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Overview of cement and concrete production in Latin America and the Caribbean with a focus on the goals of reaching carbon neutrality

Yury Villagrán-Zaccardi[1,2]*, Ricardo Pareja[3], Lina Rojas[3], Edgardo Irassar[4], Andrés Torres-Acosta[5], Jorge Tobón[6], Vanderley M. John[7]

[1] Magnel-Vandepitte Laboratory for Structural Engineering and Construction Materials, Ghent University, 9000 Gent, Belgium
[2] CCT-La Plata, CONICET, 1900 La Plata, Argentina
[3] Inter American Federation of Cement (FICEM), 110111 Bogotá, Colombia
[4] Facultad de Ingeniería, Centro de Investigaciones en Física e Ingeniería del Centro de la Provincia de Buenos Aires (UNCPBA–CICPBA-CONICET), B7400JWI Olavarría, Argentina
[5] Tecnológico de Monterrey, School of Engineering and Science, 76130 Querétaro, Queretaro, Mexico
[6] Cement and Building Materials Research Group, Departamento de Materiales y Minerales, Facultad de Minas, Universidad Nacional de Colombia, 050034 Medellín, Colombia
[7] Escola Politécnica da Universidade de São Paulo, 05508-010 São Paulo, Brazil

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Abstract

Carbon neutrality to limit global warming is an increasing challenge for all industries, particularly for the cement industry, due to the chemical emission of the process. For decades, reducing the clinker factor has been one of the main strategies to reduce the carbon footprint. Additional cuttings in the clinker content of cements seem possible with the upsurge of novel supplementary cementitious materials. This potential contribution represents only a fraction of the required carbon reductions for achieving the goal of carbon neutrality in the coming decades. This paper describes the current situation of the cement industry in Latin America and the Caribbean and the global opportunities and strategies to reduce the carbon footprint of cement and concrete and their adaptation to the regional conditions. Besides describing emerging supplementary cementitious materials, the potential contributions of industrialization and quality control are discussed. Moreover, limitations related to geography and standardization are analyzed. Regional considerations are made given the specific prospects of human development.

Keywords: Low carbon cement; Supplementary cementitious materials; Cement production; Global warming potential; Industrialization

1 Introduction

As a developing region with an increasing demand for large-scale infrastructure expansion, Latin America and the Caribbean (LAC) are likely to experience an increasing demand for cement and concrete. Moreover, suburban and rural housing construction development increases through programs and housing refurnished through informal sectors.

Global warming is an urgent worldwide problem requiring full attention from all sectors. Current scenarios preview impacts on wellbeing to different degrees depending on the actions taken in the present. Also, the effects of natural disasters will bring additional demand for cement and concrete. For a target scenario of a maximum of 1.5 °C (1.5 D) above pre-industrial levels, related global greenhouse emissions must be progressively reduced [1]. The global cement industry is thus on the path toward the challenge of achieving carbon-neutral concrete by 2050 [2]. Such a goal shifts the focus from cement (intermediate product) to concrete (final product). Therefore, policies and new strategies must cover both cement production and use. Strategies for reducing the carbon footprint of the industry should account for human development needs and avoid the intensification of inequalities.

This paper revises the current situation in the LAC cement and concrete industries concerning carbon neutrality. The cement market and standardization in LAC are described, and a discussion is presented on the potential contribution of industrialization and emerging supplementary cementitious materials (SCMs) for achieving goals concerning human development and the limitation of global warming.

2 Latin American market

Approximately 272 cement plants are currently operating in LAC, including 191 integrated plants, 78 grinding mills, and 3 clinker plants. The installed capacity of the integrated plants is 261 Mt of cement and that of the grinding mills is 43 Mt (Figure 1).

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*Corresponding authors: Yury Villagrán-Zaccardi, yury.villagranzaccardi@ugent.be

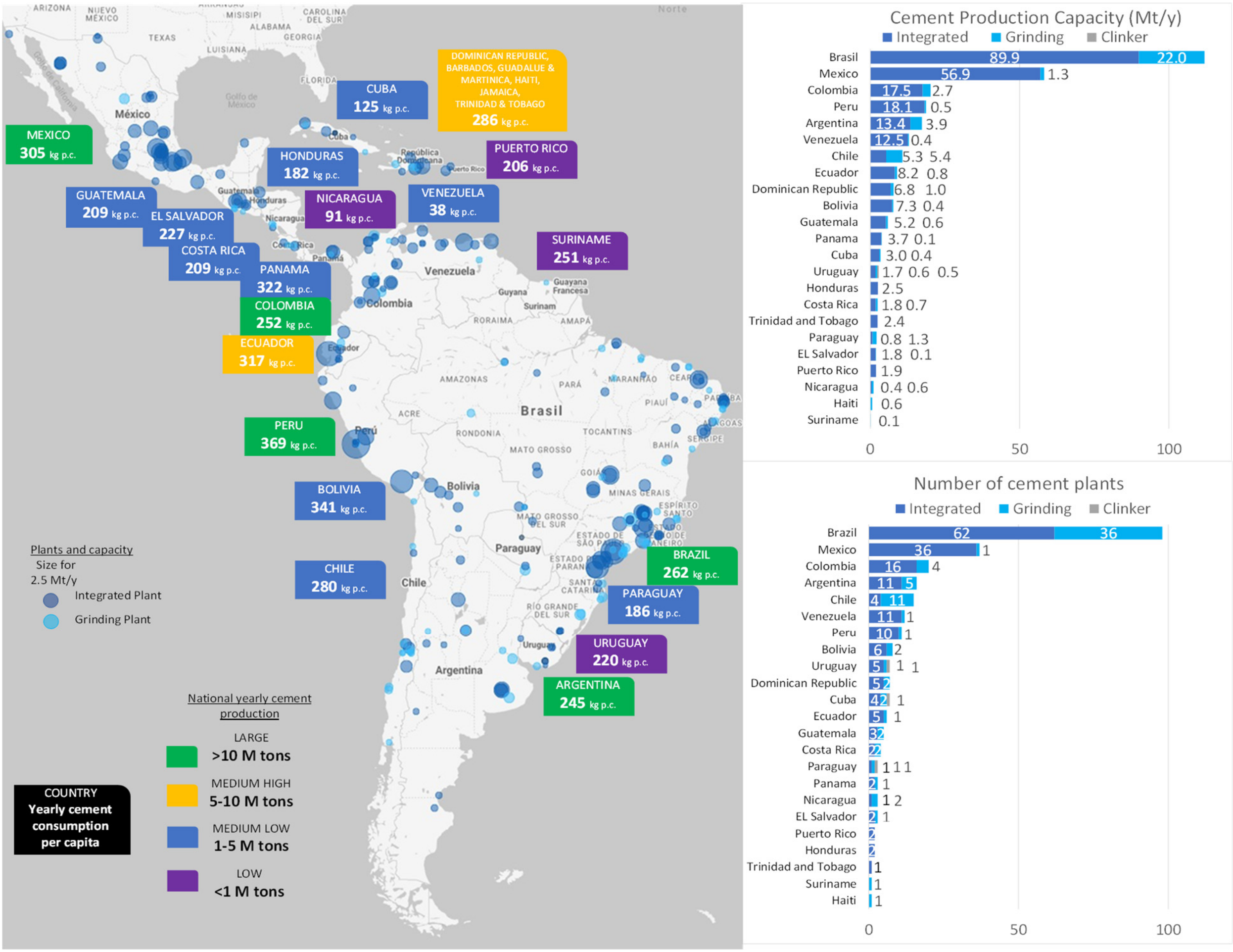

Figure 1. Latin American cement plants (source: FICEM, 2019), yearly cement consumption per capita and national cement production [3].

In 2019 (before the COVID-19 pandemic), cement production in LAC reached 170 Mt; with the largest cement producers being Brazil (7th in the world with 56.6 Mt) and Mexico (14th with 40 Mt). Other important producers in the region are Colombia (13 Mt), Argentina (11.1 Mt) and Peru (10.6 Mt) [3]. LAC is a region with variable development levels, so cement consumption per capita also varies (Figure 1).

