LC³ PROJECT

EPFL

LOW CARBON CEMENT

Harmonizing Environmental Goals and Housing Needs

The potential contribution of limestone calcined clay cement (LC³) as a viable solution to simultaneously meet climate goals and address the global housing challenge.

Anthony Boanada - Fuchs

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Supported By :

Schweizerische Eidgenossenschaft
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Swiss Agency for Development and Cooperation SDC

climateworks FOUNDATION

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FOREWORD

JANINE KURIGER

Head of the Section Climate,
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Cooperation (SDC)

Switzerland has supported research on Limestone Calcined Clay Cement (LC^3) since early 2005 through the Swiss National Science Foundation. Between 2013 and 2022, the Swiss Agency for Development and Cooperation (SDC) has actively backed the technical validation, standardization, dissemination of knowledge, and scaling up of LC^3 within its Low Carbon Cement project in both India and Latin America. The SDC's pioneering work to support the introduction and dissemination of LC^3 at a time when it was far from foreseeable that LC^3 could one day revolutionise the entire cement industry was visionary and innovative. Supporting a research project in the field of cement may appear unconventional for a development agency whose main mission is to eradicate poverty. From both climate and development standpoints though, it is logical to support innovation in an industry tied to roughly 8% of global emissions. Offering a realistic and scalable solution for decarbonizing this substantial sector is crucial, especially considering that over 90% of cement production is currently concentrated in the Global South, with the bulk of significant growth in cement consumption in the coming years expected in Asia and Africa.

This study underscores the importance of low-carbon cement, not only to meet environmental goals but also for attaining development targets and narrowing the housing gap. To fulfill SDG 11.1 by 2030, approximately 600 million housing units will need to be constructed, with 76% of these in Asia and Africa. Enhancing the quality of infrastructure amid sustainable rapid urbanization necessitates accessible and environmentally-friendly cement. Approximately 80% of forthcoming development, encompassing housing and infrastructure is due to unfold predominantly in the Global South, notably across Africa and Asia. These regions are experiencing sustained population growth and still have significant urban landscapes yet to be built. Over the next three decades, the projected cement demand in these areas will be staggering, potentially leading to the emission of nearly 100 billion tons of CO_2 equivalents if measures to decarbonize cement production are not swiftly implemented. Solutions tailored for the Global South such as using local resources are key to this transition. The construction sector can act as a catalyst for economic growth and employment as it can absorb many young people entering the labor market in the Global South.

In summary, LC^3 can profoundly contribute to aligning social, economic, and environmental objectives, particularly in the Global South. It exhibits resource and energy efficiency, cost-effectiveness, high performance, and enables local production, thereby reducing reliance on imports, especially in Africa.

The SDC is therefore delighted to have played a part in fostering Limestone Calcined Clay Cement, an innovation that holds such significance for the future of humanity.

ABOUT THIS PUBLICATION

This research was undertaken by the LC^3 Project housed at the Ecole polytechnique fédérale de Lausanne (EPFL) in Switzerland to understand the social and ecological dimensions of low-carbon cement especially to meet the high demand for housing and infrastructure in the Global South where over 90 % of all cement is produced nowadays. The LC^3 project and this research was supported by SDC, the Swiss Agency for Development and Co-operation.

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PROF. DR. KAREN SCRIVENER

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INTRODUCTION AND HOW THE STUDY IS STRUCTURED

Like the two sides of a coin, cement has two faces: Cement is an extremely useful, needed, and omnipresent material, and at the same time a considerable source of emissions. If cement were a country, it would be the third largest emitter of greenhouse gases on earth, behind only China and the United States. With 4.2 billion tons of production per year, cement is the largest manufactured product on earth by mass, no other material can substitute it.

Given the dominance of cement in material consumption and its ecological footprint, the greening of the construction industry is as urgently needed as it is challenging. A promising option to make cement greener is LC^3 (limestone calcined clay cement), allowing the reduction of the clinker factor to 50 % or less by blending clinker with calcined clay and unburnt limestone. LC^3 is an already fully operational method capable of reducing CO_2 emissions by 40 % without compromising its strength and durability.

In Chapter 2, this report attempts to quantify how many housing units are needed to ensure access to affordable housing for all by 2030, as stated in the Social Development Goal (SDG 11.1) of the UN. Some 600 million units – 40 million every year - would be globally needed between 2015 and 2030, and some 500 million, or 80 %, of them in the Global South. This is an ambitious number but, surprisingly, the cement demand to build these housing units is relatively moderate, as basic housing units in the Global South are extremely modest. Only 3 % of the global cement production would be needed to build these housing units and allow all people to have a decent roof over their heads. As such, this small increase in cement demand would also not be a major environmental threat.

However, as we shall explore in **Chapter 3**, the demand for cement is closely linked to population growth, to urbanization processes and finally to economic prosperity and affluence: these 3 factors act together as catalysts and lead to a fast increase in consumption levels. Very broadly speaking, one could say that a traditional, mostly rural – and poor - society does not consume more than two 50 kg bags of cement per person.

Even a nowadays high-income country as Switzerland consumed only around 100 kg per person in 1920, which quickly rose to 500 kg and more in the post-war economic boom period. When societies grow in population, transforming themselves from rural to urban and to industrialized societies, cement consumption increases unavoidably; it is not unusual for one person to consume more than 500 kg in phases of high economic growth. The faster this transformation takes place, the higher this consumption will be, as the rapid economic transformation of China illustrates with a per capita consumption of around 1,600 kg, three times the global average consumption. It is also typical that consumption stabilizes at around 300-500 kg per person once this transformation is done and a country is cruising at a high-income level, with the rate of urbanization slowing down.

Chapter 4 contains forecasts for the demand of cement. While the cumulative global production was around 75 billion tons in the past 30 years (1991 – 2020), production is expected to be around 127 billion tons over the next 30 years (2021 – 2050). This is a 70 % increase, and emissions could be in the order of 95 billion tons of CO_2, equivalent to 24 % of the remaining global carbon budget, which the IPCC has estimated at 400 billion tons in 2021. 90 % of this additional demand will happen in the Global South which needs large amounts of cement to build houses and infrastructure, especially for all the cities yet to be realised. This overall cement demand will be a major environmental threat if we don't urgently initiate the production of low-carbon cement.

Chapter 5 explores how such a decarbonization process could be achieved with LC^3 cement as a viable and low-cost alternative to the costly carbon capture and storage technologies. It shows how the Global South and especially Africa can produce Low carbon cement at lower cost, and what would be needed to make the housing and construction sector a driver for economic development and an opportunity to benefit from a demographic dividend. We talk of a demographic dividend when a high share of young people in the working age could boost economic growth, provided they have jobs.

THE SOCIAL LENS: ACHIEVING HOUSING FOR ALL BY 2030 (SDG 11.1)

Quantitatively speaking, housing is not the most important factor for cement consumption. Nevertheless, this report uses housing as a useful social indicator due to its fundamental importance for societies. "The first thing all creatures, including humans, need to do on leaving the nest is to find somewhere to live."[1] Housing is important for national economies and for stable and prosperous societies; adequate housing provides economic and social stability. Furthermore, the housing sector relies on a long value chain[2], and investments in housing do not only have a considerable multiplier effect but can also address major development problems, such as homelessness, unaffordable housing, and unsustainable urbanization. In the Global South, access to housing is strongly connected to poverty alleviation, stable livelihoods, and improved life expectancies.

Universal access to affordable housing by 2030 is recognized in the Sustainable Development Goals of the United Nations as a special target (11.1). In the absence of precise calculations for the challenge ahead, this study analyses how many housing units and ultimately how much cement would be required to make this vision a reality. Based on publicly available data and by applying some simplifying assumptions, we estimate that 600 million units are needed worldwide within the SDG framework (2015 - 30), or 40 million per year. Half a billion units are needed in the Global South, more than 80 % of the total need. This need stems from three dimensions:

- **The demographic need** due to population growth (around 300 million units, mostly in the Global South) and household changes
- **The replacement need** resulting from upgrading slum housing units (190 million units, also mostly in the Global South, and
- **The renewal need** resulting from the replacement of too old housing units (100 million units in total, of which 7 million in the Global North).

Most housing units in the Global South would require only modest amounts of cement: 1,200 kg for a slum replacement unit (most commonly less than 10 sqm per unit) - and 3,600 kg for a basic affordable housing unit (25 sqm). By contrast, if the needed housing units were built with high spatial standards (100 sqm, derived from housing data of European countries), each unit would consume around 27,000 kg.[3] For the global housing gap of 40 million units per year, this translates into 138 million tons of cement (3 % of the world production of 4.2 billion tons) if only very basic housing units were built, whereas around 1 billion tons would be needed if all houses were built with high European standards (24 % of world cement production). In Africa, however, the respective shares would be much higher: 12 % of cement production for basic units and 94 % for high - standard units. In some African countries, the cement needed for high standard units would reach 134 % of present cement production in Ethiopia and 437 % in Burundi, as these countries have high population growth, a small formal housing sector and a low domestic cement production.

Globally speaking, cement consumption for basic housing would have a minimal impact on total emissions: Building the basic units would emit less than 1 % of total emissions and even if all units were built with high standards this would only increase to 2.4 %. The exception is Africa, where this number would represent 12.5 % of current emissions; this is mostly due to the generally low emissions on the continent. However, the cement needs for housing represent only a fraction of the total cement demand for infrastructure and urbanization, especially as the cities in the Global South are yet to be built.

Although it is difficult to estimate the infrastructure requirements, it is evident that the Global South, has an enormous need to catch up, especially in Africa. While every citizen in the Global North has consumed some 16 tons of cement per capita in the 30 years from 1961 to 1990 and again from 1991 to 2020, every African has only consumed 700 kilograms and 2.5 tons in the respective periods. China was at such low levels (2.6 tons per capita) from 1961 to 1990 but consumed over 30 tons per capita in the past 30 years. It is therefore most likely that the total cement demand in the Global South will be massive in the 30 years to come, and that this will have an enormous impact on the environment. While the world has consumed 95 billion tons of cement in the past 30 years, it will likely consume around 130 billion tons in the 30 years from 2020 to 2050, and this will have a massive environmental footprint of almost 100 billion tons of CO_2 equivalent, if business-as-usual scenarios would continue and if the decarbonization process of cement production is not accelerated with affordable solutions also for the Global South.

THE RELATION BETWEEN CEMENT AND DEVELOPMENT, AND THE HIGH GROWTH AHEAD

We will focus on deepening our understanding of the key drivers behind cement consumption in the third and the fourth chapter of this report, highlighting the differences in cement demand and production between the Global South and North. Three key drivers strongly correlate with cement consumption and the overall development of societies:

» **The growth of population**
» **The growth of the urban population**
» **Economic growth and development.**

Globally, cement consumption has increased 13-fold since 1960, much more than the respective growth of population (2.5 times), the growth of the urban population (4.5 times) and the growth of GDP (gross domestic product) as a proxy of economic development (7 times). These three factors reinforce each other and act as multipliers.

Cement consumption per capita is also an indicator of affluence. It increases especially during transformation periods when the overall population grows, and when simultaneously a transformation from agricultural to industrial societies occurs, reinforced by fast urbanization. While the average global cement consumption is stabilizing at around 500 kg per capita, societies that are growing and urbanizing fast have seen and will see enormous increases in cement consumption. China, for example, increased the consumption from 32 kg in 1975 to over 1,600 kg per capita in 2014.

China has led the way for a major paradigm change: the Global South has taken over Europe and North America as centres of urban demographic growth.

The projected annual growth rate of the urban population between 2021 and 2050 in Europe is 0.32 %, while it is 2 % in Asia and 3.6 % in Africa. This means while most of the cities in Europe are already built, this process is yet to happen in the Global South; in Africa urbanisation will take place ten times faster than in Europe, in the 30 years to come.

The worlds cement production has already shifted to the Global South: while in 1960 12 % of all cement was manufactured in the Global South, nowadays, this share is 94 %. Projections show that global cement production - after a period of strong expansion - will remain relatively stable until 2050 (between 4 to 5 billion tons per year). The currently dominating producer China will reduce its output from 2.5 to slightly more than 1 billion tons while Africa and the rest of Asia will compensate for this reduction and increase their production massively from 1.3 billion tons to around 3 billion tons per year.

As mentioned already, the cumulative world cement production in the next 30 years will be around 70 % higher compared to the last 30 years: The additional cumulative 127 billion tons until 2050 would release around 95 billion tons of CO_2 in the case of “business-as-usual technology”, meaning without any decarbonization measures in the cement industry. Releasing 95 billion tons of emissions would represent 24 % of the remaining carbon budget of around 400 billion tons of CO_2 ; these cumulative emissions could still be emitted - as defined by the IPCC - if the 1.5^0 C goal is to be attained. And 90 % of this additional cement demand will be in the Global South.

LC^3 CEMENT AS A VIABLE OPTION FOR DECARBONIZATION AND TO CREATE PROSPERITY

The most promising option to achieve a lower footprint for cement production, is the increased use of clinker substitutes for Portland cement in concrete and mortars. The wide adoption of LC^3 could be an economically viable decarbonization option for the Global South, where the costly CCS (carbon capture and storage) technologies might not be feasible, given the already high cost of cement, especially in Africa.

LC^3 or “limestone calcined clay cement” can substitute up to 50 % of clinker and has similar or better performance characteristics than Ordinary Portland Cement (OPC). It is now widely tested and included in most standards as an acceptable option, and its biggest advantage is that it can be used just as any bag of OPC; there is no need to train an army of masons and introduce different construction practices. LC^3 could also allow local production of low-carbon cement and unlock dependency on imports, especially in Africa, where limestone deposits are scarce, but clay reserves widely available, also close to the centres of consumption. Capital investments for LC^3 production are much lower than for clinker plants.

From the perspective of these developments, a thriving construction sector represents a unique opportunity to create prosperity for national economies. The construction sector with its long value chain can create jobs and income at scale, but it can also play an important role as an emerging industrial sector to absorb rural migrants in the cities.

In Africa, this potential of the housing and construction sector is currently paralyzed by many structural hurdles and major affordability problems: A low purchasing power is exacerbated by high housing prices stemming, among other factors, from complicated regulations, inefficient building methods, costly building materials including cement and a lack of adequate financing options.

The unleashing of the construction value chain will require committed governments, interested investors and a broad range of reforms to tackle institutional bottlenecks that impede a cost - and time - effective delivery for affordable housing. Such reforms are taking place, and even in its current form the sector is quite dynamic.

Low-carbon cement is a key element in the balancing act to deliver large volumes of affordable modern building materials and to simultaneously reduce the emissions to sustainable levels. The upscaling of LC^3 production could generate jobs, create industrial capacities, and build millions of urgently needed housing units while contributing to greener cities and a more sustainable world. LC^3 is not a miracle solution but could play a significant role to harmonize social, economic, and environmental goals, mainly in the Global South.

1 INTRODUCTION: CEMENT IS ESSENTIAL FOR DEVELOPMENT, BUT IT MUST BECOME GREENT

1.1 AMBIGUOUS SIDES OF CEMENT AND CONFLICTING GOALS

Like two sides of a coin, cement has two faces: Cement is a very useful, needed, and omnipresent material, and at the same time a considerable source of emissions. If cement were a country, it would be the third largest emitter of greenhouse gases on Earth, behind only China and the United States [4]. If we exclude China, every citizen of this world consumes on average 300 kg per year - albeit with great regional differences. In the Global North, per capita consumption is stabilizing at around 250 to 500 kg, while in China, with a population of 1.4 billion, each person consumes at present a staggering 1,600 kg. By contrast, one person in Africa hardly uses 100 kg annually, even if this number is on the rise.

Globally, 4.2 billion tons of cement are produced per year. Cement is the largest manufactured product on Earth by mass and it is instrumental in advancing and harmonizing different sustainability goals:

1

ECONOMIC GOALS

The building and construction sector is important for economic growth to create jobs and income. Due to its long value chain, the sector can create millions of jobs and thus create prosperity and reduce poverty.

2

ENVIRONMENTAL GOALS

It is imperative that the construction sector meets the environmental goals of the Paris Agreement: halving emissions by 2030 and striving towards net zero by 2050.

3

SOCIAL GOALS

Millions of housing units and essential infrastructure must be built to fulfil the social goal of SDG 11.1 (Sustainable Development Goal of the United Nations),[5] defined as access to universal housing by 2030, mostly in the Global South.

