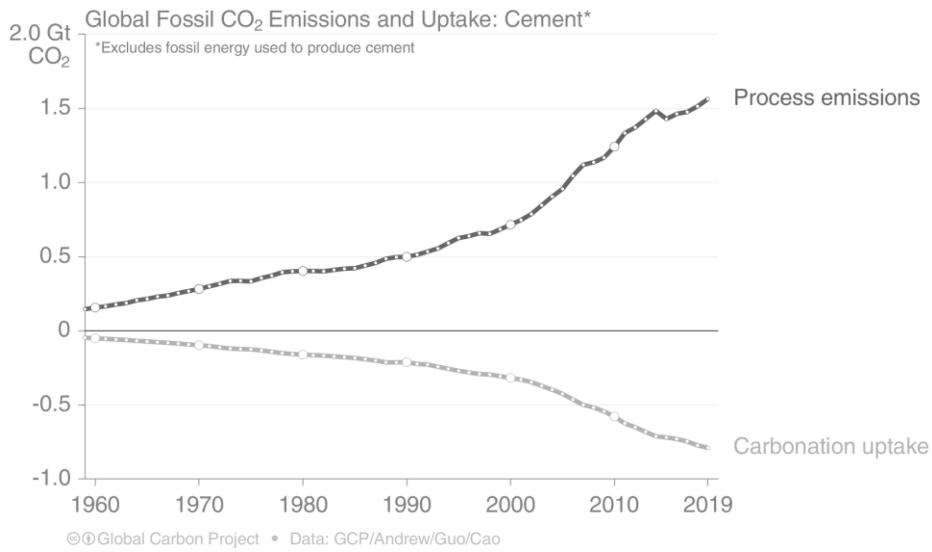

Figure 6. The production of cement results in process emissions of CO_2 from the chemical reaction. During its lifetime, cement slowly absorbs CO_2 from the atmosphere. (Global Carbon Project 2020, p. 39)

This effect also needs to be taken in account in future life cycle assessment of cement and concrete, e.g. concerning environmental product declarations. The IPCC, the Intergovernmental Panel on Climate Change, has to decide, if this sink effect can be considered in national climate balances. In a specific report, the Swedish Environmental Research Institute IVL proposed that a 23% reduction in CO_2 emissions from the raw material should be recognised in the annual greenhouse gas balance for cement production (Stripple H. et al., 2018). These percentages refer to the CO_2 process emissions, i.e. the geogenic emissions released from the limestone during the cement burning process. The potential for the absorption of CO_2 could be higher if special treatment was provided in recycling, e.g. when concrete is broken up and cement stone is exposed to CO_2.

Breakthrough technologies: Carbon Capture and Utilisation

In the near future, breakthrough technologies will make it possible to capture CO_2 and recycle it to hydrocarbons, which can be used as new raw materials. Carbon Capture and Utilisation, CCU, will be a key technology to reduce CO_2 emissions from cement plants. In recent years, significant research has been initiated at a pilot scale level to optimise reagent and membrane capture techniques. Trials are ongoing to find ways of concentrating the CO_2 in the gas stream as to make the carbon capture more efficient and cost-effective. Captured CO_2 can also be transported to geological formations such as empty gas fields, where it is permanently stored, Carbon Capture and Storage, CCS. An example is the Brevik plant in Norway, operated by Heidelberg Cement (CEMBUREAU, 2019). The storage of CO_2 is prohibited today in Austria, therefore an Austrian project with the focus on CCU is planned by a consortium of four companies (Lafarge, OMV, Verbund, Borealis, 2020). The project “Carbon2ProductAustria” or short C2PAT aims at building a plant for capturing around 700,000 tonnes of CO_2 per year by 2030 at the Mannersdorf cement plant, located about 30 kilometres southeast of the OMV refinery in Schwechat. Mannersdorf is the largest cement plant in Austria with an annual capacity of around 1.1 million tonnes. The objective of C2PAT is to build an infrastructure and a fully operating system for producing renewable based hydrocarbons and using this compound to produce a broad range of renewable based olefins, plastics and fuels. The partners aim to put the full-scale plant into operation by 2030. A first step towards this goal will be further investigations on current technological and economical obstacles by jointly conducted research and development activities regarding the envisaged Carbon Value Chain. The key innovation is the utilisation of CO_2 from cement production as a valuable raw material for the manufacture of petrochemical products: This cross-sectoral approach is a big step forward and has not been realised before. C2PAT will also demonstrate the circular economy in the cement industry and the chemical industry by recycling and reusing the renewably produced plastics in different ways. C2PAT will explore the market potential for renewable products and advance models for managing and optimising the entire value chain (Kitzweger, 2020).

Results and Discussion

With regard to the climate footprint, the Austrian cement and concrete industry have already taken a lot of measures to reduce the footprint of cement and concrete (VÖZ, 2019). In this respect, both industries hold a top international position concerning the comparatively low climate impact. Compared to the European average, almost 10 million tonnes of CO_2 could be saved between 1990 and 2020. The Global Cement and Concrete Association GCCA gathers and publishes key data recording the industry’s sustainability commitments. The GNR (“Getting the Numbers Right” or “GCCA in NumbeRs”) is monitoring and reporting tool for sustainability progress. Data of 2019 show that the Austrian Cement Industry produces cement with the least specific CO_2 emissions per ton of cement. Figure 7 gives an overview.