The main consumption centers are mostly coastal areas (except for Mexico and Colombia). The locations depicted in Figure 1 imply that 50% of the population is within 100 km distance from a cement plant, and 65% is within 150 km from a cement plant. The variable geography causes a contrast regarding the contribution of transport to the environmental and economic impacts of cement. Imported clinker has Asia as the main source on the Pacific coast and Turkey on the Atlantic coast. This transport can add around 120 and 70 $kgCO_2/t$ clinker, respectively. Therefore, logistics plays a variable role in each country.

Cement delivery in LAC is mainly through bags (68% of market share) [5], with bulk distribution in the second term (32%, distributed in 25% for ready-mix concrete, 2% for precast industry, and 5% for other forms such as mortar and screed). It differs from those in more developed economies such as Europe [4], where the delivery forms are in bulk, for use in ready-mixed concrete (56%) and precast industry (20%), and others (bags, mortar, and others, 24%). The consumption of bagged cement in LAC is mainly connected with the lack of formality in the construction sector, including self-construction and small enterprises. The relationship between bagged and bulk consumption is a function of the economic development level of each country (Figure 2). LAC follows the global trend, but some progress seems feasible considering the average GDP of the region. In terms of forms of delivery worldwide, the trend towards 2050 is the elimination of bagged cement, except for Eastern European countries; ready-mix concrete is growing in all regions, especially in LAC, with the exception of China and Eastern European countries; the trend toward precast is growing worldwide, especially in China. There is currently a higher consumption of bagged cement in LAC mainly due to self-building and informal housing construction, where a part is destined for housing improvement (reinforcement, masonry, and finishing). Also, some asymmetries persist among countries (e.g., Guatemala vs. Chile as some extreme cases), making it difficult to generalize a single approach for the whole region.

The investments required to provide the necessary infrastructure for development in LAC are in the range of 3.8-4.0% of the national GDPs for the next decades [6]. However, this requirement increases to 4.5% of GDP investments to achieve the infrastructure-related Sustainable Development Goals in low- and middle-income countries (i.e. to stay on track to full decarbonization by 2050) [7]. Also, a limited fraction of the population has access to formal housing. Low-income families rely on self-help construction schemes, a process that last years or decades and is carried on without any technical assistance. Informal settlements are frequently located in areas prone to natural disasters such as landslides and floods. In LAC, approximately 20% of the urban population lives in informal settlements [9], characterized by low-quality resource-intensive housing. Informal housing is produced with bagged cement using cement-rich popular recipes, nowadays available in the social media. In shantytowns, more than 90% of cement is consumed in bags, i.e., ready-mix rarely enters and the only advanced form of commercialization that is present are adhesive mortars for ceramic tiles. An informal dwelling can consume twice as much of the main construction materials as a formal dwelling [10, 11] and generate a larger carbon footprint. Materials consumption is high due to overdesign of the structure and materials wastage at the site associated with precarious on-site processing, losses due to theft, inadequate storage, or simply double work due to poor planning. Self-building is one of the biggest challenges facing LAC in terms of sustainable and resilient construction; everything seems to indicate that it will continue to be the most viable option for a significant proportion of the LAC population, with bagged cement use outweighing other alternatives such as ready-mix concrete. Low-carbon bagged cement or low-carbon industrialized mortar and concrete are effective ways to mitigate CO_2.

The LAC region remains one of the most unequal geographic regions in the planet and any technological and policy approaches to decarbonizing the industry must account for the need to lessen inequalities. The housing deficit in LAC is a very significant barrier to human development. In this context, applying technologies that would require significant investment and raise materials prices, such as carbon capture technologies, appears problematic. A disproportionate increase in cement cost will imply that vulnerable populations will have to invest more of their scarce money in purchasing materials or risk their investment by obtaining housing that may not provide the same structural safety, durability, and resilience to the impacts of climate change. Mitigation efforts must be spearheaded by the developed countries [8] to decline advanced technology costs and implement smart policies that enable a low-carbon path to prosperity. Low-cost carbon capture technologies, like forestation or char, and strategies to increase cement and concrete use efficiency are more viable options in LAC, at least in the middle term.

So far, the LAC region has demonstrated significant progress in decarbonizing the industry by reducing the clinker factor in cement over the last 30 years (Figure 3) [13]. In the last two decades, there has been a sustained increase in limestone consumption as a filler, even though the clinker factor (clinker/cement) remained almost constant. The traditional SMCs (fly ash and ground granulated blast-furnace slag, GGBFS) have become progressively scarce, and lately, their consumption has declined. Natural pozzolans are widely available in the Andes region and Central America, but their share is limited due to the long distance between the sources and the largest population centers. Some exceptions to this situation are Chile, Ecuador, Mexico, Nicaragua, and Peru, where there is favorable proximity between natural pozzolans sources and consumption centers. In contrast, the resources in Argentina are located in relatively unpopulated regions.

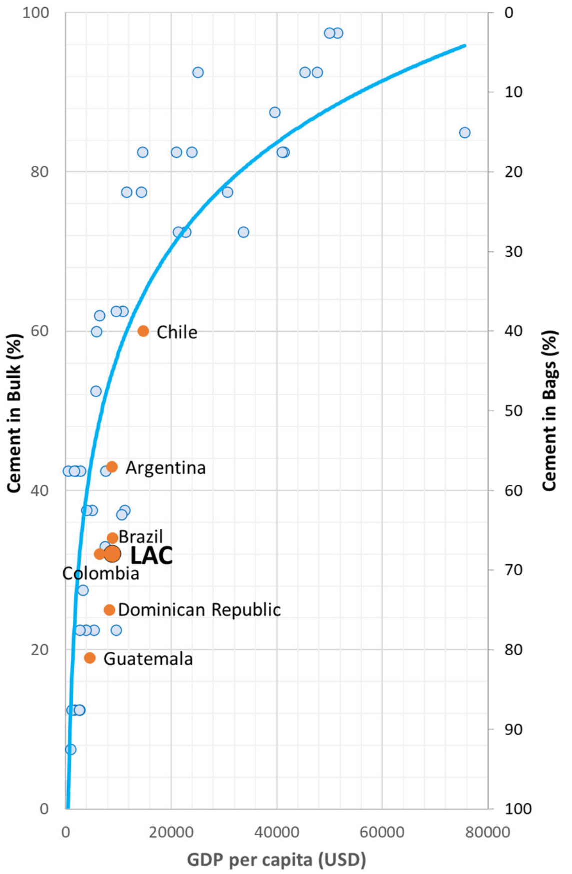

Figure 2. Market share of bagged cement in various regions and key countries with their GDP per capita (adapted from [12]).

The leader cement producer in the region, Brazil, does not have significant availability due to its geology. Colombia has significant potential with sufficient amounts of volcanic ash, tuff, and diatomite, but currently, natural pozzolan is only 3.6% of the SCMs market as no sufficiently detailed studies of the geological supply have been conducted. The limited availability of GGBFS and fly ash in Colombia drives imports of GGBFS (with the added carbon due to the transport) for reducing the clinker factor, so the further application of natural pozzolans seems strategical. However, natural materials can demonstrate a wide range of reactivity degrees and increase the water demand. Then, investigation for assessing their reactivity or water demand is an important matter to improve the performance of the resulting blended cement. A detailed description of the clinker factor and use of SCMs in LAC cement production is presented in Table 1.