Economic, environmental, and social goals are not always well aligned. In the past, the cement and construction sectors have prioritized economic over environmental goals. Nowadays, there is increasing evidence and ambition (within and outside the sector) that construction must become greener. At the same time, as argued in this report, the most important construction material in the world can help to trigger major changes in countries of the Global South, where historic infrastructure and housing deficits are paired with strong growth in population and urbanization. Low-carbon cement can reduce the environmental footprint of construction, and be economically viable, while at the same time positively impacting social and economic development in a country.

1.2 A PROMISING SOLUTION FOR GREENER CEMENT PRODUCTION – LC^3

A promising solution is LC^3 cement: Limestone calcined clay cement, or LC^3, is a promising technical solution to make cement greener and to balance these three goals. Producing cement with less CO_2 emissions is technically challenging because 60% of the emissions stem from the decomposition of limestone at 1450^0 Celsius. LC^3 cement can reduce the clinker factor by blending Portland cement with calcined clay and (unburnt) limestone and is one of the most promising and low - cost options; it can save up to 40% of the CO_2 emissions compared to Portland Cement. LC^3 can be widely applied around the globe; suitable clays are available almost everywhere, and a production plant requires much lower investments and operating costs than a Portland cement plant; it is also a much more affordable alternative to carbon capture and storage technologies (CCS).

CO_2 emissions from cement production contribute significantly to climate change: The production of one ton of Portland cement emits the equivalent of around 750 kg of CO_2 mostly while producing the clinker pre-cursor at 1450^0 Celsius (60% from the decomposition of limestone and 40% from the energy consumption). Around four billion tons of cement are produced globally per year, more than half of it by China alone. Cement is responsible for around 7 - 8 % of global CO_2 emissions, compared to 2.8 % generated by the aviation sector and 18% caused by road traffic.

It is estimated that the entire building and construction sector may be responsible for up to 40 % of total emissions,[6] although precise figures are not available. There is, nevertheless, little doubt that the construction sector is an important sector for economic growth, social welfare (e.g., housing and infrastructure) and has a big footprint on the environment.

Nevertheless, cement is essential for the development of societies and wood is not the answer: There is no alternative to satisfying the growing needs for housing and infrastructure, especially in the Global South with its strong demographic growth and fast urbanization trends. Cement is the largest manufactured product on earth by mass and cannot be replaced by any other material. For example, the large - scale substitution with wood might be possible in some highly forested countries (Canada, Sweden) but it would be an impossible task at the global level: "To replace 25% of the 6.4 billion m^3 of concrete used each year with timber would require an increase of global forest cover of about 14% – a land area representing 1.5 times the size of India."[7] Wood or other biomass materials such as bamboo can therefore only be a partial solution, not only due to volumes but also due to already endangered biodiversity and ongoing deforestation in some parts of the world.[8] Moreover, the carbon neutrality of biomass used in construction has been put into question.[9]

2 ESTIMATING THE GLOBAL HOUSING NEED FOR 2030 IN THE GLOBAL NORTH AND SOUTH

2.1 ACCESS TO HOUSING IS FUNDAMENTAL TO SOCIETY AND A SPECIFIC SDG TARGET

Access to housing is fundamental to society and recognized for its right status.[10] A shelter provides the basic need of protection from weather conditions and physical harm. “After all, the first thing all creatures, including humans, need to do on leaving the nest is to find somewhere to live.”[11] A home is important to psychological well-being and the forming of personalities. In addition to this social importance, housing fulfils a crucial economic role. In many countries, the housing sector is an important employer and engine of economic growth. It is estimated that “for every job in the house - building sector, an additional 1.5 to 2 jobs are generally created in the construction materials and other input industries."[12]

From a macroeconomic perspective, the housing and real estate sector is a pillar of national wealth and productivity. Housing “typically comprises something in the order of half a country’s tangible capital stock, a fifth to a third of gross fixed capital formation, and 10 to 30 percent of consumption.”[13] In most societies, housing is the most widely held family wealth asset. The construction sector accounts for 3 to 10 % of the national GDP,[14] and one - third of this is originating from housing.[15] The value of all the world’s real estate reached USD 326 trillion in 2020, [16] which is four times the global GDP.

Over the last years, several countries have launched major housing programs, both in the Global North and South.[17] These undertakings represent multi - billion - dollar public investments aiming to construct hundreds of thousands of houses in a short time.[18] Such programs mostly rely on concrete to ensure the cost-effective construction of housing units in a short period.

Considering the renewed interest in large-scale programs, the lens of housing presents a promising focal point to assess and discuss the social impact of cement. Housing is important to any family, no matter the place of residence, and it is an important area of intervention for governments. The housing challenge is also the greatest in the Global South, where not only the largest share of families lives in sub - standard housing but also where future urban growth will be concentrated.[19]

The Sustainable Development Goals (SDG), designed as the future global development framework and ratified by 193 UN member countries, consist of 17 goals and 169 targets, one dedicated specifically to affordable housing. SDG Target 11.1 urges governments to achieve universal access to affordable housing by 2030. [20] How many houses would need to be built and what kind of resources would be required to achieve this goal? How close or far are we from achieving target 11.1? A recent synthesis report of UN - Habitat [21] concluded that only a few regions in the Global North are on track and most regions in the Global South, especially in Asia and Africa are far or even very far from targets.

2.2 THE SIZE OF THE TASK: 600 MILLION HOUSING UNITS NEEDED BY 2030

Estimating the housing gap is a challenge: There is a surprising lack of precise information about the efforts required to achieve the SDGs. The only information relates to some projections for the investment needs[22] but they are generally difficult to translate into “on-the-ground realities”, and do not single out estimates on the number of housing units. This study quantifies this need for housing units and the cement needed to build them.

UN - Habitat states that three billion people need adequate housing in the next 15 years.[23] With an average household size of 3.97, this would translate into 756 million units.[24] McKinsey estimates that 400 million units are required in the 10 years from 2015 until 2025,[25] which corresponds to 600 million units for 15 years. To imagine the size of the task: some 20-25 housing units need to be built every second between 2015 and 2030, or around 96,000 per day[26]. This is a huge challenge both for governments and the industry.

There is evidence that many governments struggle to keep up with the increased housing demand.[27] The situation is particularly desperate in the Global South, where financial and human resources are limited.[28] As formal housing market suppliers cover only a fraction of the total demand; many families are pushed to cover their housing needs via informal mechanisms that fuel the growth of slums in the absence of government interventions. Today, more than one billion people live in slums (1,034 million); this is the result of a progressive increase from 723 million in 1990, to 817 million in 2000, and to 928 in 2014.[29] These numbers represents almost a quarter of the urban population, albeit with great regional differences: In 2018, Asia was home to two out of three slum dwellers, followed by Sub-Saharan Africa (23 %), Latin America (11%), and the Global North (4%).[30] By far the largest concentration within cities can be found in Sub - Saharan Africa (56.2% of all urban residents), while the rest of the Global South ranges between 20.9 % and 31.2% (see table 1).

SLUM POPULATION	1990		2000		2014		2018		RELATED SHARE
GLOBAL REGION	In Millions	(%)	In Millions	(%)	In Millions	(%)	In Millions	(%)	
Sub-Saharan Africa	94.8	70%	131.7	65%	202.0	56%	237.8	56%	23%
Northern Africa & Western Asia	44.2	28%	46.3	23%	63.8	22%	83.1	26%	8%
Eastern & South-Eastern Asia	284.3	47%	317.1	38%	349.4	28%	370.0	27%	36%
Central & Southern Asia	193.2	57%	205.7	46%	206.7	32%	226.8	31%	22%
Latin America & The Caribbean	106.1	34%	115.1	29%	104.7	21%	114.2	21%	11%
Europe & Northern America			0.760	0.1%	0.830	0.1%	1.000	0.1%	0.1%
Australia & New Zealand					0.007	0.0%	0.008	0.0%	0.0%
Oceania (excluding AUS & NZ)	0.40	24%	0.47	24%	0.60	24%	0.67	24%	0.1%
World	**723.0**	**43%**	**817.2**	**28%**	**928.1**	**23%**	**1033.5**	**24%**	**100%**

Table 1. Slum population from UN-Habitat (relative and absolute) 1990-2018[31]

2.3 ASSESSING THE HOUSING NEEDS – METHODOLOGICAL ISSUES

This study has composed a comprehensive **Housing Data Table (HDT)** that can be obtained upon request.[32] Excerpts from this comprehensive HDT are shown in Annex 2.2 - 2.4 (Table 24-29) in the form of a list per region and for selected countries.[33]

Calculations for the cement needs for housing are presented in chapter 2.6 below. The following chapters present the methodologies used for these calculations.

Quantifying the housing need is not a straightforward exercise. To provide the data needed for making such arguments, several calculations were conducted based on available data. These projections required several simplifying assumptions (see textbox below). The final product is a formula-based table that quantifies the number of housing units per country, which are automatically aggregated per world region.

The textbox below explains guidelines used for all calculations.

- All data is calculated for the SDG time frame from 2015 to 2030.
- The housing need is calculated for cities only: the housing challenge is greater there than in rural areas, but it is also a statistical data issue as numbers on sub-standard housing (slums) are only collected for urban areas.
- Data were collected as much as possible at the national level and preference was given to homogenized international data sets.
- Data points were aggregated per UN statistics division regions, and missing years were filled by using the closest available value, or - if that was not possible - by applying the regional averages. In case no country data was available for a region (for example in the case of Micronesia/Polynesia) the regional average of the closest region was applied.
- Future projections for slums were done by applying equal share (as practised by UN – Habitat, current slum shares equal future ones) or in the case of household size by linear projection.
- Calculated numbers can be negative (e.g., declining slum population leads to a reduction in housing needs). Negative values are considered zero for all following calculations.
- The housing need is differentiated into a slum- and a non-slum component to strengthen the policy relevance of the findings.

Textbox: Rule book of the calculations

The reference framework for all calculations is the SDG timeframe from 2015 to 2030. The starting point forms the housing stock of 2015. As data on housing units are not readily available,[35] we use the number of households as a proxy[36] for housing units,[37] not considering overcrowding, housing vacancy,[38] and homelessness.[39] Almost 4 billion people were living in cities in 2015, which translates into 1.18 billion households. The average global household size is 3.97 people (the minimum is Western Europe with 2.26 and the maximum is Polynesia with 6.0).

The second step consists of quantifying the total housing need of a country. The need has three different components: the need may come from its demographic growth, an old housing stock, or pre-existing slums, in other words, housing units unfit for human habitation. Consequently, our calculations for the global housing need between 2015 - 2030 are based on three major components: (i) housing required due to **demographic growth**, (ii) housing required to **renew old housing units**, and (iii) sub-standard housing to be **replaced.**

2.4 ASSESSING THE THREE TYPES OF HOUSING NEEDS

The demographic need is the difference between the housing stock in 2015 and 2030 or the need for housing due to **population growth** and changes in household structure. International organisations project population numbers in the future, but not households. As even basic projection methods are rather time-consuming (e.g., headship rate method), we opted for a linear growth projection (the growth of the previous 15 years equals the one of the next 15 years) based on available databases on household sizes.[40] UN - DESA[41] provides projections for the urban population in 2030 and further until 2050. Dividing these numbers with the estimated average household (3.90 people per household in 2030)[42] results in a total number of 1.48 billion housing units; this corresponds to an increase of 309.2 million units between 2015 to 2030 (see table 2 below).

WORLD REGIONS		SUB-REGIONS (SELECTION)		(IN MILLION UNITS)	
Africa	74.0	Eastern Africa	22.6	Western Africa	23.2
Asia	168.8	Eastern Asia	62.9	Southern Asia	60.8
LAC	26.7	South America	16.3	Central America	8.6
Global North	46.9	Northern America	15.4	Southern Europe	2.9
Global Demographic Need					**309.2**

Table 2. Total demographic need for new housing per world region and selected subregions

Source: Author's calculations, please note: we present here a selection and totals do not tally

The demographic need is the largest in Asia: 168.8 million units followed by Africa with 74.0 million units. This represents an effective growth rate of 1.8 % per year, albeit with regionally very different growth rates. Africa has a demographic growth rate twice as large as the second fastest-growing region (4.6 % in Africa versus 2.0 % in Asia). The Eastern African countries of Burundi, Uganda (both 6.2 %), and Niger (6.1 %) are the places in the world where most new households will be formed in relation to the existing housing stock. Southern Europe is almost stagnating (0.5%).

The renewal need: The second need for housing stems from housing stock renewal (Table 3 below). Housing is very durable - yet not an eternal good; consequently, the existing stock also needs to be replaced regularly by new structures as they are too old to fulfil their initial function.

Generally (and broadly applied in the banking sector), the average lifespan of a housing unit is estimated at 100 years, meaning that every year 1/100 of the current stock needs to be replaced.[43] For slum units, the practice is to assume 50 years.[44] This lower life span is explained by their informal construction with often inferior materials resulting in a quicker degradation, as well by the fact that the land may be subject to high risks including exposure to man-made and natural disasters.[45] The housing need from renewing existing stock is considerable but with great regional differences. On a global scale, the housing stock renewal represents 101.0 million units, and 98% of renewals will need to take place in slums. The renewal need follows the distribution of slums in the world and is mostly concentrated in Asia 63.3 million, followed by Africa 22.8 and Latin America and the Caribbean 8.0 million units.

WORLD REGIONS		SUB-REGIONS (SELECTION)		(IN MILLION UNITS)	
Africa	22.8	Eastern Africa	7.0	Western Africa	7.6
Asia	63.3	Eastern Asia	23.3	Southern Asia	29.7
Latin America	8.0	South America	4.8	Central America	2.5
Global North	12.6	Northern America	3.8	Eastern Europe	0.4
Global Renewal Need					**101.0**

Table 3. The renewal need per world region and selected subregions

Source: Author's calculations, please note: we present here a selection and totals do not tally

The Replacement need (slum upgradation): The last need derives from the inadequacy of the current housing stock. Slums are by definition[46] substandard housing units.[47] In 2015, almost one billion people lived in slums which translates[48] into a housing need of 188.1 million units by considering household sizes and the levels of deprivation.[49] The number of slum households per country is also used to differentiate the demographic and renewal need for 2030 into a slum and a non-slum component (Table 4).

In absolute terms, the backlog is concentrated in Asia (124.8 million or more than two-thirds of the total) followed by Africa (31.5 million) and Latin America (17.2 million). The countries of South Sudan (91.7 %), Chad (82.0 %) and the Demographic Republic of Congo (78.4 %) have the largest share of substandard housing in the world.

WORLD REGIONS	(IN MILLION UNITS)	SUB-REGIONS (SELECTION)			
Africa	31.5	Eastern Africa	9.1	Western Africa	11.0
Asia	124.8	Eastern Asia	59.9	Southern Asia	46.6
LAC	17.2	South America	11.5	Central America	4.6
Global North	30.0	Northern America	7.0	Eastern Europe	1.6
Global Replacement Need					**188.1**

Table 4. Replacement need (slum upgradation) per world region and selected subregions

Source: Author's calculations, please note we present here a selection and totals do not tally

2.5 ASSESSING TOTAL HOUSING NEEDS – RESULTS

To ensure housing for all by 2030, around 40 million housing units[50] must be built every year (table 5 below). For the SDG horizon of 2015 to 2030 this represents a total of nearly 580 million units. Please note: the totals of table 5 add up to 598 million units because of some double counting in the Global North.[51] Of these 598 million, 309 million units stem from demographic needs, 101 million from renewal (renovation) needs, and 188 million from slum upgradation. To remember, we speak of demographic needs if the increase is determined by population growth and household changes, replacement needs in case of slum upgradation and renovation needs when housing units need to be renewed because of their age.

WORLD REGIONS (MILLION UNITS)	DEMOGRAPHIC NEED	SHARE	REPLACEMENT NEED	SHARE	RENEWAL NEED	SHARE	TOTAL NEED	SHARE OF 2015 STOCK
Africa	74.0	63%	31.5	27%	22.8	19%	117.0	106%
Asia	168.8	48%	124.8	36%	63.3	18%	349.3	58%
LAC	26.7	52%	17.2	34%	8.0	16%	51.0	41%
Global North	38.0	63%	14.52	24%	6.9	11%	60.5	22%
Others	1.8	97%	0.04	2%	0.0	1%	1.8	41%
Total Need	**309.2**	**51%**	**188.1**	**7%**	**101.0**		**579.7**	**49%**
Totals of the columns								**598.3**

Table 5. Total housing need per world region and selected subregions

Source: Author's calculations, please note we present here a selection and totals do not tally

There are strong regional differences in housing needs: Most of the new housing units (349 million) must be built in Asia, 117 million in Africa, and 51 million in Latin America.

To achieve SDG 11.1 the Global North will need to add some 60 million units, or only 22 % of the existing housing stock in 2015.