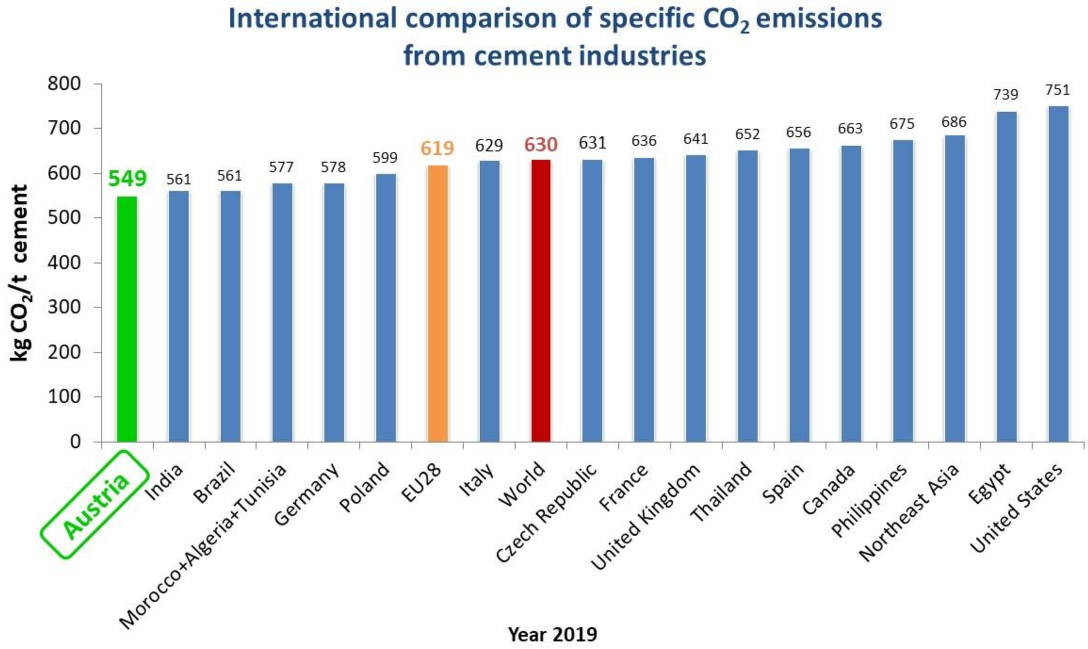

Figure 7. Specific CO_2 emissions from cement industries [kg CO_2/t cement] – international comparison (chart by VÖZ, 2021, based on GCCA, 2021).

Technical possibilities for a more climate friendly production of cement, like minimising energy consumption or substituting fossil fuels, are already widely in use in Austria and CO_2 as well as other emissions are very low in comparison to the rest of the world. In terms of building materials, the binding agent "cement" has also been continuously improved concerning its climate foot-print and the CO_2 intensive Portland cement clinker has been replaced by additives such as granulated blast furnace slag or fly ash. However, due to economic and technical changes in the steel industry and the decrease of fossil fuels such as coal, a shortage of these raw materials is taking place. Therefore, alternative strategies must be pursued to reduce the climate impact. From the point of view of building materials, various optimisation strategies are being pursued, whereby a further reduction of the clinker content is currently the most advanced and seems the most promising. This comprises the production of so-called composite cements or binders with an increasing proportion of climate-friendly additives (pozzolana, limestone, etc.).

Another strategy for minimizing CO_2 emissions is the capture and storage of CO_2 (CCS), where ideally the CO_2 is further processed (carbon capture and utilisation CCU).

Conclusions

In its roadmap 2050, CEMBUREAU (2019) concludes that the objective of climate neutrality for the cement sector is ambitious but feasible. A concerted effort, by the European cement industry and its value chain with the support of governments at the European, Member State and local levels can move climate neutrality in the cement and concrete sector from vision to reality. The most effective scenario on the way to decarbonisation and climate neutrality is the cooperation of all actors along the entire value chain of concrete, namely through the following measures:

- CO_2 reduction in clinker production including the development and upscaling of carbon capture, storage and utilisation.
- the use of composite cements with low clinker content (CEM II/B, future CEM II/C, CEM VI etc.)
- the targeted selection of concrete types with low CO_2 emissions already in the planning stage, the CO_2 optimisation of concrete types through combinations of cements and additives
- material-efficient or CO_2-efficient constructions by optimising the shape of components and structures;
- durability of concrete structures and life time (esp. for infrastructures) have to be guaranteed and
- consideration of the CO_2 absorption of concrete over its lifetime and recycling.

The optimisation of climate compatibility with accompanying CO_2 savings requires investments in terms of research and demonstration, the training of employees, additional infrastructure and deep investments. At the end of the day, however, these expenditures must be cost-covering for the companies in order to ensure a level playing field. Policies have to guarantee a certain planning security, e.g. predictable CO_2 prices, to create a stable economic environment. The Austrian Cement Industry is ready to meet these challenges; strong political support and a supportive framework have to follow.

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