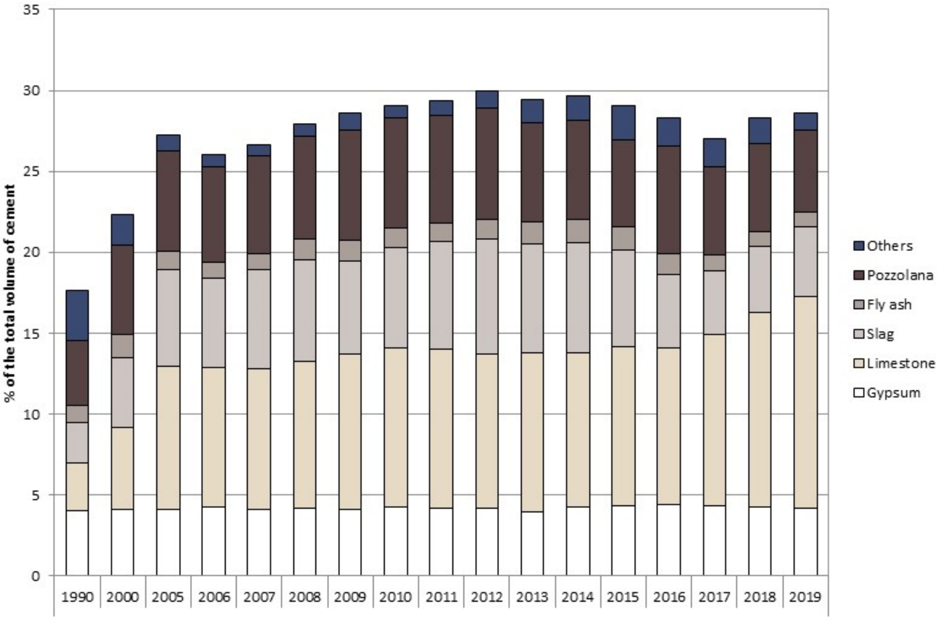

Figure 3. Mineral components used to produce clinker-based Portland cement in LAC (GNR data – GCCA [13], estimated LAC coverage: 71% in 2010, 74% in 2018, 74% in 2019).

3 Industrialization of the concrete industry and quality control in Latin America

In LAC, 81% of the population is urban. Approximately 24% of the population lives in the ten largest metropolises (> 5 million people). These ratios will continue growing by 2050. The number of following large cities (1 to 5 million people), currently hosting 23% of the population, will also grow from 65 to 77; medium cities (0.3 to 1.0 million people) represent 16% of the population, and small cities (< 0.3 million people) and rural areas correspond to 18% and 19% of the population, respectively [14]. The development of the urban population demands infrastructure and housing, and consequently, construction industrialization and building materials.

From the point of view of the product, industrialization can make significant improvements in productivity, quality, cost reduction, and environmental performance by reducing waste. According to the UN Environment report [12], industrialized production of cement and cement-based materials can reduce waste by at least 20-30%. In this sense, industrialized production employing more ready-mix concrete is within the strategies established in the roadmap toward carbon neutrality of concrete of the Global Cement and Concrete Association (GCCA) [2].

Cement producers estimate cuts in cement consumption in concrete production of 5% and 14%, respectively, in 2030 and 2050, through more efficient use of cement [2]. The main aspects to focus on are the proper use of aggregate particle packing and less use of bagged cement. In LAC, most of the volume of ready-mix concrete is produced by companies owned by cement producers. Although the industry has a history of more than 80 years in LAC, indicators of per capita consumption and cement use of ready-mix concrete remain low compared to other regions of the world. While LAC consumes an average of 0.2 $m^3 \cdot year^{-1}$ per capita [15], in more industrialized countries that have already developed their infrastructure and covered their housing needs, per capita consumption is 0.4 to 0.7 $m^3 \cdot year^{-1}$.

Therefore, cement consumption by the ready-mix concrete industry in LAC countries is between 5 and 25% of the total cement consumption (whereas in more developed countries, this indicator is generally close to 50%). Bagged cement is mostly used in masonry, plasters, and other non-structural applications (estimations for cement use in Brazil are 40% masonry, 40% concrete, 20% precast). The main reason for the limited development of the ready-mix industry is the timid investment in infrastructure and the very high informality in housing construction, which can reach up to 70% in some countries [15]. As an example of active policies, the Argentine Regulation for structural concrete [16] highly penalizes structural concrete production without appropriate quality assurance by increasing the minimum specified compressive strength value. Thus, producing structural concrete with low technology equipment is more expensive. Initially, a negative impact in terms of eco-efficiency may be inferred (as more cement is needed to produce the same functional unit with higher compressive strength). However, the policy has contributed to the migration towards more formal channels in the production chain, where the ready-mixed industry has progressed to supply more and more of the structural concrete that is placed nationwide.

Table 1. SCMs in the LAC cement industry (F: fly ash; P: natural pozzolan; S: GGBFS; L: limestone; O: others). Note: 'Gypsum' is reported as the impure amount of raw material that is industrially added during cement production, i.e. including impurities.

Country	Clinker/ cement factor (year)	Gypsum (%)	SCMs relative to cement production (%)					SCMs relative to total SCMs production (%)					Source of supply
			F	P	S	L	O	F	P	S	L	O	
Argentina	0.68 (2015)	5	-	2.5	4.6	17.6	1.8	-	9	17	66	7	Main SCMs are limestone, GGBFS, and natural pozzolan. Siliceous fly ash is very little present, not used by cement producers but by (a few) concrete plants. Silica fume is imported and is used only in particular cases of relevant works. Local produced calcined clays in one cement plant.
Bolivia	0.70 (2017)	5	-	30	-	3	-	-	90	-	10	-	Natural pozzolan (e.g., pumice, tuff) is obtained from the processing of rocks or directly as natural powder. Several quarries are present. No presence of GGBFS.
Brazil	0.685 (2019)	4	2	1	10	13	0.6	7	4	37	48	2	GGBFS from pig iron production. Fly ash from coal-fired power plants. Calcined clays produced specifically from clay deposits. Also, acid blast furnace slag from the pig iron production with charcoal and steel slag from steel production.
Chile	0.70 (2018)	5.2	4.8	17.1	2.3	0.8	<0.1	19	68	9	3	-	Significant natural pozzolan quarries. Also, fly ash from thermoelectric power plants and industrial GGBFS.
Colombia	0.68 (2015)	5.5	0.7	3.6	4.4	16.7	0.6	3	14	17	64	2	Limestone as the main clinker replacement. Fly ash as by-products of other industries, slag from ferronickel mines. Import of GGBFS from India.
Ecuador	0.70 (2021)	4.6	-	30.3	-	-	-	-	100	-	-	-	Volcanic ashes are the only SCM.
Mexico	0.75 (2016)	3.8	0.6	7.1	0.6	11.3	2.4	2	33	2	53	10	Cement replacers come almost exclusively from quarries of natural pozzolans and limestone.
Peru	0.77 (2016)	4.6	<0.1	11.3	1.1	5.8	<0.1	0.5	65	2.7	31	2	Cement replacers come almost exclusively from quarries of natural pozzolans and limestone. Some imported GGBFS.
Dominican Republic	0.73 (2015)	5.2	1.1	12.3	-	8.8	-	5	55	-	39	<0.1	Quarries of natural pozzolans and limestone. Some fly ash from thermoelectric power plants.
Macro zone Central America (Panama, Costa Rica, Honduras and Guatemala)	0.72 (2014)	3.9	0.2	14.8	<0.1	8.6	0.9	1	60	0.1	35	4	Fly ash from thermal power generation plant (Honduras). Natural pozzolans come from volcanic pyroclastic deposits and are characterized as rhyolites. Ashes from coal mines (Guatemala).

The effects of superplasticizers on fresh and hardened concrete properties already contribute to the goal of optimized cement consumption in concrete. Superplasticizers reduce the water-to-cementitious material ratio while maintaining adequate workability, which increases concrete durability and cement efficiency. In addition, superplasticizers contribute to improved hydration of cement grains. Consequently, superplasticizers are essential components of modern concrete and mortar. The correct application of superplasticizers is well established in the ready-mix industry, whereas structural concrete produced with bagged cement can hardly benefit from these advantages. Therefore, the contribution of superplasticizers to reduce the carbon footprint of the industry is hand-in-hand with the development of the ready-mix industry in the LAC countries.

The industrialization by precast production may further complement strategies of optimizing mixes and reducing the clinker factor. The concrete manufacturing process can cause a building's global warming potential to vary by more than 100% depending on if it is precast or cast-in-place [17–19]. The selection and production of precast concrete elements become more significant with optimized concrete mixes when production processing gains relevance over the impact of resources. It can increase from 20% to 37% of the total global warming potential when conventional mixes are replaced by optimized mixes [20]. The concrete precast industry is moving ahead in LAC to supply fast new infrastructure construction in terms of processes. Significant growth in this industry is expected in the coming years, especially due to its underdevelopment in most LAC countries (except for Mexico, Chile, and Brazil). In relative terms, in LAC, improvements in the systemization of concrete mixes seem more direct and less investing intensive than further reductions of the clinker factor.