There are two established indicators to put this need in relation to required efforts: the first one is the supply as a percentage of the current housing stock, the second indicator expresses the housing gap as number of units per 1,000 inhabitants. Globally we would need to build the equivalent of 2.8 % of the housing stock annually, which is considerably higher than the highest rates within OECD countries (slightly above 2 %).[52] A similar picture manifests itself if we consider the second indicator: the required rate of 9.7 units per 1,000 inhabitants is well above the numbers of the best-performing national supply structures.[53]

Figure 1 below shows **the first indicator in a map**, or the effort required to build new housing units as percentage of the existing housing stock, and it shows an enormous variation. The highest housing gaps exist by far in some countries in Africa where more than the existing housing stock needs to be newly built. The world regions of Middle Africa (177 %), Eastern Africa (137 %), and Western Africa (114 %) have the largest supply need, while the bottom three are Eastern Europe (15 %), Southern Europe (14 %) and Western Europe (12 %).

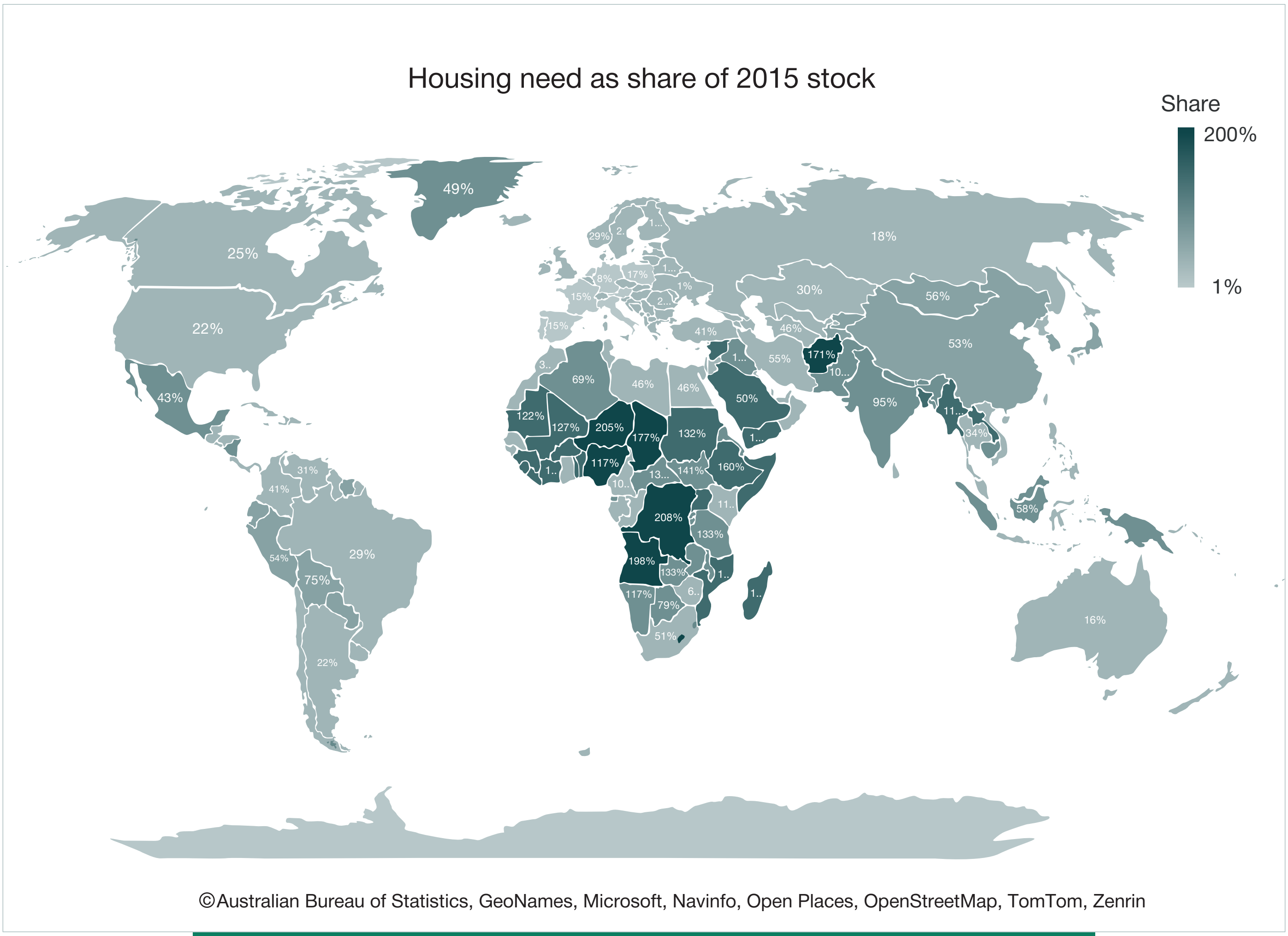


Figure 1. Housing need as share of current stock presented as a map

Source: Based on author's calculations

Annually needed supply rate per 1,000 people

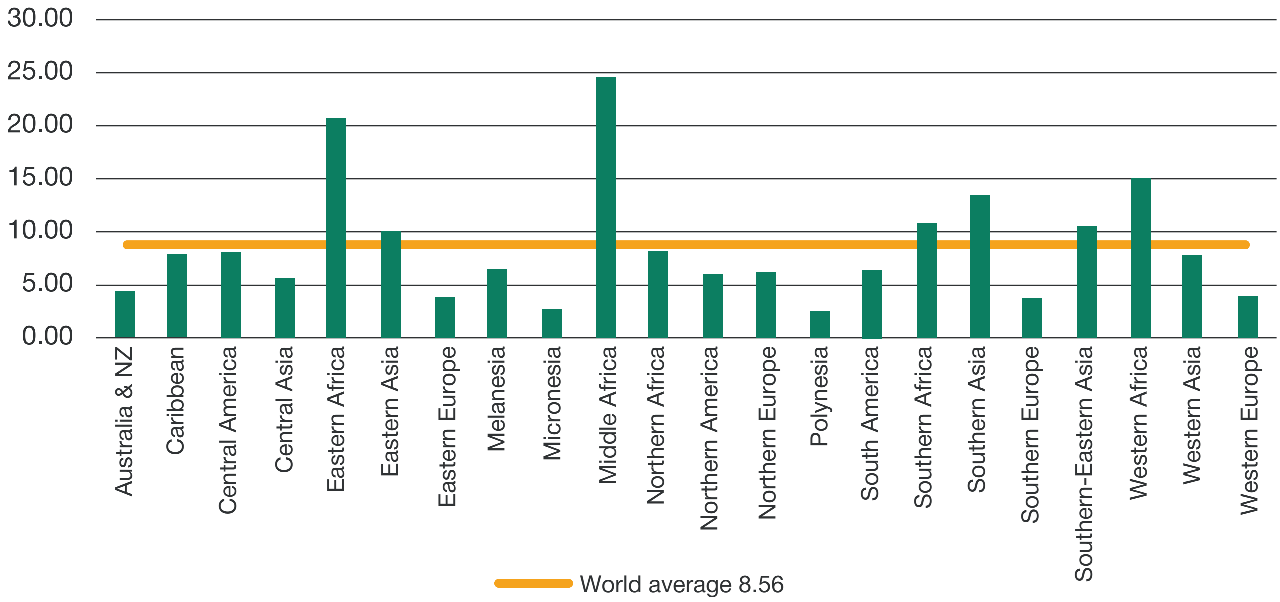


Figure 2. Annually needed supply rate per 1,000 people and world regions

Figure 2 shows the **second** indicator, or total housing need per 1,000 inhabitants in the different regions of the world. While most regions are hovering around the global average of 8.56 units per 1,000 inhabitants and year, some regions exceed this number considerably (Eastern, Middle and Western Africa, Southern and South-Eastern Asia) and just very few, such as Southern Europe have much lower requirements, mostly stemming from a shrinking population.

2.6 CONNECTING HOUSING NEEDS AND CEMENT DEMAND

This study quantified the housing needs in different world regions and linked these needs with cement demand. The methodological issues are described in more detail in annex 2.1. As a simplified result we used the following average cement needs for different housing units:

CEMENT NEEDS FOR DIFFERENT TYPES OF HOUSING UNITS	KG/UNIT	CO_2 EMISSIONS
Slum Housing Unit*	1,210	908
Affordable Housing Unit*	3,576	2,682
Housing Unit as if built per European Standards**	27,204	20,403
*Slum and affordable units are mentioned below as modest units **European standard units are mentioned below as high-standard units		

Table 6. Cement needs for different types of housing units[54]

Source : Author’s calculations, for methodological details, see annex 2.1

Based on these average cement needs we arrived at the following results (detailed calculations can be seen in annex 2.2). Table 7 below shows that the cement demand for modest housing units is moderate: 138 million tons for the modest housing units and 1,051 million tons for the high - standard units (World). This represents only 3.2 % of the global world production for the modest units. Across the world regions this does not exceed 12.3 % of the present cement production. This relation changes if we talk about housing units for a middle-class population built as per European standards: to build high-standard housing units would use up 24.1 % of the world production and all or almost all the present cement production in Africa and Latin America.

HOUSING UNITS AND CEMENT NEEDS PER YEAR	WORLD	AFRICA	ASIA	LAC	EUROPE	NORTHERN AMERICA	OCEANIA
Total housing needs in million units	38.6	7.8	23.3	3.4	2.3	1.8	0.1
Cement needs modest housing units [Mt]	138.2	27.9	83.3	12.2	8.1	6.3	0.4
Cement needs high-standard units [Mt]	1,051.4	212.3	633.6	92.5	61.7	48.0	3.3
Cement production in 2021 [Mt]	4,360.2	226.1	3,541.9	193.4	278.9	107.3	12.6
Cement need of modest units [% of production]	3.2%	12.3%	2.4%	6.3%	2.9%	5.9%	3.4%
Cement need of high-standard units [% of production]	24.1%	93.9%	17.9%	47.9%	22.1%	44.8%	26.0%

Table 7. Summary of cement needs for different housing types and in % of 2021 production[55]

This picture is even more accentuated if we look more closely at specific African regions (table 8 below). In Eastern Africa, the modest housing units would consume 19.8 % and in Middle Africa 60.7 % of the present cement production, while building the high-standard units would use up 1.5 times the actual production in Eastern Africa and 4.6 times in Middle Africa.

HOUSING UNITS AND CEMENT NEEDS PER YEAR	AFRICA	EASTERN AFRICA	MIDDLE AFRICA	NORTHERN AFRICA	SOUTHERN AFRICA	WESTERN AFRICA
Total housing needs in million units	7.8	2.2	1.9	0.9	0.4	2.4
Cement needs modest housing units [Mt]	27.9	7.7	6.7	3.4	1.5	8.6
Cement needs high-standard units [Mt]	212.3	58.8	50.7	25.8	11.5	65.5
Cement production in 2021 [Mt]	226.1	39.0	11.0	102.9	13.5	59.8
Cement need of modest units [% of production]	12.3%	19.8%	60.7%	3.3%	11.2%	14.4%
Cement need of high-standard units [% of production]	93.9%	150.7%	461.8%	25.1%	85.1%	109.6%

Table 8. Summary of cement needs for different housing types in African regions

The situation in Asia is quite different (table 9): Here, cement production is much larger, even if the numbers are somehow distorted due to the high share of China (included in Eastern Asia). To build the modest units would consume only 1.4 to 6.1 % of the cement production.

Building the high-standard units would consume 17.9 % of the production, and even in Southern Asia only 46.1 % of the present production. However, building around nine million units per year in Southern Asia and around four million in Southern Eastern Asia is certainly very challenging.

HOUSING UNITS AND CEMENT NEEDS PER YEAR ASIAN REGIONS	ASIA	CENTRAL ASIA	EASTERN ASIA	SOUTHERN ASIA	SOUTHERN-EASTERN AFRICA	WESTERN ASIA
Total housing needs in million units	23.3	0.2	9.9	8.6	3.1	1.4
Cement needs modest housing units [Mt]	83.3	0.7	35.3	30.9	11.2	5.2
Cement needs high-standard units [Mt]	633.6	5.1	268.6	235.2	85.3	39.3
Cement production in 2021 [Mt]	3,541.9	35.9	2,480.7	509.9	296.9	218.6
Cement need of modest units [% of production]	2.4%	1.9%	1.4%	6.1%	3.8%	2.4%
Cement need of high-standard units [% of production]	17.9%	14.3%	10.8%	46.1%	28.7%	18.0%

Table 9. Summary of cement needs for different housing types in Asian regions

Much more accentuated are the challenges if we look with a magnifying glass at some African countries. Even building the modest housing units would use up half (Burundi) or a relatively high share of the present cement production (table 10).

HOUSING AND CEMENT NEEDS PER YEAR SELECTED AFRICAN COUNTRIES	BURUNDI	EHIOPIA	KENYA	TANZANIA	BURKINA FASO	GHANA	NIGERIA	SENEGAL
Total housing needs in thousands units	26.2	461.0	260.7	336.5	78.1	193.2	1,404.5	53.6
Cement needs modest units [kt]	93.7	1,648.5	932.4	1,203.3	279.5	690.8	5,022.5	191.7
Cement needs high-standard units [kt]	712.7	12,541.0	7,092.9	9,153.9	2,126.0	5,255.3	38,208.1	1,458.7
Cement production in 2021 [kt]	180	9,500	9,248	6,500	3,040	5,600	29,000	7,473
Cement need of modest units [% of production]	52.0%	17.4%	10.1%	18.5%	9.2%	12.3%	17.3%	2.6%
Cement need of high-standard units [% of production]	395.9%	132.0%	76.7%	140.8%	69.9%	93.8%	131.8%	19.5%

Table 10. Summary of cement needs for different housing types in African countries

2.7 CONNECTING HOUSING NEEDS AND ENVIRONMENTAL FOOTPRINT

Based on these considerations in the previous chapter we will look now at the environmental footprint of the cement demand for housing.

The following tables look at the environmental impact of the housing needs: Table 11 below converts the cement needs per unit (as defined in table 6) in total cement needs (rows 3 and 4) and then into CO_2 emissions (rows 5 and 6, using 750 kg of CO_2 emissions per ton of cement). These emissions are then compared with the total amount of CO_2 emissions (row 7). We can see that these emissions are quite moderate in % of total emissions: the modest units would only consume 0.23 % of the present total emissions (row 8) and 2.29 % for the case that the houses were built as per European standards (row 9). For the conversion, we assumed a BAU scenario of 750 kg CO_2 emissions per ton of cement. BAU or "business-as-usual technology" scenario means that no decarbonization efforts have taken place yet in the cement industry.

We are also comparing these emissions in table 11 with the global remaining carbon budget[56] (row); the remaining carbon budget is defined by the IPCC in 2021 as those emissions (400 billion tons of CO_2 equivalent) that the world can still emit if the 1.5^0 Celsius goal is still to be matched. Again, these emissions from closing the housing gap show quite moderate footprints (rows 11 and 12): in the first column (World) the cumulative emissions over 15 years would consume 0.4 % of the global remaining carbon budget in case only affordable units would be built; slightly more important would the footprint be for the case that the housing units would be built as per European standards (3.0 % of the remaining carbon budget, row 12).

ROW	ENVIRONMENTAL FOOTPRINT OF CEMENT FOR HOUSING UNITS	WORLD	AFRICA	ASIA	LAC	EUROPE	NORTHERN AMERICA
1	Total housing needs in million units 2025-30	579.7	117.0	349.3	51.0	34.0	26.5
2	Total housing needs in million units per year	38.6	7.8	23.3	3.4	2.3	1.8
3	Cement needs affordable units [Mt] per year	138.2	27.9	83.3	12.2	8.1	6.3
4	Cement needs high-standard units [Mt] per year	1,051.4	212.3	633.6	92.5	61.7	48.0
5	CO_2 emissions of cement for affordable units [Mt] (@750kg/ton)	103.7	20.9	62.5	9.1	6.1	4.7
6	CO_2 emissions of cement for high standard units [Mt] (@750kg/ton)	788.6	159.2	475.2	69.4	46.3	36.0
7	Total CO_2 emissions [2020] per year	32,320.8	1,274.1	19,584.8	1,438.1	4,768.4	4,837.4
8	CO_2 emissions in % of total emissions (modest units)	0.3%	1.6%	0.3%	0.6%	0.1%	0.1%
9	CO_2 emissions in % of total emissions (high-standard)	2.4%	12.5%	2.4%	4.8%	1.0%	0.7%
10	Remaining carbon budget [Mt] (for 29 years until 2050)*	400,000	80,083	232,141	33,047	34,687	18,277
11	CO_2 emissions modest units in % of remaining budget (15 years)	0.4%	0.4%	0.4%	0.4%	0.3%	0.4%
12	CO_2 emissions high-standard in % of remaining budget (15 years)	3.0%	3.0%	3.1%	3.1%	2.0%	3.0%

Table 11. Environmental footprint of cement for housing

*The total remaining carbon budget of 400 billion tons is distributed as per the total population of 2030

These footprints are slightly higher in Africa and Latin America but remain generally very low for the modest housing units; the simple reason is that these housing units use very little cement, as we have seen earlier. Even if the housing units were built as per European standards, the footprints remain quite low.