One of the main advantages of technification of concrete production is further reducing the binder intensity of mixes. Scrivener et al. [12] presented data sets for binder intensities of concrete mixes produced internationally compared to mixes produced in Brazil. The Brazilian market may significantly benefit from further reduction of binder intensity. A higher specified compressive strength allows, by its own, to considerably reduce binder intensity (~ 60% reduction from ~ 15 $kg \cdot m^{-3} \cdot MPa^{-1}$ for 30 MPa concrete to ~ 9 $kg \cdot m^{-3} \cdot MPa^{-1}$ for 80 MPa concrete). This shift is feasible in LAC as it only requires the adoption of higher specified strengths by stakeholders. Moreover, laboratory studies on several advanced design methods demonstrated that is also feasible to reduce further the binder intensity below the current best practices available in the industry by applying packing methods.

Specifications of long lifetimes of construction can also provide a significant long-term reduction of emissions. This is a pending subject in the LAC region, where the durability and resilience of infrastructure are often overlooked. In developing countries, the early need to replace concrete structures overlaps with the need for new infrastructure to support economic development. This can put additional pressure on LAC countries, where advanced technologies such as carbon capture and storage appear extremely expensive. The situation is critical in regions with particular conditions that favor corrosion or in locations with a high risk of natural disasters (e.g. hurricanes, earthquakes) where periodic damage and destruction of buildings is produced.

4 Development Goals concerning the fight against global warming

The road map for the LAC cement industry to comply with the 1.5 D scenario implies that cement's carbon footprint should reduce further from 520 to 472 $kgCO_2eq/t$ cement by 2030. Carbon emissions in the cement industry originate mainly from the decarbonation of calcined limestone during clinker (60% of CO_2 emissions) and from the combustion of the fuel used for limestone calcination (40% of CO_2 emissions). The required reduction puts significant pressure on new technologies as further emission reductions using SCMs are limited (~ 9% of the required reduction).

The strategy for the LAC cement industry is aligned with the global efforts mainly guided by GCCA. However, the strategy for carbon reduction cannot be the same as that in high-income economies. One notorious difference is the link between cement consumption per capita and the GDP. The GDP is a good indicator of cement consumption per capita in high-income economies. In contrast, cement consumption is better linked with the population of middle or low-income economies. The population growth seems to be a much better indicator of the future consumption of cement in LAC (explained by the significant need for infrastructure to develop) in contrast to the high-income economies where the demand is more connected to industrial activity.

The most straightforward strategy for reducing carbon emissions is further reducing the clinker factor (i.e. increasing SCMs content). New sources of SCMs (additional to those mentioned in Figure 3 and Table 1) are becoming available, with calcined clays as the most promising new SCM. It is important to highlight that even within the same country, the solutions are local; not everywhere is there the same availability of SCMs. Thus, each case must be studied in a particular way. Colombia is an example where the limited local offer of SCMs could be increased with more exploitation of natural pozzolans (volcanic ash and diatomite), and agro-industrial waste, waste from the coal industry, clays, and limestones, among others [21].

The quality of the clinker is also critical regarding the clinker factor. Good quality of very reactive clinker allows further reduction of the clinker factor with full compliance of performance requirements for the cement. Cement plants can obtain significant benefits from multichambered silos that allow a perfect balance of the raw meal. Therefore, in some cases, a higher emission in terms of clinker may eventually lead to greater possibilities of reducing clinker factors. However, the clinker factor should not be assumed as an absolute indicator of low emission cement. Imported clinker or SCMs with high quality can include significant transport emissions, and the overall carbon footprint of the cement can be higher even with a lower clinker content.

The use of SCMs can be only one of the complementary strategies for reducing global warming potential. The cement industry's prediction of the demand for SCMs shows a scenario that will not change drastically. For a base scenario that considers the current practices for cement production, the overall demand of SCMs for 2050 would be 111 Mt (65% more than the current demand of 67 Mt). This would only slightly reduce in an optimized scenario to comply with the maximum emissions corresponding to a 1.5 D scenario.

Among the new technologies that have been considered are new synthesis routes for clinker, such as flame spray pyrolysis and solution combustion, alternative processes to the traditional solid-state reaction method [22, 23], and carbon capture (at a very high cost). Also, a complementary strategy is increasing the thermal efficiency of the kilns (today at 3560 MJ/ton clinker). Continuing with the technological reconversion will help to optimize this indicator.

The substitution of traditional fossil fuels also has significant progress to be made. In LAC, 90% of the energy consumed by the kilns comes from traditional fuels, such as coal, pet coke, and, to a lesser extent, natural gas. The energy source must be replaced by other less carbon intensive and/or carbon neutral, which in LAC is still limited to 10%. Hence, the importance of promoting the use of fuels derived from waste recovery through co-processing technology. In addition to the benefit of carbon savings in cement and waste sectors, there are safe waste disposal and a sustainable solution for the deployment of the circular economy.

Concerning the source of electric power, it is necessary to continue increasing the supply of non-conventional renewable energy to reduce greenhouse gases (GHG) emissions. This is, of course, something that does not depend solely on the cement plant but also on the regional energy matrix.

Currently, carbon emission savings are transitioning from focusing on having less carbon-intensive cements to having less carbon-intensive concretes. Such a shift implies a lower consumption of cement, which was resisted by the industry some decades ago. The urgent need for a low carbon economy has reconfigured the industry to commit to the highly efficient use of non-renewable resources. Previous strategies alone will not achieve the required CO_2 reduction, so advanced technologies will be necessary to achieve the climate ambition by 2050. Some examples are CO_2 capture, storage and use (CCUS), oxy-fuel, green hydrogen, new SCMs and intelligent plants (where process data reduces uncertainties related to the product performance). Carbon Capture Utilization (CCU) can be a suitable option for the cement sector to reduce emissions further, converting the CO_2 into materials with added value, for example, through mineral carbonation of industrial waste or natural minerals (serpentinite or wollastonite) [24]. This is hands down a better option than simply storing it in, e.g. abandoned mines. The capabilities for the development of each additional strategy are very variable in the LAC region in terms of investment capacities.

As shown in Figure 4, reducing the clinker factor is the second most important strategy for achieving carbon neutrality by 2050. However, considering the 2021-2030 period, it represents more than 50% of the industry's reduction.

Considering the previously discussed strategies for carbon reduction, the LAC cement industry (FICEM) developed consolidating statistics and made projections for four cement forms of delivery and their respective clinker factors. This model seeks to reduce the clinker content in cement and the cement content in concrete. Table 2 shows the projections for 2030 and 2050 (based on 2020) for the forms of delivery and their related clinker factor. Meeting these optimizations would imply a 21% reduction in total projected emissions by 2050, in line with cement industry trajectories in the 1.5 D scenario.

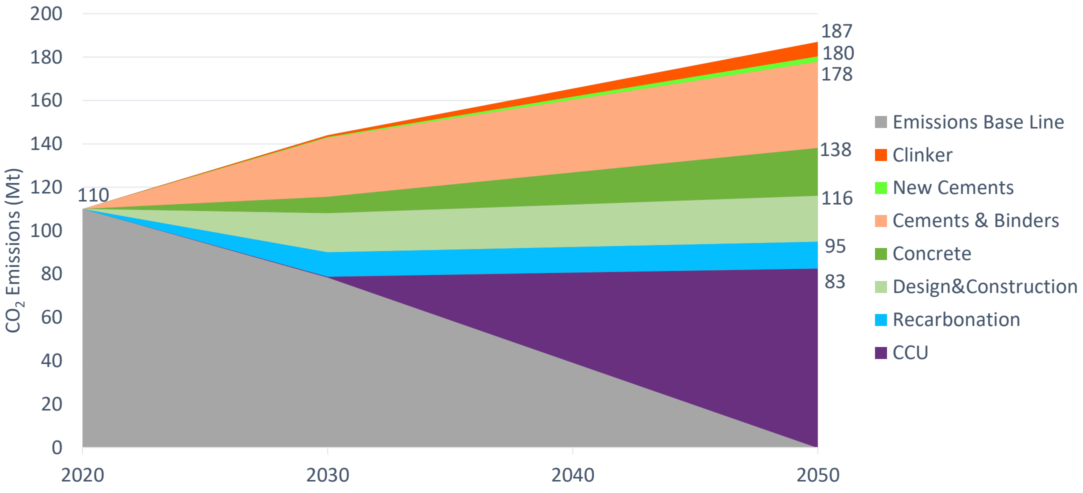

Figure 4. The road to net zero emissions by 2050 from concrete in LAC: contributions by levers (Source: FICEM).

Table 2. Required reductions in clinker factor per form of delivery of cement in LAC and corresponding demands of clinker and SCMs.

Cement form of delivery - base scenario	2020	2030	2050
Bagged Cement	68%	59%	42%
Clinker/cement	60%	45%	40%
Ready-mix	25%	33%	48%
Clinker/cement	83%	72%	65%
Mortar, screed, others	5%	5%	5%
Clinker/cement	60%	45%	40%
Precast	2%	3%	5%
Clinker/cement	90%	85%	85%
Optimized Baseline scenario	**2020**	**2030**	**2050**
Cement (Mt)	196	198	227
Clinker/cement	0.66	0.53	0.51*
Clinker (Mt)	128	105	115
SCMs (Mt)	67	93	111

(*) This weighed clinker factor considers the clinker factors for all forms of distribution as well as supplementary cementitious materials used directly in concrete and cementitious mixes as a separate constituent of cement

5 Standardization of cements in Latin America

The description of the national standards in the LAC region is presented in Table 3. Almost all national standards in LAC are based on their equivalents in the USA or Europe. A few countries, such as Nicaragua, the Dominican Republic, and Uruguay, also take some LAC standards as reference. Lately, the USA standards have gained slightly greater influence in the region. Only the countries that adopted ASTM C1157 classify cement types based on their performance (Colombia, Peru, and Central American countries). Most LAC countries maintain a prescriptive approach with requirements based on composition and compliance with physical and chemical properties.

Among the countries where regulations take a prescriptive approach are the two countries with the highest installed production capacity (Brazil and Mexico) and other countries that are also important in the region, such as Argentina and Chile. The fact that the regulations of these countries are prescriptive may limit the further use of SCMs. Although several national standards require that SCMs meet individual technical requirements (such as chemical composition, reactivity, fineness, and water demand), the best solution seems to evaluate the water demand and reactivity of the SCM in the blended cement as a whole.

In general, minimum clinker factors are near 0.2 for GGBFS cement and 0.45 for pozzolanic cement. CEM I is still included in standards, but it is not commercially available with very few limited exceptions (and always in bulk). A potential benefit can come from a change in regulation. For example, if it considers properties at 56 days instead of 28 days. Currently, only under exceptional situations, the industry profits from microstructure development between 28 days and 56 days (which usually is more noteworthy for blended cements). This could be further improved if regulation is changed. It could initially increase costs and reduce productivity, but appropriate models could compensate for this disadvantage by estimating late properties based on early-age properties. This is similar to the current practice, except that after 28 days, no further consideration of strength development is considered in the design.

Prescriptive standards can pose a barrier to the adoption of new SCMs. The application of performance-based specifications can encourage investment and the adoption of new technologies based on locally available materials. For SCMs that have limited availability, it is unrealistic to expect large-scale research programs to standardize them and encourage their use. In these cases, proof of suitability should be sufficient when reactivity, full compliance with human and environmental safety requirements, and adequate performance of the blended cement are considered. Local solutions can contribute in a limited but certain way to reduce the industry's overall carbon footprint. The main importance of such new approaches stems from the urgency to meet the increasing demand for SCMs.

The effort for reduced the clinker factor in cement must also be accompanied by market acceptance and regulatory frameworks governing cement quality. The decreasing availability of CEM I (or Type I) Portland cement in LAC started changing the market 20 years ago. This was accompanied by an incomplete adaptation and qualification of users to new low-clinker cements. The appropriate training of users should account for the LAC market characteristics and prevent reducing quality levels in the construction industry. The aimed reduction of emissions is not effective whenever the resulting structure cannot achieve the expected durability performance and requires early intervention. The frequent appearance of pathological signs at early ages in reinforced concrete structures in Mexico are some examples of this.

Table 3. Standards for cements in the LAC region.

Country	ID	Year	Type (C=Compulsory; V=Voluntary)	Reference international standard(s)			Composition (P=Pozzolan, G=GGBFS, L=Limestone filler; F=Fly Ash; S=Silica Fume; H=Shale)	Minor components	Approach	Discussions ongoing
				USA (ASTM)	Europe	Others				
Argentina	IRAM 50000	2017	C		EN 197-1 / 197-2		P or F < 50% G < 75%. L < 25%	< 5%	Prescriptive	NO
Brazil	NBR 16697	2018	C				P or F < 50%. G < 75%. L < 25%			NO
Cuba	NC 1340	2020	C				P (or calcined clay) < 35% P + L < 40 + 15%			NO
Paraguay	NP 17 044 80	2007	C				P < 50% G < 75% L < 20%			NO
Bolivia	NB 011:2012	2012	V	C150 C595			P or F < 55%. G < 35%. L < 35%			NO
Chile	NCh 148-2021-041	2021	C	C150			P or F < 70% G < 75%			NO
Costa Rica	INTE C147:2015	2018	C	C150 C595 C1157			P or F or H < 80%. G < 95%. S < 10%. L < 55%			YES
Dominican Republic	RTD 178	2009	C	C595 C1157		IRAM 50000 (Arg.), NMX C 414 11578 (Mex)	P < 35% F < 35% S < 10% L < 35%			YES
Uruguay	UNIT 20	2017	C	C595		IRAM 50000 (Arg.), NBR 11578 (Bra)	P < 50% G < 35% L < 20%			YES
Mexico	NMX-C-414-ONNCCE-2017	2018	V	C150 C595			P or F < 50% G < 80% S < 10% L < 35%			NO
Colombia	NTC 121/NTC 128	2018	V	C1157			/	/	Performance-based	NO
Ecuador	NTE INEN 2380	2011-2012	V	C1157						NO
El Salvador	PNTS 91.86.01:14	2014	C	C1157						NO
Guatemala	NTG-41095	2018	V	C1157						NO
Peru	NTP 334.009/082/090	2020	C	C150 C1157			P < 40% G < 95% L < 15%	5%	Prescriptive & Performance-based	NO
Panama	DGNTI-COPANIT 5-	2019	C	C91 C150 C595 C1157			P < 40% L < 15%			NO
Nicaragua	NTON 12 006 – 11	2011	C	C150 C1157		RTCR 383 (Costa Rica)	P < 40% G < 70%			YES
Honduras	No standard: The Honduran Construction Code is currently being published, one part focuses on materials (incl. cement) and the other on construction processes. The regulatory framework is erroneous and does not reflect reality. The code only makes reference to ASTM 150 (CEM I, representing only 20% of the national market) when in reality the country uses mostly blended cements (GU, 80% of the national market). Currently, at the initiative of the cement producers and under the umbrella of the Honduran Chamber of the Construction Industry, an application for the adoption of ASTM C150, C595 and C1157 as Honduran Standards has been submitted to the Honduran Standardization Organization (OHN).									

The potential challenges for durability due to the clinker factor in cement are mostly limited to applications in reinforced concrete structures. Conversely, exposure to deleterious chemical processes (e.g. alkali-silica reaction, sulfate attack, acid attack) has demonstrated the value of natural pozzolans, fly ash and GGBFS to prevent alkali-silica reaction and GGBFS to prevent chloride penetration. In the marine environment, the literature refers to the [Cl-]/[OH-] as the most appropriate parameter to define reinforcement pitting [25]. Given that the parameter depends on the alkalinity of the pore solution, cements with a reduced clinker factor may therefore affect the chloride threshold value. In urban/industrial environments, carbonation has historically been presented as a threat to the durability of reinforced concrete structures. Carbonation causes the concrete itself to absorb CO_2 from the environment, but at the same time, it reduces the alkaline reserve that keeps reinforcement in a passive state. Again, a more holistic design of concrete structures comes into play. A recent review [26] highlights that this is not the only condition leading to corrosion, as sufficient moisture is necessary for active corrosion to progress. LAC involves plenty of humid environments favorable for corrosion conditions, such as the Caribbean and other coastal areas, tropical forests, and humid regions. A reduced clinker factor in cements decreases the amount of hydrated products that can carbonate, meaning blended Portland Cement (BPC) concretes carbonate faster (e.g. limestone cement, fly ash-blended cement). The overall carbon capture by blended cements is at least partially compensated by this faster carbonation rate of the less alkaline material.