2.8 BASIC HOUSING NEEDS - AND WHY WE NEED MORE AND MORE SPACE PER PERSON

As a general conclusion, we can say: **To fulfil the target of SDG 11.1 with modest housing units is possible in accordance with the Paris Agreement, even if no low-carbon cement were available.** This statement is, however, misleading because we only talk of very basic needs, and the housing units represent only a fraction of the total need for cement to build the infrastructure and especially the cities with their non-residential space needs. We will discuss these infrastructure needs more in detail in Chapter 2.9.

The housing needs that we considered are indeed very basic: The difference between slum and non-slum needs is enormous. The space requirements for slum housing used in our calculations represent an absolute minimum (1.33 sqm per person, barely enough to lay down to sleep), higher space standards would automatically lead to higher cement consumption. Ensuring 25 sqm per family (still less than three square meters per person in some countries) would increase cement demand by a factor of 13, and a minimum house standard of 50 sqm by a factor of 21.

Average housing spaces are considerably higher in wealthier countries and range from 45 sqm in South-East Asia to 165 sqm in Australia and New Zealand. Housing growth in the Global North is occurring foremost in the form of growing space standards as there appears to be a rather strong link between wealth and residential built-up requirements.[57] Currently, the gap in the built-up space between the Global North and South is one to two, while the difference in units is one to five. This means that the Global South will need five times more housing units but only twice the housing space of the North.

Housing needs in the Global North are driven by other factors: This study analyses only the housing needs stemming from demographic growth, replacement needs and renewal needs.Considering these three factors, a country like Germany would need around 200,000 new housing units per year. However, Germany's Government has a plan to build 400,000 new units per year and is failing to deliver them. This is necessary to combat the prevailing housing shortage in most cities. The additional housing needs of 200,000 units per year are stemming from other factors, for example the increased share of single households[58] (singularization) and the increasing surfaces per person.

Surfaces are also rising due to ageing; many old people continue to use their houses even once the children have left the house. These factors lead to a demand for housing units that goes much beyond the demographic growth, even if the total population is declining in the Global North. One important factor for the housing shortage is the fact that Germany is hosting one million refugees from Ukraine; the gap is therefore close to 700,000 units per year, and at the present capacity there are hardly 250,000 units built per year.[59]

The ambition for better and larger housing space is a driving force for economies: the aspiration for more space, also known as a variant of the "American Dream" is a driver for economic growth, not only in America but also in the rest of the world. It has also become known as the "Chinese Dream". We will see below that it is quite natural for poor people to dream of a better (more solid) and more spacious home. This motivation has triggered economic booms in many countries, and it will also be the driving force for the millions of people in the Global South who have been deprived of decent housing so far. We will therefore look in the following chapters not only at the challenges provoked but also at the opportunities that the ambitious SDG target 11.1 offers to societies.

2.9 FROM BASIC HOUSING TO OVERALL INFRASTRUCTURE NEEDS

Cement is needed for many elements of the built-up space, ranging from residential housing to major infrastructure projects such as roads, bridges, and all type of non-residential buildings. New housing units also trigger a lot of additional cement demand due to the urban infrastructure needs (water, sewerage, stormwater, electricity) and services (health, security, education, etc.). It is, however, very difficult to calculate the cement demand for infrastructure needs. We have seen in table 6 that even the term "housing unit" is quite heterogeneous. Adding needs for roads, railways, bridges, dams, offices, and supermarkets is comparing pears and apples.

As first approximation we can look at the built-up space in different regions and per capita keeping in mind that basically cities in the Global North **are already built** while the still low degree of urbanization points to a kind of pent-up infrastructure demand in the Global South where the cities **are yet to be built.**

Table 12 below shows the evolution of built-up area between 1975 and 2015 in thousand square kilometres and in square meters per person. The data were collected by remote sensing[60] and show a **fourfold increase** in Africa (from 15,000 square kilometre in 1975 to 62,000 sqkm in 2015) and in Asia (from 62,000 to 223,000 sqkm), whereas in Europe this increase is "only" twofold (from 66,000 to 119,000 sqkm).

If we look at the right side of the table, we see that the Global South has constructed about 60 to 90 sqm of built-up area per person, while Europe shows 220 sqm and Northern America 412 sqm per person.

It seems, therefore, likely that the built-up area in the Global South is growing twice as fast and will drastically increase in the coming 30 years, for two reasons, first because of population growth and second because of the still low prevailing levels of built-up space per person.

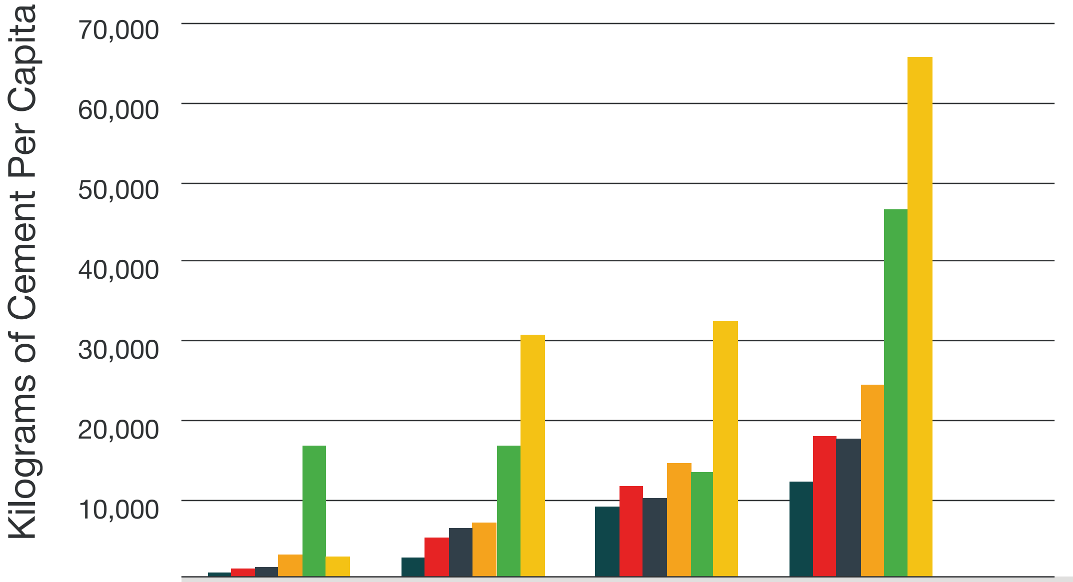
BUILT-UP AREA REGION	BUILT-UP AREA (1,000 SQKM)				BUILT-UP AREA IN SQM/CAPITA			
	1975	1990	2000	2015	1975	1990	2000	2015
Africa	15	33	43	62	51	69	68	64
Asia	62	136	169	223	31	49	52	58
Latam	20	35	41	47	81	99	97	91
Europe	66	100	109	119	129	188	205	220
Northern America	52	82	94	108	325	425	423	412
Oceania	5	7	8	9	333	368	364	300
Global	**220**	**393**	**464**	**568**	**68**	**91**	**92**	**92**

Table 12. Evolution of built-up space 1975 - 2015

A similar picture is given in **figure 3** below: it shows the cement consumption per capita from 1960 to 2050 in 30 year's intervals. In the first interval, the Global North had already consumed over 16 tons of cement per capita (from 1960 to 1990), whereas China had used only 2.6 tons and Africa only 700 kg for each citizen. This consumption has remained relatively steady in the second interval (from 1990 to 2020) in the Global North, whereas China has used more than 30 tons per person in the last 30 years.

The other regions have increased their consumption significantly to around 6 tons while Africa lags still behind with only 2.5 tons per capita in the last 30 years. We must add, however, that these numbers may be underestimating Africa's cement consumption because we only have production data available . As Africa imports a lot of cement, the actual consumption patterns may be higher, but consumption in Africa is still much less than the other regions.

CEMENT CONSUMPTION
PER CAPITA IN 30 YEAR'S INTERVALS



	1960-1990	1990-2020	2020-2050	Total 1960-2050
Africa	696	2,457	9,025	12,178
India	1,173	5,079	11,673	17,925
Other Asia	1,350	6,316	9,989	17,654
Latam	2,948	6,977	14,441	24,365
Global North	16,658	16,693	13,289	46,640
China	2,676	30,811	32,488	65,975

Figure 3. Cement consumption per capita 1960-2050 in different regions

Source: Own calculation of the authors based on US Geological Survey and IEA projections

Interestingly, China has used and will use far more cement per capita as even the Global North. This underlines the fact that the enormous economic progress in China was very resource intensive.[62] Whether China will use another 32 tons per capita in the 30 years to come might be questionable given the decline of the construction sector. However, even if housing construction seems to slow down, the infrastructure projects are extremely ambitious. China is constructing large dams for hydroelectricity and may use enormous amounts of cement for this[63]; interestingly, these large hydropower projects will also save enormous amounts of CO_2 because they are planned to replace coal-power-plants. Similar ambitious efforts are planned in high-speed train networks[64] ; these plans will also use enormous amounts of cement but at the same time reduce motorized trips by car and buses and decrease air traffic and therefore save CO_2 emissions.

The fact that India, the rest of Asia (without China and India) and especially Africa have still much lower levels of consumption indicates that those regions may have very likely a fast-growing demand in the 30 years ahead.

If we look again at the right side of the graph, we can say that a citizen in the Global North may have consumed some 47 tons of cement in the 90 years from 1960 to 2050, whereas China has used 65 tons, a Latin American, 24 tons, while the rest of Asia (except China) will have used only 18 tons and Africans only 12 tons of cement.

We can thus conclude: The Global South, Africa, and Asia, will have huge needs to catch up and construct not only residential buildings, but all kinds of non-residential buildings, offices, factories, workshops, shops, supermarkets, markets, airports, roads, bridges, ports, and so on.

3 CEMENT AND ECONOMIC AND SOCIAL DEVELOPMENT

The following chapters explore the key role of cement in the overall development of societies. We will analyse the correlations of cement consumption with economic growth, have a closer look at the transformation from agrarian to industrial societies and interpret urbanization trends around the globe.

3.1 OVERVIEW : TRENDS IN CEMENT PRODUCTION AND POPULATION GROWTH

World cement production has grown significantly faster than the population in the last 60 years, and this explains the more than five - fold increase in cement consumption per capita, from around 100 kg per person in 1960 to more than 540kg on average worldwide. Table 13 below shows this more in detail.

YEAR	WORLD CEMENT PRODUCTION	WORLD POPULATION	CEMENT/CAP IN KG	PRODUCTION GROWTH IN %	POPULATION GROWTH IN %	CEMENT/CAPITA IN %
1960	317	3,035	104	100%	100%	100%
1970	606	3,700	164	191%	122%	157%
1980	887	4,458	199	280%	147%	190%
1990	1,148	5,327	216	362%	176%	206%
2000	1,650	6,143	269	521%	202%	257%
2010	3,280	6,957	471	1,035%	229%	45%
2020	4,210	7,795	540	1,328%	257%	517%

Table 13. World cement production and population (1960 – 2020)

Source: Own calculations based on data of US Geological Survey

Global cement production has increased from

317 Million Tons in 1960 → to → **4.2** Billion Tons in 2020 (+1,328 % Increase)

While the world population has grown from

3 Billion → to → **8** Billion (+257%)

This phenomenal 13-fold growth of cement demand should be better understood, and here we analyse the key factors that are responsible for this growth.

3.2 THREE KEY FACTORS : POPULATION GROWTH, ECONOMIC GROWTH AND URBANIZATION

If we could look at the world from space, we could see a similar process over the last 200 years: many societies lived for centuries without much change and often in dire poverty, but in some places, the population suddenly started to grow, economic activities intensified, and urban development took place and spread to different parts of the world. An amazing demographic growth occurred first in the Global North, starting with the industrial revolution in England and spreading over the rest of Europe and North America. In the past decades, this process became globalized: it has spread to Asia and especially China, and it continues now in the rest of the Global South.

Population growth is not an eternal process, and it is usually declining with better living conditions, education and urbanization. This flattening of the growth curve has happened in the Global North and in many emerging countries, but some regions have a still growing population. Overall, the world's population has been growing at an accelerated pace since around 1950.

While it took earlier 200 years to add a billion more people, it now takes only ten years for the world to grow by another billion. The curve is flattening, and the times of high population growth will come to an end within this century, but obviously at a high level of 9 or 11 billion people, depending on the scenarios.

This demographic growth influences the size and shape of the built environment and requires enormous amounts of materials, especially cement. The paramount importance of cement for this process is not so widely recognized and understood, but it is indeed comparable to the consumption of fossil fuels. Historically, fossil fuels (coal and oil) and cement are key ingredients for the development of societies and economies, especially for built environments. This process would be visible from space over time: while only a few large cities existed 200 years ago, the process of urbanization has become more intense and faster with emerging cities and mega-cities around the world, and the increase of built-up space, as we have seen in table 12.

Historically, three factors stimulate the development of societies, and act as factors of change:[67]

1

POPULATION GROWTH

The World population was around three billion in 1960 and reached eight billion in 2023. Projections of the United Nations indicate a further growth to nine billion by 2060 in the low-growth scenario and up to eleven billion in the high-growth scenario. It is uncertain, which scenario will come through, but while some regions will have slower growth or even a declining population, other regions in the Global South – mostly in Africa and Asia – are still growing substantially. Most OECD countries are not growing any longer, and even some Asian countries, especially China, have reached a population peak. Population is the main driver for cement demand: More people need more space, houses, and infrastructure. **Overall, the world population has grown by a factor of 2.5 from 1960 to 2019.**

2

AFFLUENCE AND ECONOMIC TRANSITION

Economic prosperity can occur when pre-industrial societies undergo a transition from agrarian to industrial societies. This leads to rising per capita incomes and thus to an additional demand for housing and infrastructure, but also office buildings, factories, roads, bridges, and ports. A rough estimate says that around 40 % of cement is used for residential buildings and the rest for infrastructure, but it is likely that in the Global South, the need for infrastructure is higher, when people get out of poverty. While poverty is persisting in many parts of the world, there is no doubt that over a larger time span, people have become more affluent, most strikingly in China where at least 800 million have escaped from poverty. **The world GDP has grown by a factor of 6.9 from 1960 to 2019, and the GDP per capita by a factor of three.**

3

URBANIZATION

The process described above is further accentuated by urbanization. People migrate to cities when agriculture cannot offer economic perspectives for all and absorb a growing population; this results in rapid urbanization. In 1950, around 30 % of the world's population lived in cities; today, urban areas are already home to 55 % of the global population, and that figure is expected to rise to 68 % by 2050. The most dramatic changes will happen in Asia and Africa. The urbanization in Africa may not happen the same way as in Europe or China and have it's own cultural and physical expression. **The urban population has grown by a factor of 4.3 from 1960 to 2020, from one billion to over four billion, almost twice as fast as the total population.**

A detailed analysis of these three factors can be found one by one in Annex 3. We think that **these three factors have worked together as self-reinforcing, catalytic drivers for an unprecedented global development.** Overall, it has brought prosperity and better living conditions to the world – unfortunately not yet for all – but it has also led to an unprecedented and challenging climate crisis.