Effective reduction of global warming potential should consider reducing the clinker factor in cements while ensuring adequate durability performance. Concrete mixes with blended cements that perform deficiently in durability will reduce the initiation period. Whenever an early corrective repair is necessary, more cement in the repairs of these structures with low durability performance will increase the overall global warming potential.

6 Cement use in non-structural applications

Industrialized mortar is an increasing industry in many places. The market has been evolving to produce dry anhydrous mortar products ready to be mixed with water on site. This is, for example, a common practice in China. Such practice has quite some spread in developed countries (e.g. United Kingdom, Spain, USA), but its implementation in developing countries such as in LAC requires additional considerations. In Brazil, the provision of ready-mixed fresh mortar is a growing practice, where the mortar market represents ~ 8% of the use of cement. The potential impact of improvements in eco-efficiency is significant. The optimization of these mixes, incorporating also entrained air in a controlled manner, can greatly contribute to the binder efficiency of the mortar, which has marginal strength development requirements.

The production of cement should be differentiated depending on its uses. Non-structural applications require lower strength, and broader limits and lower clinker factors can be established for non-structural uses. This strategy should be cautious and pay attention to the education of users. In Brazil, there have been cases where cement for masonry use was applied to fabricate structural concrete, leading to significant safety issues. A potential solution could be to change the color of the cement when it is not suitable for structural applications.

Additional improvements can also be made in cement oriented to either the production of reinforced concrete or other non-reinforced applications. The cement market can be differentiated to account for the much lower requirements than non-reinforced applications have in terms of the alkaline reserve. In 2015, the production of reinforcing steel bars in 15 LAC countries (91% coverage) was 13.4 Mt [27]. Considering an average concrete mix with cement and steel consumptions per m^3 of concrete of 350 and 100 kg, respectively, the reinforcing steel consumption leads to a cement usage of 46.9 Mt. This is only 27% of the cement production for the same coverage (173.7 Mt). Thus, an estimation of 70% of cement produced in LAC does not need to comply with the performance requisites for reinforcement protection.

7 Emerging SCMs in LAC

The increasing demand of SCMs in LAC (Table 2, from 67 Mt/year in 2020 to 111 Mt/year in 2050) will require complementation by new sources. Limestone, the most used one, faces technological limitations for further use as clinker replacement; GGBFS and fly ash are progressively scarce; natural and calcined pozzolans depend on their geographic availability. There is a need for a multitude of local solutions. Therefore, novel strategies for optimizing the existing SCMs and new sources must be identified and evaluated. Some comments on the main groups follow.

7.1 Fillers

In cement production, limestone and marble are the primary sources of filler used as SCM, and its composition is limited by standard (> 70 to 75% of $CaCO_3$). Other types of filler are allowed as minor constituents (< 5% by mass) in the cement. Comparative studies of limestone and dolostone [28, 29] have demonstrated similar performance (grindability, hardness, strength). Dolostone stability was proven in cement paste containing reactive SCM [30]. Recently, EN 197-5 [31] allows dolostone as filler in blended cements, limiting the sum of $CaCO_3 + MgCO_3 > 75$wt%. Filler mineralogy in blended cement mostly plays a role in the corresponding density (e.g. quartz with a lower density than limestone occupies a larger volume for the same weight replacement ratio). Another aspect to consider for fillers is their energy demand for grinding. This would imply the different environmental impact of each mineralogy and different particle size distribution when intergrinding with clinker.

New technologies to further increase the filler content in cement are in development. Up to 50wt% replacement of cement by fillers can be achieved if the water-to-cement ratio is maintained constant to keep rheological properties constant [32], as opposed to the usual comparatives based on the same water-to-solid ratio. The reduction in the water demand of fillers may allow higher substitution rates, especially filler that demonstrates some reactivity (e.g., cristobalite, nepheline syenite, rhyolites, dacites, basalt). Recently, the design of multimodal particle size distributions with high particle packing and low-water demand has demonstrated that the limestone content may eventually increase up to 70wt% replacement ratio [33]. Thus, further progress is possible for non-reinforced concrete applications.

The consumption of fillers is not limited to the application in binders. There is a demand for fine particles (not necessarily reactive) to produce fluid and cohesive systems in many current mixes, such as self-compacting mixes. In these cases, the filler mineralogy is of secondary interest, provided that the content of absorbent clays is kept low to prevent increased water demand. When limestone filler is not available in the market or when sources of limestone filler are distant, small concrete producers may apply high cement contents (despite of cost) to achieve self-compacting mixes. Alternative fillers, especially the wastes produced in quarrying, have demonstrated appropriate performance [34].

Silicosis can be a limitation to some fillers containing high amounts of quartz. Inhalable silica particles that cannot be eliminated from the lungs by self-cleaning mechanisms with sizes of 10 µm (PM10) and 2.5 µm (PM 2.5) or smaller are a threat to human health [35, 36]. This can be the case of some mineral wastes producing silica dust when used at too fine particle sizes.

7.2 Slags

During pig iron production, the rapid water-cooling of slag gives GGBFS. The pig iron production in LAC was ~40 Mt during 2010-2019, and the slag production can be estimated as 25 to 30wt% of iron (10 to 12 Mt per year). GGBFS production is concentrated in three countries Brazil (64%), Mexico (24%), and Argentina (6.8%), and the rest is mostly produced in Chile, Venezuela, and Colombia. In 2018, the available GGBFS was enough to substitute less than 10% of clinker at the regional level. Except for Brazil, Mexico, and Argentina, all the other LAC countries using GGBFS as SCM depend on imports (e.g. from Turkey, Japan, and Korea). Therefore, the eco-efficiency of GGBFS should consider its transport and production methods, which can be quite variable for imports. Using imported GGBFS means a reduction in chemical carbon emissions for the LAC cement industry, but it is an unfavorable practice for global carbon emission. Clinker is also imported when demand is high, which involves the double disadvantage of carbon emission due to chemical processes outside the LAC region and the carbon emissions connected with transportation. Despite the global trend that primary iron production is declining due to increasing recycling, the LAC region is deficient in the scrap for recycling [37], and the estimate for the coming decades is a stable availability of GGBFS.

Other slags (different from GGBFS) are receiving worldwide attention as aluminosilicate sources. This includes the steel industry and the production of other metals. Such a strategy is also applicable in some LAC countries where steel and diverse metals are produced. Low reactive slags face the limitation of cost-effective processing for their application because, in general, the substitution does not imply a significant improvement of concrete properties [38]. Slags need to conserve an amorphous structure in order to react. Such an approach may improve the applicability, but it requires significant capital investment to apply a fast-cooling granulation process. There is a huge question of contamination by heavy metals, but the amounts are really small at the end of the day. Leaching studies have demonstrated that when used in road construction, the concentration of heavy metals in the leachate is far below standards for industrial wastes [43]. The application in cementitious systems, which have a significant encapsulation capacity of heavy metals, seems an even safer alternative. The urgent need to recover energy and new materials contributing to the circular economy pushes the industry to incorporate them in developed countries to prevent downcycling rather than carbon savings. The situation in LAC is much more incipient, where applications as aggregate are still more convincing.

Steelmaking is dominated by basic oxygen furnace (BOS) processing (where oxygen is blown into the molten metal) and electric arc furnace (EAF) processing. Slags from these processes are usually strong and rock-like, potentially used as aggregates. The worldwide production of steel slags is ~ 190-290 Mt/year, with slag being ~10-15wt% of raw steel production [39]. BOS and EAF slags are the major by-products worldwide among the various steel slags. In South America and Mexico, crude steel production was 60.5 Mt/year, from which 42.4 Mt/year were produced by BOS and 18.1 Mt/year using EAF [37]. Their valorization in cement production has great potential. BOF slag could be used as SCMs when the lime is carbonated to prevent unsoundness, while BOF and EAF are potential raw materials for cement clinker production [40].