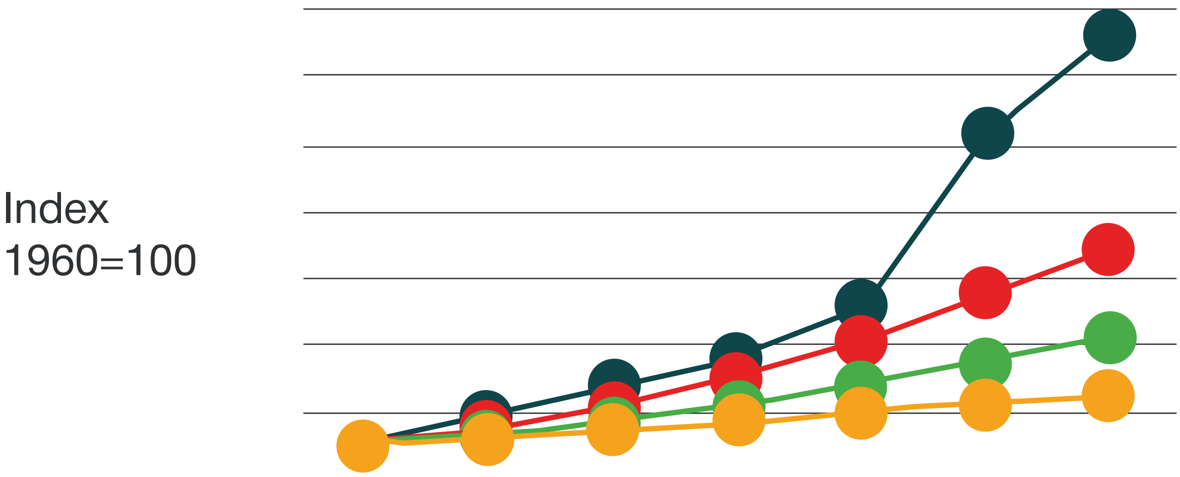
3.3 SYNOPSIS : WORLD CEMENT PRODUCTION, POPULATION, URBANIZATION, AND GDP

If we are analysing the respective impact of the three factors together as a synopsis, we can conclude: The three key factors have all grown substantially, but much less than cement production and it seems that cement production is the catalytic result of these three self-reinforcing key factors.

World cement production grows faster than population, urban population, and economic wealth. While the world population has grown by a factor of 2.5, the growth of GDP was even steeper by a factor of 6.9 between 1960 and 2020.

However, urbanization, the third key driving factor, is probably playing the most dominant role in explaining the phenomenal increase in world cement production: urbanization changes the structure and is virtually adding “more floors” to a society. The urban population has grown by a factor of 4.28, almost twice as much as the overall population (factor 2.5). Affluence expressed by GDP per capita has grown by a factor of 6.9 and has certainly increased cement consumption and has also acted as an important multiplier. Figure 4 shows these trends in a synopsis.

WORLD CEMENT PRODUCTION, WORLD GDP, URBAN POPULATION, TOTAL POPULATION INDEX (1960-100)



	1960	1970	1980	1990	2000	2010	2020
Cement Production	100	191	280	362	521	1,035	1,328
GDP Total	100	159	225	306	413	563	688
Urban Population	100	132	171	224	280	351	428
Total Population	100	122	147	176	202	229	257

Figure 4. World cement production, world population and GDP per capita (1960 – 2020)

Source: Own calculations based on data of US Geological Survey

3.4 CEMENT PRODUCTION HAS SHIFTED TO THE SOUTH AND CHINA BECAME THE CHAMPION

The music plays now in the Global South: Cement production has stagnated in the Global North and has dramatically shifted to the Global South. The fastest and highest growth of production has occurred in China, followed by India, and by the remaining countries of the Global South (**Table 14**). It is impressive to see that in 1960, 88 % of global cement was produced in the Global North and only 12 % in the South. In 2019, this picture has totally changed, with 94 % of the global cement being produced in the Global South and only 6 % in the Global North. (For more details **see table 20 in Annex 1**). These numbers reflect the 20 largest cement producing countries, as we could only find data for these countries.

GLOBAL NORTH AND SOUTH	CEMENT PRODUCTION IN Mt PER YEAR				CEMENT PRODUCTION IN % OF TOTAL PRODUCTION			
Region/Year	**1960**	**1980**	**2000**	**2019**	**1960**	**1980**	**2000**	**2019**
World Total	320	1,000	1,698	4,459				
Top 20 Producer Countries	268	755	1,378	3,951	100%	100%	100%	100%
Global North	237	551	353	229	88%	73%	26%	6%
Global South	32	204	1,025	3,722	12%	27%	74%	94%

Table 14. World cement production in the Global North and Global South (1960 – 2019)

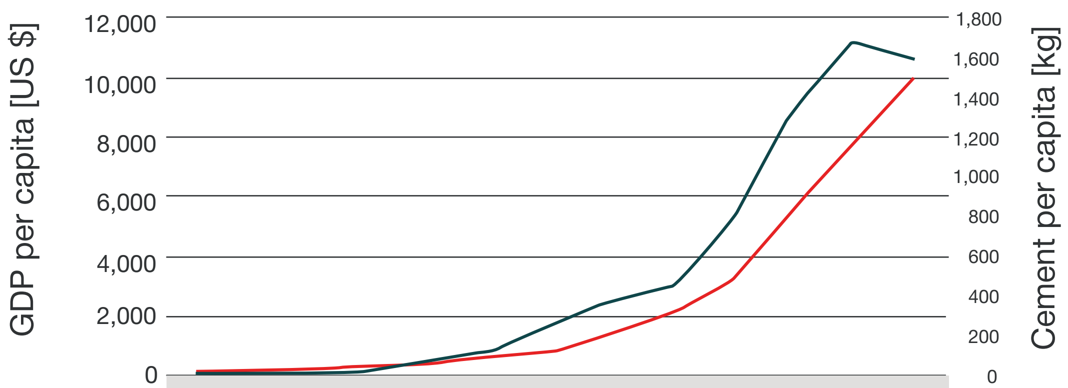
Source: Own calculations based on US geological survey data and the very useful info-graphic to be seen at https://www.dailymotion.com/video/x7vhhbl

China faced a particularly spectacular growth of cement production: In 1960, the most populous country (until recently) had produced only 16 million tons and is currently the largest producer in the world: the 2.6 billion tons produced by China (see table 20 in annex 1) represent more than 50% of the world's yearly production. Figure 5 below shows the two indicators of GDP per capita and cement consumption per capita for China. The high correlation between the two shows how cement played a crucial role in China's escape from poverty.

It is striking to see that cement consumption per capita was as low as 20 kg in 1960 and 32 kg in 1975, when China was still extremely poor and predominantly rural. This has changed dramatically when Deng Xiaoping initiated his institutional reforms in 1978: cement consumption per capita immediately leapfrogged to 81 kg in 1980, passed 500 kg in 2000 and reached 1,590 kg in 2019, more than three times the average global consumption of 500 kg per capita. This development is driven by an extreme promotion of urbanization, housing, and infrastructure in the past 20 years. China has by and large emerged from poverty but gone very far in pushing the construction sector excessively to the point that it is now faced with a deep crisis in the real estate market.

CHINA GDP PER CAPITA AND CEMENT PRODUCTION PER CAPITA 1960-2019

(Deng Xiaoping's reforms started in 1978)



	1960	1965	1970	1975	1980	1985	1990	1995	2000	2005	2010	2014	2019
GDP Per Capita	241	230	280	334	423	652	873	1,476	2,146	3,322	5,519	7,863	9,971
Cement/Capita	20	15	16	32	81	132	258	384	463	803	1,331	1,677	1,590

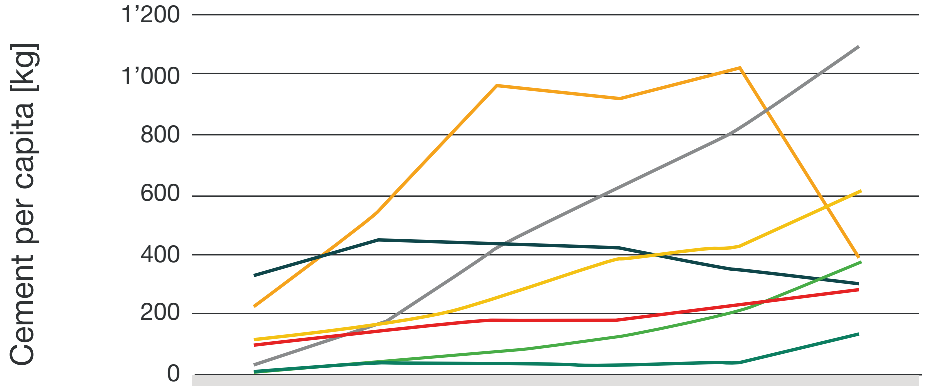
Figure 5. China GDP and cement production per capita (1960-2019)

Source: Own calculations based on data of US Geological Survey

3.5 PHASES OF GROWTH AND REASONS FOR STAGNATION

How does cement consumption per capita evolve over time and in different development phases?
Figure 6 below shows the cement consumption per capita in the period of 1960 to 2015 for different regions of the world.

CEMENT CONSUMPTION PER CAPITA IN LOW - AND HIGH - INCOME COUNTRIES 1960-2015



	1960	1970	1980	1990	2000	2015
High Income Europe	327	449	425	422	347	302
Low Inc Europe	231	537	961	915	1,018	382
High Inc Asia	42	162	426	624	812	1,086
Low Inc Asia	12	42	74	126	211	378
Mid East, N Africa	114	164	250	380	427	608
Latam	79	131	180	173	218	281
Africa	10	39	29	30	42	138

Figure 6. Cement production per capita in low - and in high-income countries (1960 – 2015)*

Source: Own calculations based on data of US Geological Survey
* Low - income Europe: Italy, Greece, Spain; high-income Europe: rest of Europe
* High - income Asia: China, Taiwan, Korea; low-income Asia: rest of Asia

Figure 6 illustrates three major trends:

1. Cement consumption per capita is low in societies with low industrialization and lower income levels (GDP per capita). One can very roughly say: poor societies hardly use 100 kg per person.

2. Cement consumption rises with industrialization and higher income levels and then stabilizes to typical consumption levels of 300-500 kg per person. At a certain level, this consumption even declines, and high-income countries show a typical “hump” in consumption (see especially low-income Europe, mainly Spain, Italy and Greece, and high-income European countries).

3. However, cement consumption per capita increases enormously in the transformation phases with high growth of population and incomes. This is even more the case in phases of rapid rural urban migration and in boom phases of the economy. Many countries have stimulated the construction sector as an engine of economic growth, for example in Southern Europe and especially in China. This has led to extremely high per capita consumption levels of 1,000 and more kg per capita.

Cement demand is expected to grow in many lower - income countries: While countries in the Global North and China had phenomenal growth rates in the past and are showing today signs of saturation, most countries in the Global South have still an enormous unsatisfied demand. Many large and populous regions have a low consumption level of around 200 kg per person, especially in Africa where consumption was at less than 50 kg per person until the year 2,000 and did not exceed 150 kg per person even in 2015.

4 FUTURE TRENDS IN CEMENT PRODUCTION – PROJECTIONS TO 2050

4.1 OVERVIEW: STABLE PRODUCTION AT HIGH LEVEL UNTIL 2050

Global cement production may stabilize in the future at a high level with high growth in the Global South. Forecasts of the global cement demand until 2050 vary between four and five billion tons per year. World production will thus stabilize at a very high level and even an increase by 500 or 800 million tons is possible. The distinction between demand (consumption) and production is tricky because some countries are net-exporters and some net-importers. We use here projections by IEA, the International Energy Agency[73] , for the future production. (Table 15 and 16). Most of this growth will take place in the Global South and the share of the Global North will be only slightly more than 10 %.

COUNTRY	CEMENT PRODUCTION DURING THAT YEAR (Mt)									
	1960	1970	1980	1990	2000	2010	2020	2030	2040	2050
China	16	12	110	305	775	1,985	2,555	1,670	1,310	950
India	8	15	29	70	120	253	415	545	673	800
Other Asia	2	16	53	139	223	456	479	585	743	900
Lat Am	8	19	55	54	90	187	193	295	398	500
Africa	3	9	7	33	51	87	199	520	710	900
Global North	267	489	617	538	391	293	282	468	482	495
Global	**304**	**560**	**871**	**1,139**	**1,650**	**3,261**	**4,123**	**4,083**	**4,314**	**4,545**

Table 15. Past and future cement production by region (1960 – 2050)

Source: Own calculations based on US Geological survey data for the numbers of past production (1960 to 2020); for the projections, IEA & WBCSD (2009b)

COUNTRY	CEMENT PRODUCTION DURING THAT YEAR (Mt)									
	1960	1970	1980	1990	2000	2010	2020	2030	2040	2050
Remaining Global South	13	44	115	226	364	730	871	1,400	1,850	2,300
India	8	15	29	70	120	253	415	545	673	800
China	16	12	110	305	775	1,985	2,555	1,670	1,310	950
Global North	267	489	617	538	391	293	282	468	482	495
Global	**304**	**560**	**871**	**1,139**	**1,650**	**3,261**	**4,123**	**4,083**	**4,314**	**4,545**

Table 16. Past and future cement production Global North and Global South (1960 - 2050)

Source: Own calculations based on US Geological survey data for the numbers of past production (1960 to 2020); for the projections, IEA & WBCSD (2009b)

4.2 REGIONAL SHIFTS FROM CHINA TO OTHER REGIONS OF THE GLOBAL SOUTH

What we have seen from these two tables (15 and 16v) is that there will be a significant regional shift of production within the Global South. While Chinese production should decrease from 2.55 to 0.95 billion tons, the remaining Global South may consume up to 2.3 billion tons of cement in 2050, mostly in Asia (excluding China) and in Africa.

India may increase its production to almost 800 million tons, other Asian countries to 900 million tons and Africa to 900 million tons, a four-fold increase in the 30 years to come. The following Figure 7 illustrates this trend (the Figure is compiled from the numbers of Table 15).

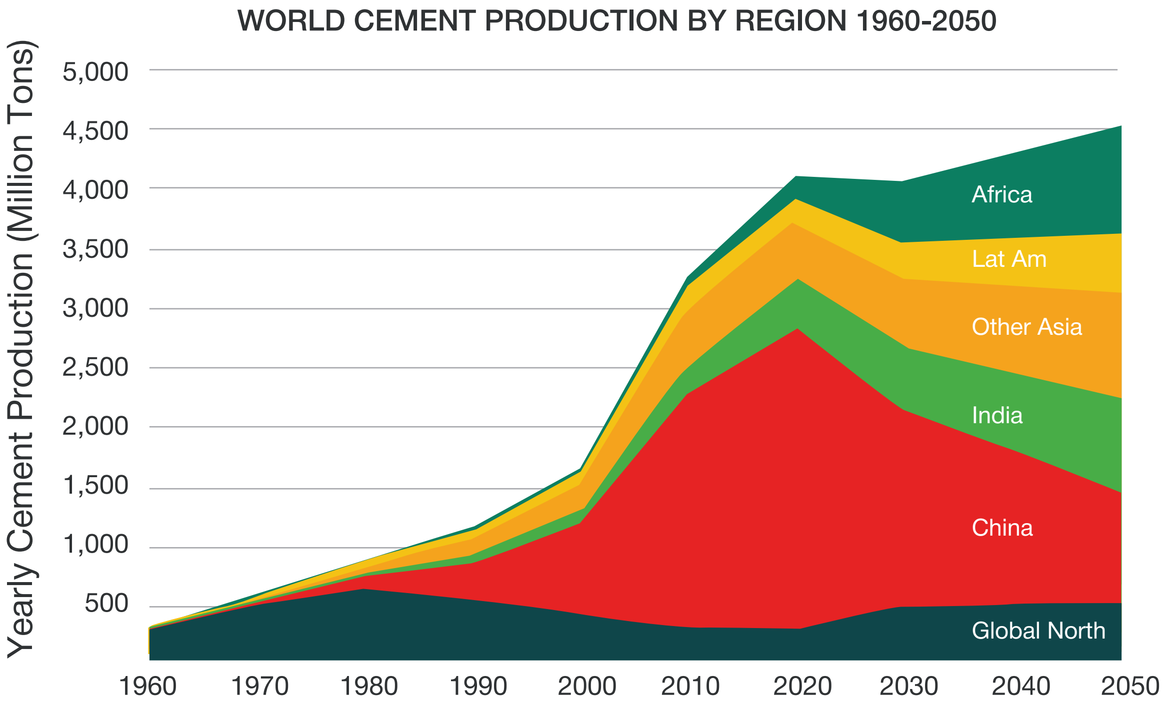


Figure 7. Cement production in different countries / regions (1960 – 2050)

Source: The figure is compiled from the numbers of table 15

4.3 REGIONAL SHIFTS: THE DECREASE IN CHINA IS COMPENSATED BY OTHER REGIONS OF THE SOUTH:

The forecast shows a stabilization of the world's production at around 4.5 billion tons, but this is only possible if China's production will decrease from 2.3 today to 0.95 billion tons by 2050. The first question is whether this projected decrease is a realistic scenario? There are indeed good reasons for this trend: It is expected that China's population has reached its peak in 2021 with around 1.4 billion inhabitants and will shrink to 1.3 billion in 2050. This may also slow down the urbanization trends which have been dramatic in the last 40 years. The national urbanization rate has reached 65 % in 2021, but the growth rate of urbanization is declining (see Figure 18 in annex 1).