Solidification studies on BOF slags [41] have shown that basicity below 1.2 and alumina content between 10 and 12.5wt% favors the formation of amorphous phases in the range between 25 and 31wt% of solidified BOF slag, with cooling temperatures as fast as 21 °C/s showing no consistent contribution to amorphization. This does not yet appear to be sufficient for adequate activation of the slag. Concerning hydraulicity, C_2S and C_2F contents in BOF slags are in the range 40-50wt% and 20-30wt% [42], but these seem insufficient to develop sufficient strength even with the use of accelerators. Given the remaining knowledge gaps for industrial implementation, further research in this area can be valuable.

Nonferrous slags derive from copper, manganese, nickel, and lead represent a local opportunity in some LAC countries. These slags contain a large proportion of Fe_2O_3, silica and alumina, and a low proportion of CaO and MgO. They require more energy for grinding than other slags [44], but their use as clinker replacement may be an appropriate valorization strategy [45]. Appropriate methods for activation through amorphization or other methods are still a matter of study.

The annual worldwide production of copper is estimated at ~20 Mt/year; then, the corresponding amount of copper slag is ~ 44 to 60 Mt/year [46]. Globally, the figures are very small compared to clinker production, but copper slag can contribute to local solutions at certain locations in the main copper-producing countries. Chile produces 5.6 Mt/year, Peru 2.40 Mt/year, and Mexico 0.75 Mt/year of cooper [39]. The sources of copper slag would differ depending on the geological origin, especially regarding the calcium content. A recent review [47] shows that copper slag contains high levels of iron oxide and has low grindability compared to conventional raw materials for cement production. As SCM, copper slag retards the hydration causing a reduction of the setting times and the heat of hydration at early ages. The compressive strength gain with copper slag is slightly slower than with fly ash cement. The pozzolanic reaction of copper slag at later ages provides concrete with relatively lower permeability, absorption, and diffusion properties [47].

EAF slag from ferronickel mine is produced in Colombia, and the daily stock increase is ~ 0.01 Mt, generating an accumulated environmental liability of more than 20 Mt. This slag is acid, siliceous, and aluminous by nature, and glassy due to its granulation process. These are common characteristics in pozzolanic materials. The slag at laboratory scale and under ASTM C989 showed no latent-hydraulic properties, and compressive strength results obtained were comparable with Type III cement (ASTM C150) pattern at an addition rate of 15wt% [48].

7.3 Fly Ash

The role of coal in the energy generation of the LAC region was limited to only 5% in 2019. Colombia (80%) is the largest coal producer in LAC, followed by Mexico (11%), Brazil (6.2%), and Chile (2.2%), and very small consumption in Venezuela, Peru, and Argentina [49]. However, a significant part of this production is exported and only a fraction is used for energy supply. The main producers of coal-based energy [50] are Brazil (40% of LAC coal-based energy), Mexico (30%), Chile (17.2%) and Colombia (9%). For future scenarios, demand for electricity in LAC will rise to more than double by 2050, but the carbon fuel share in the generation is expected to decrease to 0% by 2060. Based on the transformation of the energy matrix, predictions for fly ash sources in the near future are in decay.

7.4 Natural Pozzolans

The increasing scarcity of GGBFS and fly ash makes natural pozzolans one of the main potential future sources of SCM. Figure 5 shows the distribution of natural pozzolans in the LAC region [51]. Most of the natural pozzolan deposits are currently in use as SCM to produce blended cement in several LAC countries (in the Andes region: Ecuador, Chile, Peru, Colombia, Bolivia, Argentina; the trans-Mexican volcanic belt; the Pacific coast of Central America; and the Maimon formation in the Dominican Republic). Different pozzolanic sources can have a very wide range of reactivity degrees, and exploring new chemical activation technologies is the key to the development of pozzolanic cements with low clinker factor. Better tests of reactivity can help further exploit their potential. The natural pozzolans have a volcanic origin, and the pyroclastic rocks (ashes and pumices) show high glass content and good pozzolanic activity [51]. Alteration of the glassy material to crystalline zeolites can occur due to the diagenetic process resulting in coherent tuffs that, when finely ground, have high pozzolan activities. The limitations to greater use of natural pozzolans are local availability, the legal land designations limiting access to known deposits, and the transportation costs. Studies with local natural pozzolan have been reported in Argentina [52–54], Chile [55], Peru [56], Ecuador [57], Colombia [58], Cuba [59], Mexico [60, 61]. They are classified as rhyolitic to andesitic glass with different zeolitization degrees in most cases. Large pumice reserves have been identified on all continents [39, 62]. Besides the known reserves, more exploration is needed to estimate its significant potential. Among the non-volcanic natural pozzolans, diatomite deposits (originated from the accumulation of amorphous hydrous silica cell walls of dead diatoms in water) are found in Mexico, Peru, Colombia, Brazil and Argentina [39]. The unit cost of diatomite varies widely, and the cheap sources are currently used in construction. Diatomite has a good pozzolanicity degree, but it can significantly increase the water demand in cement. It can also require calcination to improve its performance.

7.5 Calcined Clay

Calcined pozzolans appear, as well, as a potential solution for the rising demand for SCMs in cement production [63–65]. The thermal transformation and the pozzolanicity of reference mineral clays (kaolinite, montmorillonite, illite) have been widely studied [66–68]. Low-grade kaolinite [69, 70] and common clays (illite and smectites) with several impurities are also used to produce SCM [71–74]. The pozzolanicity of combinations of clays in residual soils has even been studied [75]. In LAC, the clays available in the soil (0.3-2 m depth) are included in Figure 5, for illite-mica, smectite, and kaolinite resources. The Brazilian cement industry has produced calcined clays for several decades [76, 77], with a production of ~ 2 Mt/year since 1970's [12]. Calcined-clay blended cements have been recently adopted in Colombia [78] and Argentina [79] for general applications. In Colombia, there is an installed production capacity for calcined clays of around 500.000 tons/year, at an average energy consumption of 550 kcal/kg (30% less than a dry clinker line). Pilot production of calcined-clay blended cement has been implemented in Cuba [80] and Guatemala [81]. The low investment required, the cost of calcination, and the low emission present calcined clays as a good option for increasing volumes of SCMs in the near future.

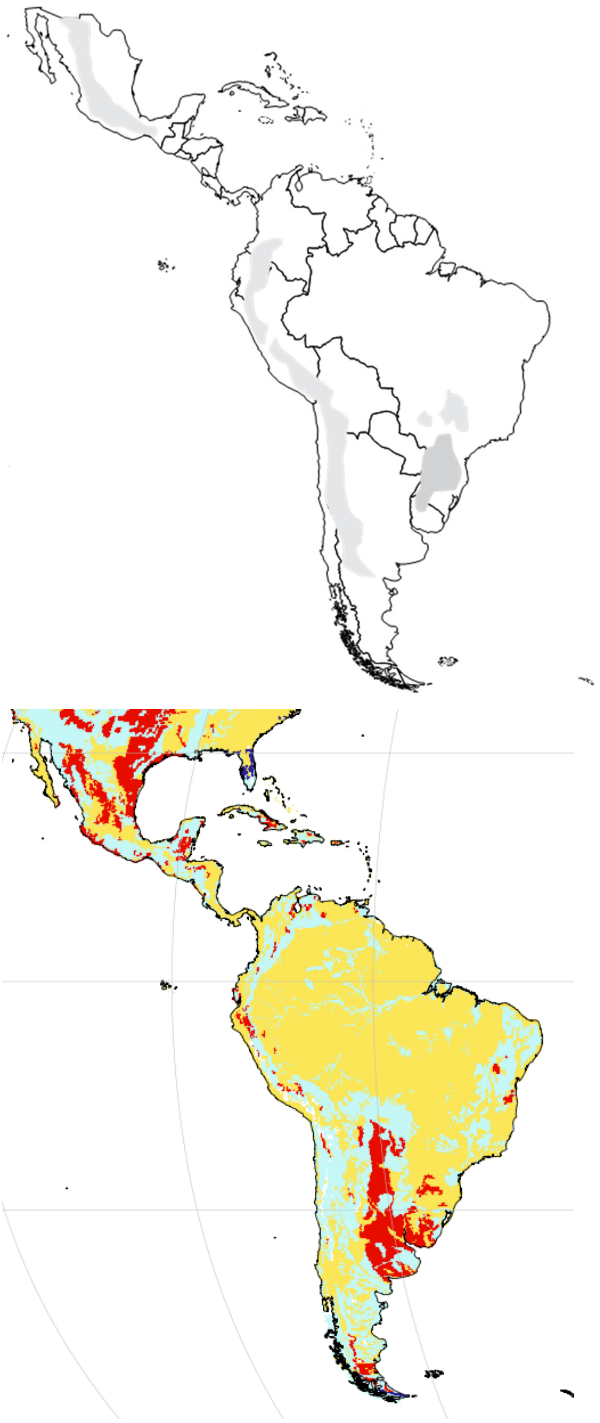

Figure 5. Localization of natural pozzolans (top; grey: volcanic rocks) and types of clay in the soil (0.3-2 m depth) (bottom; light-blue: illite, yellow: kaolinite, red: smectite) in LAC (adapted from [51] and [82]).

7.6 Other industrial and mineral wastes

A scrap of the ceramic industry from different ceramic sources (bricks, tiles, sanitary wares, pottery) can be recycled as SCMs based on its pozzolanic activity [83–86]. More than 50% of construction and demolition waste comprises ceramic materials. This allows incorporating this residue as SCM for mortar production. The amount of construction and demolition waste in urban centers with a population larger than 0.5 MHab makes it feasible to produce it at competitive prices for commercial use based on transport distances. The industrial production of scrap is estimated as 3-5% of the volume of ceramic products. Historically, the LAC ceramics industry has been concentrated in tile, flooring, construction materials, and sanitary ware products. Brazil and Mexico are the largest producer in the region, followed by Argentina, Uruguay, Paraguay, and Bolivia. In LAC, the Spanish and Portuguese influence on the construction style joined with the lack of stone in the Atlantic region, contributed to using a lot of ceramic brick and tile in residential and non-residential construction.

Also, the glass from several sources (packing, bottles, windows, car windscreens, and others) can be used as SCM in the future. ASTM C-1866-20 [87] has standardized the glass waste for use as SCM, and the volume estimated is more than 10 Mt in the region [88]. Compared to clinker production, this is still a small volume, but as such it can be a small contribution in some local contexts.

The world's production of bauxite residues during aluminum production was estimated at 160 Mt in 2020 [89]. This residue consists of red mud produced in Brazil at 10.6 Mt/year [90]. Red mud is usually discharged as a highly alkaline slurry (pH 10-13.5) with 15-40% solids, pumped away for suitable disposal. Its chemical and mineralogical composition may change temporarily, depending on the source of bauxite and on the technological processing conditions. Red mud comprises six major oxides: Al_2O_3, Fe_2O_3, Na_2O, SiO_2, CaO, and TiO_2, and a large variety of minor elements. Due to its strong alkalinity (Na_2O + NaOH = 2.0 - 20wt%), the conditions in which it can be discarded are restricted to minimize environmental problems such as soil and groundwater pollution. For its valorization in the cement industry, a recent report [89] indicates that there is enough knowledge for bauxite residues to be immediately used in Portland clinker production. There are, however, still important unresolved obstacles that impede the application of red mud as SCM, such as the effect on later ages strength (even at very low replacement ratios of 5wt%) and the high alkali content that may promote alkali-aggregate reaction [91]. Cement production in Brazil is five times larger than red mud production, allowing it a potential valorization path.

7.7 Agroindustrial ashes

Some agro-industrial residues have also shown pozzolanic potential after calcination. Among them are rice husk [92, 93], sugarcane bagasse [94], and bamboo [95, 96] ashes. They have demonstrated good potential based on their content of silica. However, they may serve as a partial solution for some specific regions. In the global picture, their estimated availability is limited. LAC produced approximately 28 Mt [97] of paddy rice in 2018 (12 Mt corresponds to Brazil). From the paddy rice, ~20% is husk, from which ~ 18% can be the remaining produced ash [98]. From the sugar cane, ~ 25% will result in bagasse, from which ~ 2.5% will be the remaining ash [94]. These are the highest possible yields, while lower ratios are industrially feasible in practice. Rice husk ash contains more amorphous silica (~ 90% [98]) that demonstrates much more efficiency as pozzolanic material than sugar cane bagasse (with maximum amorphous silica of 35 % when produced by controlled burning [99]). Maximum potential production of rice husk ash of ~ 1 Mt would have been possible in 2018, representing only 0.6wt% of cement production. Therefore, the potential contribution is quite limited. The use of rice husk ash in combination with limestone has proved effective for replacing clinker of up to 25% [100], showing promising contributions for ternary systems that may further reduce clinker demand in about 1.7%. A more significant advantage seems feasible in co-processing, especially in terms of costs when saving on conventional fuels [101]. The composition of the rice husk is compatible with co-processing, but it might affect burnability. The application of rice husk as a modifier of hot meals mainly composed of refuse-derived fuel has been proven efficient at ratios of up to 5% [102]. The rice husk can increase operational stability in a co-processing cement plant in this scenario. Many other less investigated waste biomass, e.g. cassava peel [103], cotton stalk [101], and cereal straw [104], could serve a similar purpose even though they may not contribute with as significant amounts of amorphous silica as those from rice husk.

8 Conclusions and Final Remarks

- The LAC region, currently on a development path, has great potential for future increased demand for cement and concrete for the development of large-scale structures and infrastructure. In addition, the impact of natural disasters also contributes to this demand in the region.
- To achieve carbon neutrality by 2050, a further reduction in the clinker factor from the current 0.66 to 0.51 is required in the LAC region, in line with the roadmap of the global cement industry. Therefore, finding sources of SCMs in sufficient quantity and quality is critical.
- Carbon reduction and human development goals need to be reconciled. A reduced carbon footprint can be kept in sync with the LAC need for more investment for human development through strategies for more efficient use of materials in concrete. Some promising options are the reduction of bagged cement in the market, the differentiation of products according to use, improved structural design, and consideration of concrete re-carbonation. New carbon capture and utilization or storage technologies will be required starting in 2030. Because of the expected high costs that could conflict with human development, special attention must be paid to local conditions in LAC.
- The implications of the reduction of the clinker factor that cements have experienced in LAC since the end of the 20th century are not yet sufficiently known by many cement users in terms of their performance. Doubts about the performance of blended cements and interaction with other additions (chemical or mineral) persist and lead to inconvenient practices for producing structural concrete. The durability of reinforced concrete structures is one of the aspects to be better considered, e.g. additional challenges in terms of carbonation posed by low clinker cements. Most cement is used for non-reinforced applications, so a decoupled market can help meet the requirements of reinforced concrete and further reduce clinker factors for other applications.
- Adjusting prescriptive standards can help accelerate the adoption of new SCMs. Most new SCM alternatives are presented as a variety of local solutions that cannot individually provide a complete answer but contribute to satisfying the demand. Emerging SCMs in LAC include calcined clays, construction and demolition waste, steel and non-ferrous slags, and agro-industrial ashes. Moreover, natural pozzolans remain under-explored in the region and could be a more significant source of SCM in the near future. Moving towards performance-based specifications can encourage investment and implementation of these. This is especially necessary as the SCMs demand is expected to increase by 65% by 2050 to meet the 1.5° C scenario for limited global warming.
- The application of low clinker factors cannot be implemented as an isolated tool, as in some cases, this resulted in imports of SCMs, which adds up the impact of transportation and does not contribute to the production of low carbon cements.

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CRediT Authorship statement

Y. Villagrán-Zaccardi: Conceptualization, Investigation, Writing – Original Draft, Funding acquisition;

L. Rojas: Formal analysis, Investigation, Writing – Original Draft, Visualization;

R. Pareja: Conceptualization, Formal analysis, Investigation, Writing – Original Draft, Visualization;

E.F. Irassar: Conceptualization, Investigation, Writing – Original Draft, Funding acquisition;

A. Torres-Acosta: Conceptualization, Investigation, Writing – Original Draft;

J. Tobón: Conceptualization, Investigation, Writing – Review & Editing;

V. John: Conceptualization, Investigation, Writing – Review & Editing.

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