Moreover, as we have seen before, China has constructed its infrastructure aggressively, with apparent over-investments in housing and infrastructure: it is estimated that 65 million housing units are empty, and the real estate sector is currently in turmoil.[75] All these factors are pointing to a declining demand curve for cement in China, and we can, therefore, conclude that the projected decrease seems realistic.

COUNTRY	PER CAPITA CEMENT CONSUMPTION (kg)									
	1960	1970	1980	1990	2000	2010	2020	2030	2040	2050
China	24	15	112	258	597	1,472	1,765	1,134	951	563
India	18	27	42	80	114	204	301	362	417	474
Other Asia	3	21	53	119	161	279	264	293	340	469
Latam	35	65	152	122	172	317	295	418	545	667
Africa	11	24	14	52	63	82	148	308	339	362
Global North	328	554	686	523	366	194	243	397	386	419
World	**101**	**151**	**196**	**214**	**269**	**442**	**529**	**478**	**467**	**468**

Table 17. Cement consumption per capita 1960 to 2050 for selected regions

Source: Own calculations from table 15 and UN population data

As table 17 shows the cement consumption per capita is still lower in most developing countries than in the Global North and especially compared to China, but it is expected to increase to the levels of highly urbanised countries. There are thus good reasons to believe that the decrease of China will be compensated by high growth in the rest of Asia and in Africa. On the one hand, there is a pent-up demand due to the low average consumption per capita in all these regions in 2020 (Africa only 148 kg, Asia less than 300 kg) and this consumption may increase with higher incomes. However, the main drivers for growth in these regions are the still high population growth along with the fast increase in urban population as the most important growth factor; we have seen this already in Chapter 3.3.

4.4 FUTURE CEMENT PRODUCTION AND THE REMAINING CARBON BUDGET

These opposing trends of decreasing production in China and increasing production in the rest of the Global South looks on the surface like a net-zero game, but it is indeed much more worrying. The continued production at this high level leads to a significant net-increase in the 30 years to come, the crucial period for the climate between 2020 and 2050, and **may represent a major threat to environmental sustainability** unless the cement sector introduces decarbonization measures **urgently.**

Table 18 shows the cumulative world cement production in the past 30 years (1990 – 2020) and the expected cumulative production for the next 30 years (2020 – 2050). **The world has consumed 75 billion tons of cement in the past 30 years (column 1) and may produce another 127 billion tons in the coming 30 years** (column 2). This represents an increase of almost 70 % (column 3) and could release 95 billion tons of CO_2 (column 4). These emissions are counted for a "business-as-usual scenario" (BAU), meaning that every ton of cement emits 750 kg of CO_2. The BAU scenario assumes that no decarbonization measures are introduced. Fortunately, there is a strong commitment of most cement companies and governments to decarbonize cement production, but the question is if this will be sufficient and if it happens fast enough.

The IPCC estimates the remaining carbon budget[76] in 2021 at 400 billion tons of CO_2 as the total quantity of emissions that the world can emit and still achieve the 1.5⁰ C target of the Paris Agreement. We have distributed this remaining carbon budget according to population strength of 2030[77] among the different regions (column 5) and calculated the CO_2 emissions from this additional cement production as share of the remaining budget (column 6). The last column shows emissions if all cement were LC_3 cement (column 7). We can see a reduction to 14 % of the remaining carbon budget, 10 % less than the BAU scenario. A more detailed table can be found in table 21 in Annex 1.

COUNTRY/ REGION	PRODUCTION past 30 years	PRODUCTION next 30 years	PRODUCTION INCREASE (%)	CO_2 EMISSIONS [Mt]	REMAINING BUDGET [Mt]	CO_2 CEM OF rem budget	CO_2 IF LC^3 [Mt]	CO_2 IF LC^3 of rem budget
COLUMN#	1	2	3	4	5	6	7	8
China	41,900	47,325	113%	35,494	70,060	51%	21,296	30%
India	6,155	18,250	297%	13,688	70,366	19%	8,214	12%
Other Asia	9,880	20,170	204%	15,128	88,603	17%	9,077	10%
Latam	4,005	10,390	259%	7,793	33,051	24%	4,676	14%
Africa	2,540	17,795	701%	13,346	79,008	17%	8,008	10%
Global North	10,941	13,380	122%	10,035	58,913	17%	6,021	10%
Global	**75,421**	**127,310**	**169%**	**95,483**	**400,000**	**24%**	**57,290**	**14%**

Table 18. Emissions from cement production as share of remaining carbon budget

Source: Own calculations of the author, numbers compiled from table 15

These results are worrying: Globally, these 95 billion tons of emissions would use up 24 % of the remaining carbon budget (column 6), meaning that **cement production alone would use up almost one quarter of the remaining carbon budget.** China would use up 51 % of her budget while India, other Asia and Africa would consume 17 to 19 % of their budgets. The whole of Africa has used much less in the past 30 years, slightly more than 2.5 billion tons of cement, but will need a staggering 18 billion tons for the next 30 years.

All this is a strong argument for immediate action and a strong push for low-carbon cement. The fast adoption of LC^3 cement would be a significant contribution to reduce the environmental footprint (see column 8) of cement, especially in the Global South where carbon capture and storage technologies (CCU) might be far too costly. CCS may represent a valid decarbonization strategy for the Global North, but the Global North is not a major player in cement production anymore, and the environmental footprint in the North is relatively small, roughly 10 % of the total production. The wide application of LC^3 is therefore an important and most promising solution for the Global South; it can reduce the emissions from 95 billion to 57 billion tons of the remaining global budget. This alone may not be sufficient to achieve net zero in cement production, but there are many more measures possible to reduce carbon emissions in constructions before using CCS technologies.

4.5 FUTURE URBANIZATION IN THE GLOBAL SOUTH AND THE STRESS ON RESOURCES

Can the anticipated urban growth and the growth of the built-up space be aligned with the climate goals? What are the resources needed to build the required infrastructure? A rough estimate is that around 40 % of cement is consumed for residential housing and 60 % for infrastructure[78]. This estimate is mentioned in the GCCA roadmap to net zero for cement and concrete, but this proportion may have a bias from the Global North. In the Global South, the share of housing might be smaller and the share for building the deficient infrastructure might be higher than these very rough figures.

A more precise indicator for all material resources required by a country is the Domestic Materials Consumption (DMC) index. Cement is included in the DMC as part of the category of non-metallic minerals which is predominately composed of cement, and bricks. Non-metallic minerals often account for 50 % of the total DMC.[79] The following table 19 shows a projection of the annual material consumption in different regions by 2050.

MAJOR GLOBAL REGIONS	2010 MATERIAL CONSUMPTON (1.000 Mt)	2050 MATERIAL CONSUMPTION (1.000 Mt)	TOTAL URBAN DMC CHANGE (%) (2010-2050P)
Africa	2.0	17.7	792%
Southern Asia	2.7	8.6	223%
South-Eastern Asia	2.0	5.6	180%
Central and Western Asia	1.9	4.7	151%
Oceania	1.1	2.6	136%
Eastern Asia	9.0	19.2	113%
South and Central America	6.5	11.1	71%
Europe	8.3	10.4	25%
North America	7.7	9.0	17%
World	**41.1**	**88.8**	**116%**

Table 19. Domestic Materials Consumption (DMC) in different regions (2010 – 2050)

Africa represents again an extreme case due to its anticipated population growth and urbanization trend. The estimated DMC may increase from 2 billion tons to 17.7 billion tons per year in 2050, an increase of 792 %. This rapid increase is certainly due to the doubling of the population, the lack of housing and infrastructure, and the unprecedented urbanization.

It is an enormous increase, and whether Africa will have the economic means to finance this development is an open and worrying question. Many emerging regions in Asia show – not surprisingly - similar trends of big DMC increases, again driven by the fast growth of urban population.[81]

4.6 TACKLING EMBODIED CARBON IS CRUCIAL IN EMERGING COUNTRIES.

Unlike in the Global North where "urbanization has already happened"[82] the cities in the Global South have yet to be built. Circular economy concepts aiming at recycling used concrete in the built environment are only partially applicable in the Global South as there are just not enough old materials and buildings to be recycled. Another bias in the environmental discussion on the built environment is the focus on operational energy savings rather than on the reduction of embodied carbon. Despite its massive contribution to global greenhouse gas emissions, embodied carbon has previously been under addressed in strategies to reduce building emissions.[83]

The situation in rich countries where the cities are mostly built, and where heating and cooling are primary emitters, has dominated* the methodologies to measure the environmental footprint : It is usually assumed that **operational energy** (heating, cooling, lighting, elevators) has a share of 50 to 75 % of total energy of buildings. The operational energy is so high because it is calculated over 50 years. However, the operational energy is for three reasons less important in the Global South: first, less heating and cooling is generally required, second most buildings have yet to be constructed, and finally, operational energy will become greener in the 50 years to come.

Certainly, millions of housing units in the South will be equipped with air-conditioning along with rising incomes and the rise of more people to the emerging middle class, and this will also have its environmental footprint. The only hope is that the electricity will become greener also in the Global South in the coming 30 to 40 years.

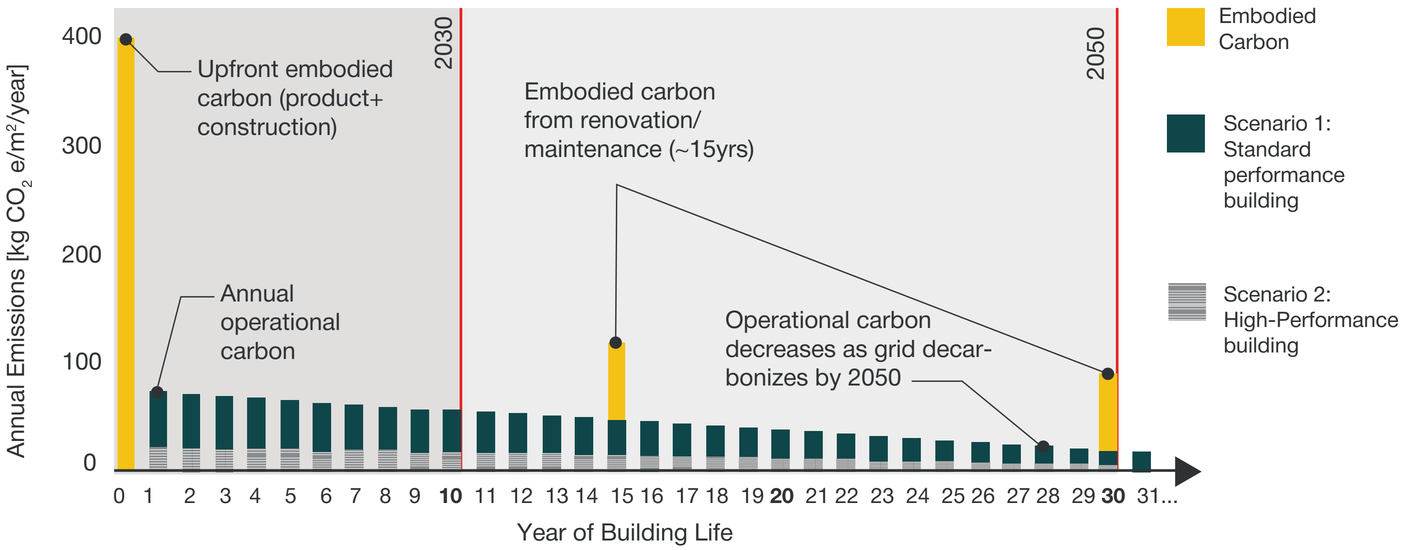


Figure 8. Relative impact of embodied and operational carbon of a new building from 2020 - 2050[84]

The focus should therefore be on the reduction of **embodied carbon** while building these huge amounts of houses and infrastructure for the first time.[85] An important aspect is the time dimension: reduced **embodied carbon emissions act upfront,** whereas operational carbon emissions are counted over 50 years, and they are also over-rated because these emissions will be less with greener energy. Figure 8 illustrates these upfront savings with the example of a medium-sized commercial office building. The assumption is a gradual grid decarbonization to zero by 2050.[86]

5 | THE NEED FOR LOW-CARBON CEMENT IN THE SOUTH, ESPECIALLY IN AFRICA

The Global South will need enormous amounts of cement, to a minor extent for closing the housing gap and to a major extent to meet the challenges of fast urbanization. As we have seen in the last chapter, Asia (excluding China) and Africa will increase their cement consumption to more than 3 billion tons per year by 2050, much more than what China produces today (see Table 15 and 18 before). Without significant improvements in the footprint of emissions from cement, we may still be far away from net zero. Large - scale mitigation measures are needed, and the challenge is to develop low carbon solutions that do not increase production costs and cement prices further in the Global South.

5.1 LIMESTONE CALCINED CLAY CEMENT (LC³) AS A VIABLE AND LOW-CARBON SOLUTION

The most promising option to achieve a lower footprint, is the increased use of clinker substitutes for Portland cement in concrete and mortars, as the UNEP study on Eco-efficient cement has shown: The wide adoption of LC³ and "increasing the average level of clinker substitution in cement to reach 40 %, for instance, through the use of LC3 could avoid up to 400 million tons of CO_2 emissions annually."[87] This estimate is based on today's global cement production and appears conservative in view of the projected increase of production in the next 30 years.

LC³ or limestone calcined clay cement[88] can substitute up to 50 % of clinker and has similar or better performance characteristics than Ordinary Portland Cement (OPC). It is now widely tested and included in most standards as an acceptable option, and its biggest advantage is that it can be used just as any bag of OPC; there is no need to train an army of masons and introduce different construction practices.

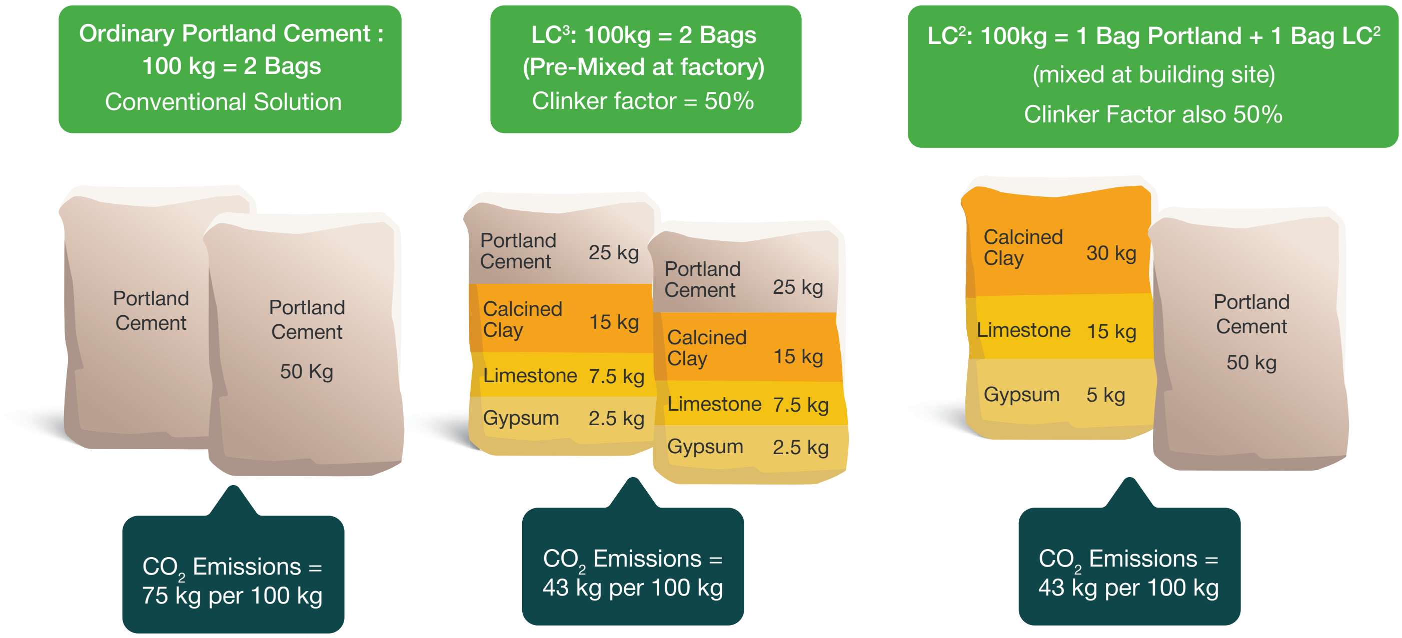


Figure 9. Illustration of LC³ and LC² Cement Mixture[89]

What is LC³? Figure 9 illustrates the difference of OPC and the two forms of calcined clay cement: LC³ (drawing in the middle) is a pre-mix of 50 % OPC blended with 50 % of substitute (15 kg of calcined clay, 7.5 kg of - uncalcined - limestone and 2.5 kg of gypsum). The drawing to the right shows LC², whereas one bag of OPC is to be blended with one bag of LC². The production of 100 kg of OPC releases around 75 kg of CO^2 emissions (around 40 % due to the high energy consumption when heating limestone to 1450°C, and 60 % due to the decomposition of limestone). LC³ has lower emissions because clay calcination occurs at lower temperature (800°C) and there is no decomposition of limestone (the limestone in LC³ is mixed without burning).

LC³ is economically viable: What is even more promising is the fact that LC³ production is – in most circumstances - economically viable and requires lower investments than the production of OPC. The most important factor to make LC³ production financially attractive are suitable clay reserves within a reasonable distance (around 200 km).[90]

Blending cement, or clinker substitution, is the most effective solution to reduce the environmental footprint of cement. This substitution is already practiced widely by adding fly ash from coal, blast furnace slag or volcanic ashes. However, these substitution materials are already quite extensively used, and their availability may be further reduced when coal-based electricity generation and steel production will switch to non-fossil fuels. Suitable clay - deposits are widely available almost everywhere, especially in Africa.

Carbon - capture and storage (CCS) technologies may be too costly for the Global South. CCS technologies are still under development and most of the big cement companies invest heavily in pilot productions. CCS may be needed to make cement production totally carbon neutral, but it is a very costly technology. Estimates indicate that CCS "would increase the marginal cost of clinker production 2-3 times."[91] The additional costs may be bearable for companies in the Global North where EU-ETS carbon pricing[92] is expected to be in the order of 100 Euros and more per ton in the near future. A cost increase from around USD 40 per ton to around USD 70 per ton for carbon - neutral cement might be eventually acceptable for customers in rich countries, but is unthinkable in the Global South, especially in Africa where cement prices are already unaffordable.

Cost - effective alternatives to CCS exist: LC³ cement could be a first significant step towards a lower footprint, but is not sufficient to achieve full decarbonization. Additional smart measures could reduce the carbon footprint of buildings massively; a study showed that "reductions of up to 80 % of CO_2 emissions compared to the 1990 value is achievable by 2050 without using carbon capture and storage technologies."[93] These alternatives are more challenging to implement because they imply a whole set of minor savings along the entire value chain, involving construction companies, masons, engineers, as well as concrete- and cement producers, but they require much lower investments than just banking on CCS technologies.

5.2 LOCAL PRODUCTION IN AFRICA SEEMS MORE PROMISING WITH LC³

Many countries in Africa still have a high share of imports, mostly due to lack of local limestone deposits. This leads to long transport routes, especially in the landlocked countries of inner Africa and thus to high prices.

Local production would not only save foreign exchange but also create more jobs and value added within African countries. The following figure 10 shows this dependency on imports drastically.[94]

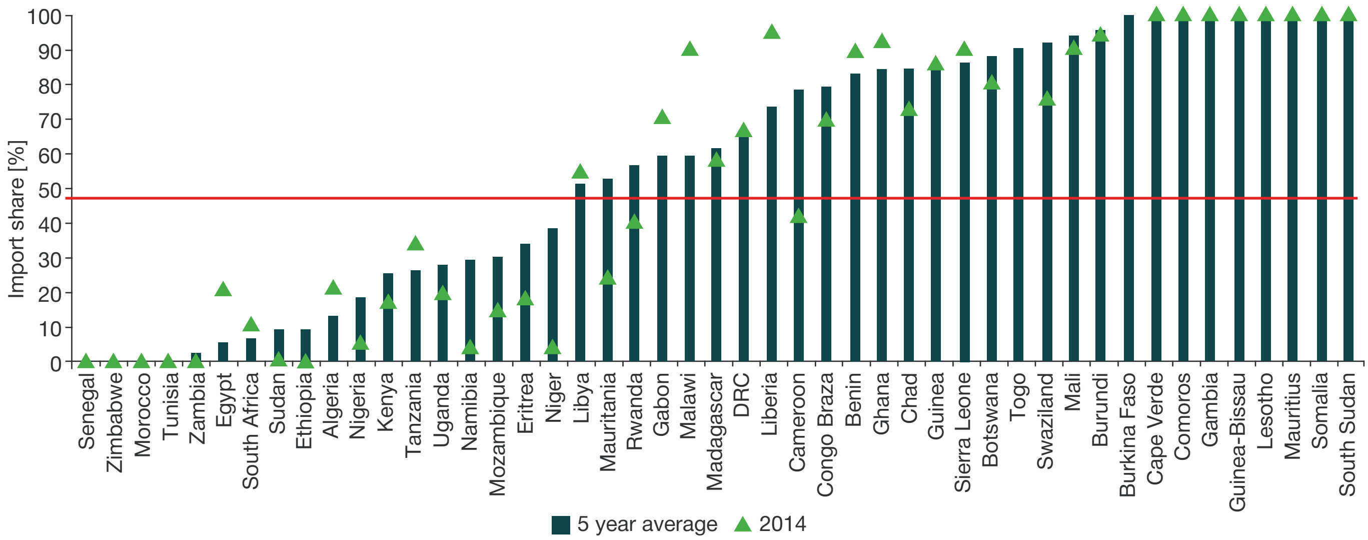


Figure 10. Import share of cement consumption in African Countries

Source: Byers et. al 2017, p. 20

Setting up local production of cement in Africa is hampered by several restricting factors:

- **Limestone deposits** are scarce and concentrated in some spots, often far away from cities;
- **Logistics:** Long distances for road transport and high transport costs;
- **Lack of infrastructure** and high costs for power and energy.

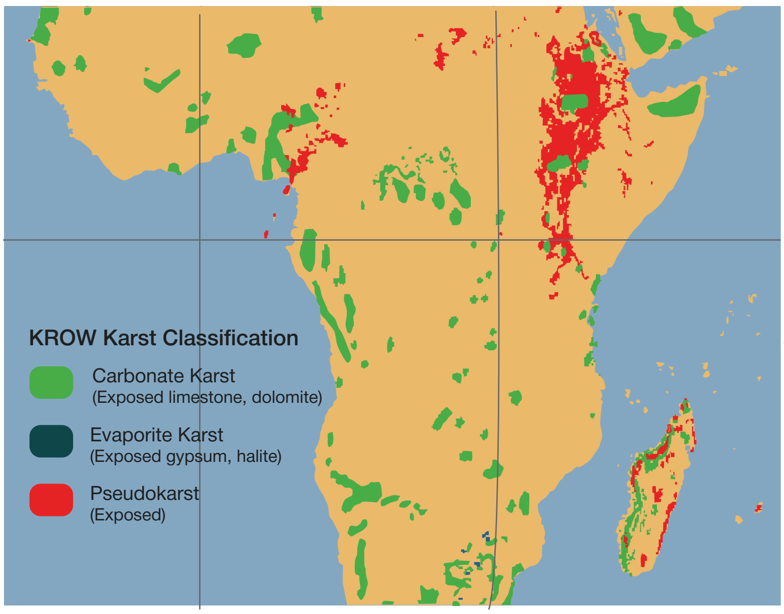
Non-availability of limestone is the most important hurdle for local clinker production. Limestone comprises typically 80 % of the raw material input for clinker production: “Accessibility is the challenge, which brings into play the balance between limestone deposits, electrical power and water supply and transport of either clinker, in bulk or bagged cement to local or regional markets or ports for export. Plants are only built adjacent to deposits that are large enough to supply the plant for 30-years. The size of the deposit is thus also an important factor.”[95] Moreover, the lifespan of a cement plant is much longer than 30 years.

Logistics: Most limestone deposits in Africa are concentrated in clusters and located far from the urban centres with the highest demand. This leads to high transportation costs and fosters imports via sea transport.[96] “Cement production and trade are highly dependent on the location of limestone deposits, but these are unevenly distributed across West Africa - deposits are found in Benin, Burkina Faso, Ghana, Mali, Nigeria, Senegal, and Togo - but they are frequently far from the main urban population that extends from Abidjan to Lagos along the Southern coast.”[97] Figure 11 below shows how the limestone deposits in Africa are concentrated in some clusters[98]. “A viable distribution network is a logistical challenge: Dangote bought 1,000 trucks from China to distribute cement along the West African coast, and Heidelberg Cement added 700 so - called ‘Buffle’ trucks due to their buffalo logo.”[99] Dangote trucks are plying in convoys of 400 trucks along the coast to ease tax payments at the borders. Cement produced in Nigeria must cross several borders to reach other West African countries such as Burkina Faso or Mali.

Production costs for clinker are also higher in Africa due to higher costs for power, water, and transport. As maritime transport is cheaper it is therefore more advantageous to import cement. However, it still must be transported from the port to the destination and the cost of land transport may be very costly, especially to reach landlocked countries such as Burkina Faso or Rwanda.

Local production of LC^3 or LC^2 could be attractive: Clay deposits are more widely distributed almost all over Africa (see figure 11 right side) and local calcination could be exploited much closer to the place of consumption. We have already mentioned that local calcination can be cost-effective if the clay deposits are within 200 km of a plant or a grinding station. The clay map below shows the available subsoil clay deposits in Africa. It should be possible to produce calcined clay and add clinker in many places locally. Similarly, could it be interesting to produce LC^2 locally and blend it with imported clinker.

Investment costs LC^3 production are lower than for clinker: investment costs for machinery to produce one million tons of calcined clay are in the order of USD 30 million. If cement production in Africa will grow from 200 million tons in 2020 to 900 million tons in 2050, it would require additional capital investments of some USD 21 billion, but for Portland cement plants the necessary investments would be at least five times higher.[100]



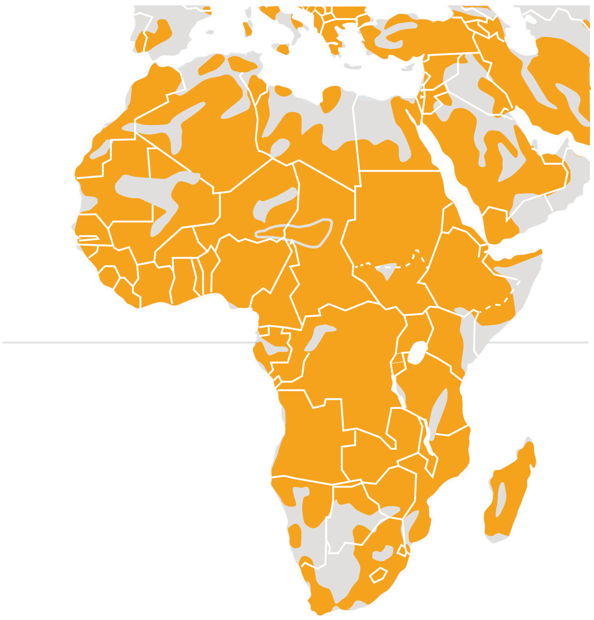


Figure 11. limestone (left) and clay deposits (right picture) in Africa[101]

5.3 THE ISSUE OF PRICING: WHY DOES A CEMENT BAG IN AFRICA COST SO MUCH?

Cement prices in Africa are astronomically high, as a World Bank study[102] shows. The study has analysed why African countries face much higher prices for some essential commodities such as cement and fertilizers. On average, a 50 kg bag of cement in Africa costs almost USD 10 while the world market price is around USD 3.25 per bag.

The World Bank explains the reasons for the high cement prices in Africa (Figure 12) mostly because of lacking competition and monopolies[103], but there are many other underlying factors such as high prices for transport and energy, as we have seen.

Figure 12. High cement prices in Africa due to lack of competition

These high prices are even more accentuated if compared with the purchasing power of the people in Africa. Figure 13 below shows the number of required working days to purchase one ton of cement in selected countries. Whereas a Congolese needs to work almost half a year to buy a ton of cement, an American or European needs less than a day and a Chinese only three days.[104] This is a Figure from Wolfram Schmidt who has collected data from personal interviews during a workshop. It may not meet all criteria of statistical rigour, but it is an illustrative example of why our lives are so easy and why people in Africa are struggling so hard to get a roof over their heads.

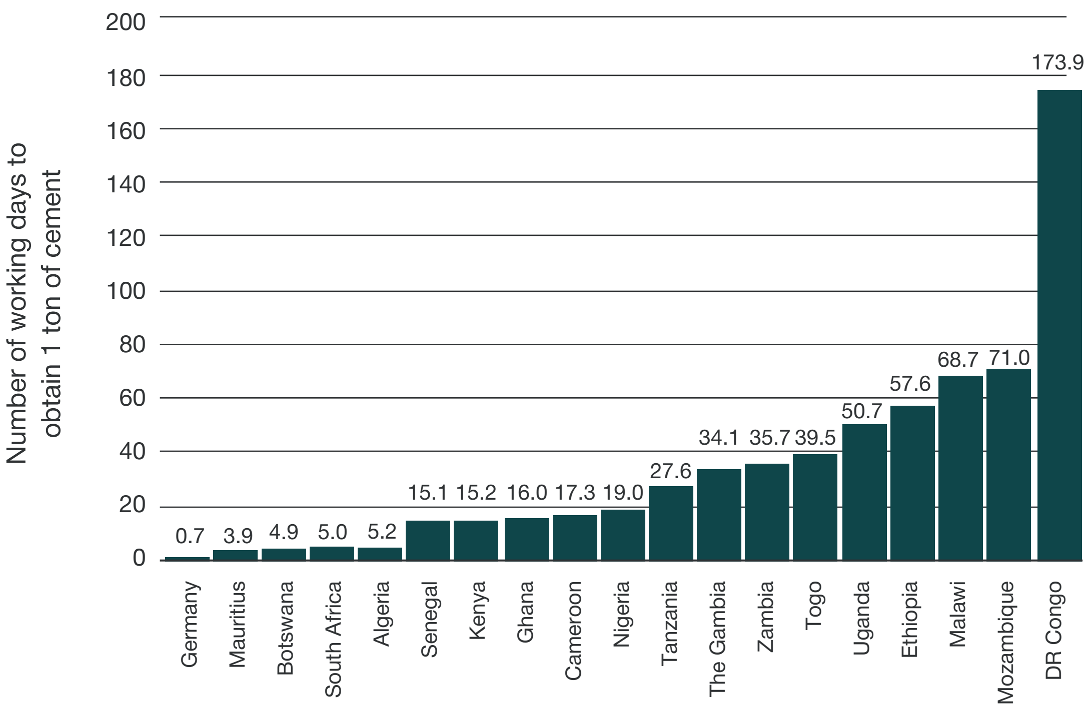


Figure 13. Cement prices compared to purchasing power in different countries

Source: Schmidt, W. (2023)

5.4 CEMENT MARKETS IN AFRICA ARE HIGHLY DYNAMIC EVEN AT HIGH PRICES

Nevertheless, cement markets in Africa are growing fast, despite the high prices: Lyal White calls Africa "the last great cement frontier"[105] and sees enormous potential for developing the African cement industry. Low consumption levels and high population and economic growth are for Lyal White a great opportunity to produce cement locally and to cater to the needs of infrastructure, housing, and urbanization. The high prices make local production attractive, and these prices may not fall immediately. "Development of basic infrastructure from roads, rails and ports to hospitals, schools, shops, and housing all require cement as a primary input, making it a key indicator of performance and the trajectory of an economy – especially those coming off a low base. Given the growth story in Africa and the requirements around infrastructure development and construction, cement is clearly a key strategic sector on the continent, with significant players and, increasingly, African companies investing and exporting to other African markets."[106]

Whether this expansion will lead to lower prices, and how soon, is an open question. Prices may not fall much in the short run: In Burkina Faso, prices have come down from 213 € per ton in 2014 (USD 13 per bag) to 178 € per ton in 2015 (USD 10 per bag) through competition, but only the transport of clinker from the coast to Ouagadougou costs 53 to 61 € per ton (USD 3 to 3.60 per bag of 50 kg).[107]

Other inputs such as coal may also be very costly on the world market and this cost goes up even more with transport over large distances. In the long run, it is hoped that economies of scale and increasing competition and better infrastructure will bring down the prices to acceptable levels. What is certain is that production costs for LC_3 are lower than for OPC, and this is a great opportunity to develop the cement industry in Africa.

5.5 URBANIZATION AND CONSTRUCTION SEEN AS AN OPPORTUNITY FOR JOB CREATION

While, for many years, development theory has perceived the rural exodus as a threat, leading to insane slum housing and misery, today, urbanization is seen as a positive development opportunity. "Globally, cities are major drivers of economic growth, and the quality and location of housing have long-term consequences for inclusive growth. People move to cities to improve their lives and those of their families because of better economic opportunities compared to rural areas. Access to a diverse, quality housing stock that is affordable to households will set a foundation for inclusive growth in rapidly urbanizing cities. For most households, purchasing or building a house is the single largest expenditure they will ever make."[108]

Building cities and their infrastructure, but especially housing the population is a source of economic growth, and the construction sector is one of the most important and dynamic sectors to create jobs. "After several decades of debate on what housing might contribute to economic growth, it is now a widely held view that housing is not just a peripheral activity but a central force of sound economic development, much in the same way as investment in transportation, power and communication."[109] El Hadj M. Bah, Principal Research Economist of the African Development Bank is pointing out that the construction sector contributes a major share to GDP in most OECD countries and even more in developing countries, especially in Africa.[110]

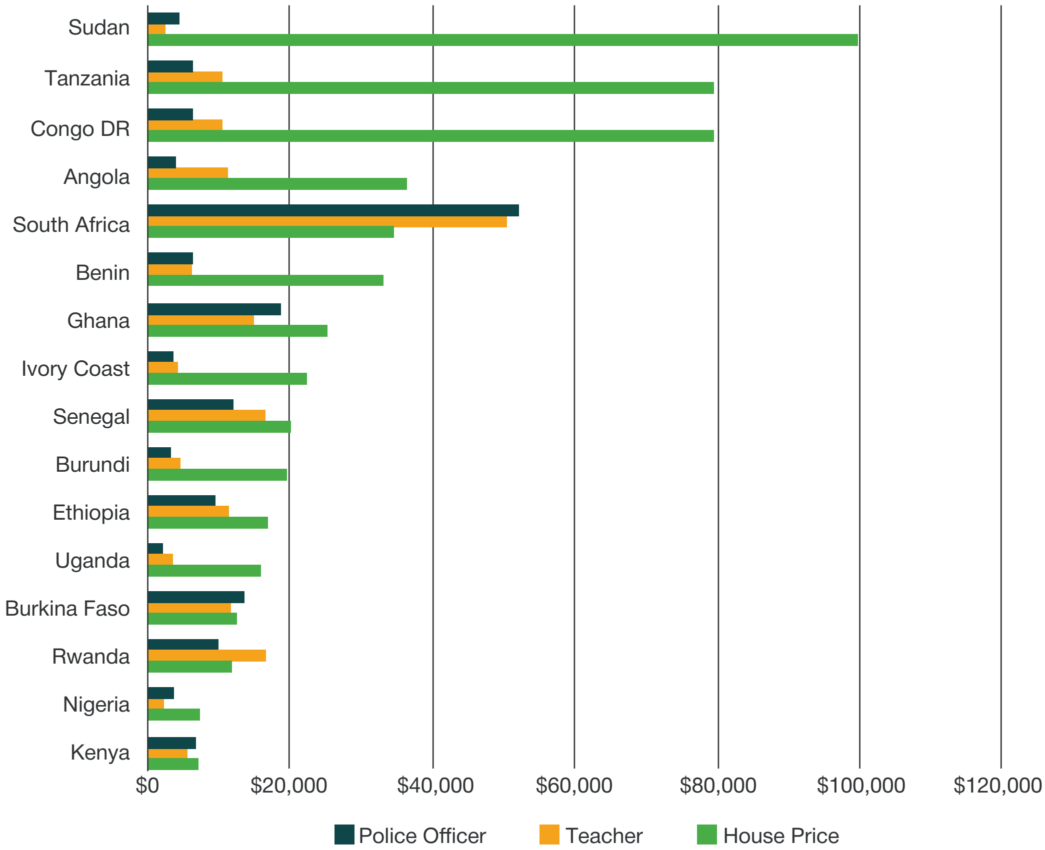
It is thus obvious that affordable building materials and low-carbon cement are one of the key ingredients to unfold this economic potential. The fast urbanization can therefore and should be seen as a great opportunity for development.

5.6 SOLVING THE AFFORDABILITY ISSUE FOR HOUSING CAN UNLEASH A DYNAMIC MARKET

How can the housing market be unleashed? Today, the development of a dynamic construction sector is restrained by low purchasing power and high prices for buildings and houses. In its Yearbook, the Centre for Affordable Housing Finance (CAHF) has published an affordability map for housing in Africa.

The following figure 14 shows house prices and the maximum of mortgages that a police office or a teacher could afford. The Figure and the table show a very high affordability gap in many countries.[111]

AFFORDABILITY OF CHEAPEST NEWLY BUILT HOUSE IN SELECTED AFRICAN COUNTRIES



AFFORDABILITY HOUSE PRICE VS. MORTGAGE	HOUSE PRICE	MORTGAGE TEACHER	MORTGAGE POLICE OFFICER
Sudan	$99,842	$2,361	$4,101
Tanzania	$79,684	$10,571	$6,278
Congo DR	$58,218	$4,660	$2,806
Angola	$36,452	$11,163	$3,944
South Africa	$34,501	$50,565	$52,099
Benin	$33,267	$6,248	$6,206
Ghana	$25,253	$14,960	$18,700
Ivory Coast	$22,365	$4,261	$3,409
Senegal	$19,960	$16,517	$12,113
Burundi	$19,513	$4,525	$3,232
Ethiopia	$16,999	$11,362	$9,573
Uganda	$15,816	$3,576	$2,008
Burkina Faso	$12,475	$11,750	$13,562
Rwanda	$11,644	$16,515	$9,910
Nigeria	$7,312	$2,999	$3,501
Kenya	$7,111	$5,507	$6,736

Figure 14. Affordability map for housing in Africa

Source: CAHF (2021), p. 22

Launching a Ford T revolution in affordability: To step out of this vicious circle, a similar revolution should be initiated as Henry Ford has done when he revolutionized automobile production in America with the Ford T model: it was made so efficiently and designed so modestly that even blue - collar workers could afford to buy a Ford T, and this paved the way for marketing cheap cars to the masses. Nowadays, most private house developers in Africa are only serving the expensive market segments of the higher middle class and are missing the mainstream markets at the base of the pyramid.

Unleashing Africa's housing industry would require a series of significant reforms to address the artificially high costs of construction materials and especially cement. Africa has also very high construction costs due to informal construction methods. Moreover, the non-availability of affordable housing finance options aggravates the market failures. The renowned economist Paul Collier sees a major opportunity to unlock the housing and construction sector through industrialization and modernization, but also access to affordable housing finance. [112]

5.7 CONCLUSION: LOOKING AT THE CHALLENGE AS AN OPPORTUNITY

The large - scale delivery of housing and the gigantic challenge of urbanization might well imply a lot of headaches, but it should also be seen as an opportunity … **an opportunity to invest, create jobs, and enable prosperity.** This report has aimed at convincing the reader with numbers and arguments for making the building and construction sector a top priority on the development agenda.

This agenda will require huge amounts of affordable green cement, low-cost building materials and affordable financing mechanisms. The challenge in Africa is huge if we consider the numbers – one billion people more to be fed and to be housed in a period of less than 30 years, but so is the opportunity. This requires substantial efforts to mobilize large financial volumes and new financial models in emerging countries in Africa. It would also need a comprehensive reform package for the entire building and construction sector. The Sustainable Housing Initiative[113] by the French Development Agency (AFD) is such an attempt, many more such scaling - up efforts will be needed.

The availability of green cement will be a key element in such a puzzle, because only with low-carbon cement can the social needs and the environmental goals be harmonized and met simultaneously. Making low-carbon cement at affordable prices available through the large - scale production of LC^3 is only one element of this puzzle, but it is one that can become a game changer.

ANNEX 1

TABLES AND FIGURES

EVOLUTION OF TOP 20 CEMENT PRODUCERS

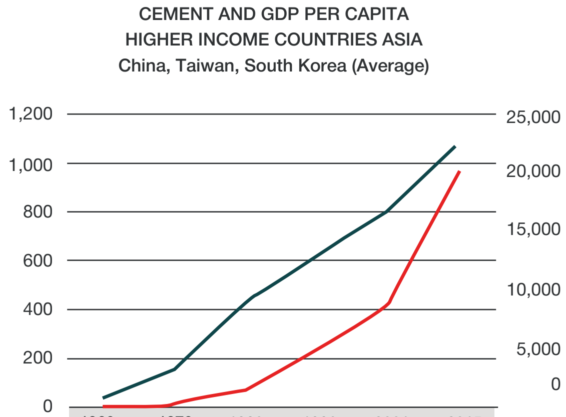
Rank	1960	[Mt]	1970	[Mt]	1980	[Mt]	1990	[Mt]	2000	[Mt]	2010	[Mt]	2019	[Mt]
1	USA	57.1	USSR	106.1	Soviet Union	138.2	China	224.5	China	625.4	China	1959.3	China	2,674.1
2	Soviet Union	46.2	USA	75.9	Japan	96.5	USSR	132.9	India	99.5	India	229.9	India	322.4
3	West Germany	25.2	Japan	63.5	China	88.7	Japan	86.7	USA	89.9	USA	67.9	USA	85.5
4	Japan	22.8	W Germany	42.8	USA	76.2	USA	69.4	Japan	79.1	Turkey	63.1	Vietnam	83.9
5	China	15.8	Italy	36.4	Italy	46.0	India	49.9	South Korea	51.6	Iran	63.5	Turkey	80.7
6	Italy	16.1	France	32	W Germany	39.1	Italy	40.3	Italy	40.0	Brazil	61.6	Indonesia	67.6
7	France	14.4	UK	19	France	31.9	South Korea	34.2	Brazil	39.1	Vietnam	57	S Arabia	63.5
8	UK	13.6	Spain	18.5	Spain	30.9	Spain	28.1	Spain	39.2	Russia	53.3	Brazil	62.7
9	India	8.2	India	15.2	Brazil	29.8	Brazil	26.6	Germany	36.1	Japan	51.5	Russia	60.9
10	Poland	6.7	Poland	13.6	Poland	19.7	France	26.5	Turkey	33.3	South Korea	47.8	Iran	59.7
11	Spain	5.6	China	11.4	India	19.8	Turkey	25.1	Russia	33.6	Saudi Arabia	45.6	Egypt	59.1
12	Canada	5.3	Brazil	10.1	Mexico	18.2	Mexico	24.4	Mexico	32.7	Egypt	43.9	S Korea	54.9
13	Czechoslovakia	5.1	Romania	9	South Korea	17.2	W Germany	17.3	Indonesia	29.4	Indonesia	42.3	Japan	51.0
14	East Germany	5.0	East Germany	8.9	Romania	17.1	Taiwan	18.9	Thailand	26.5	Mexico	39.8	Thailand	40.7
15	Brazil	4.5	Czechoslovakia	8.3	UK	16.0	Thailand	18.1	Iran	25.2	Italy	33.8	Mexico	40.6
16	Belgium	4.4	Canada	8.2	Taiwan	15.6	North Korea	16	Egypt	24.8	Thailand	31.7	Pakistan	37.4
17	Mexico	3.1	Mexico	8	Turkey	14.5	Egypt	15.1	France	20.3	Germany	31.6	Germany	31.7
18	Romania	3.1	Belgium	7.5	Greece	14.1	Indonesia	14.8	S Arabia	19.2	Pakistan	29.9	Phillippines	26
19	Switzerland	3.1	Turkey	7.3	East Germany	13.7	Iran	12.9	Taiwan	17.8	Spain	23.2	Algeria	25.5
20	Austria	3.1	South Korea	6.5	Czechoslovakia	11.7	Greece	8.4	Greece	14.8	Malaysia	20.4	Nigeria	23.1

COMPARISON GLOBAL NORTH AND GLOBAL SOUTH

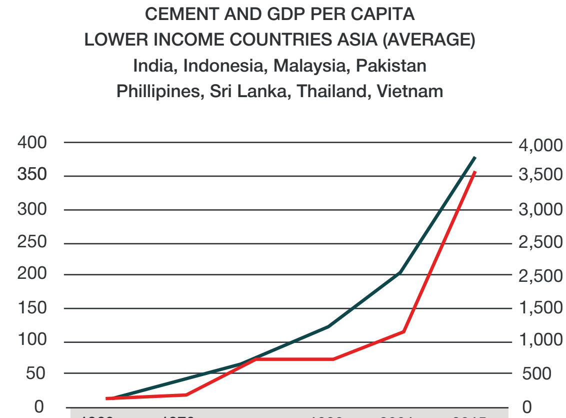
1960	[Mt]	1970	[Mt]	1980	[Mt]	1990	[Mt]	2000	[Mt]	2010	[Mt]	2019	[Mt]
World	319.8	World	650.8	World	1,000.3	World	1,199.8	World	1,698.1	World	3,445.8	World	4,459.2
Top 20	268.4	Top 20	508.2	Top 20	754.9	Top 20	890.1	Top 20	1,377.5	Top 20	2,997.1	Top 20	3,951.0
Other Coutries	51.4	Other	142.6	Other	245.4	Other	309.7	Other	320.6	Other	448.7	Other	508.2
Global North	236.8	North	456.2	North	551.1	North	434.7	North	353.0	North	261.3	North	229.1
Global South	31.8	South	52.0	South	203.8	South	455.4	South	1,024.5	South	2,735.8	South	3,721.9

Table 20. The top 20 cement producing countries in the world (1960-2019)[114]

While in 1960 only four countries of the Global South were among the 20 top producing countries, the situation in 2019 has totally reversed: now, only four countries of the Global North are among the top 20. The lower part of the table shows the respective production in million tons for the Global North and South.

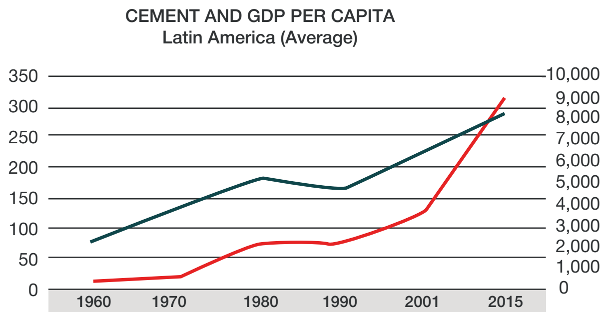


	1960	1970	1980	1990	2001	2015
Avg Cem/cap	42	162	426	624	812	1,086
Avg GDP/cap	81	262	1,463	5,041	8,655	20,037

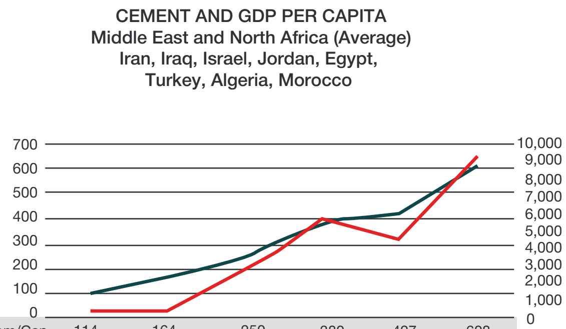


	1960	1970	1980	1990	2001	2015
Avg Cem/cap	12	42	74	126	211	378
Avg GDP/cap	116	183	714	731	1,131	3,593

Figure 15. The relation between cement and GDP per capita in Asia



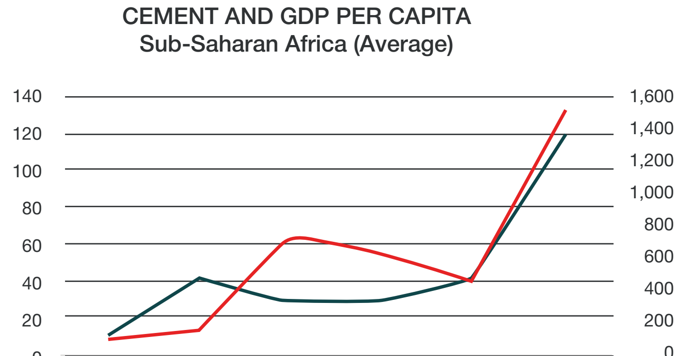
	1960	1970	1980	1990	2001	2015
Avg Cem/cap	81	134	180	164	224	291
Avg GDP/cap	443	571	2,125	2,042	3,711	8,937



Com/Cap	114	164	250	380	427	608
GDP/Cap	424	537	2,561	5,520	4,510	9,137

Figure 16. The relation between cement and GDP per capita in Latin America and MENA countries

Source: Own calculations based on data of US Geological Survey [116]



	1960	1970	1980	1990	2001	2015
Avg Cem/cap	10	39	29	30	42	119
Avg GDP/cap	93	147	732	616	466	1,509

Figure 17. The relation between cement and GDP per capita in Sub - Saharan Africa

Source: Own calculations based on data of US Geological Survey [116]

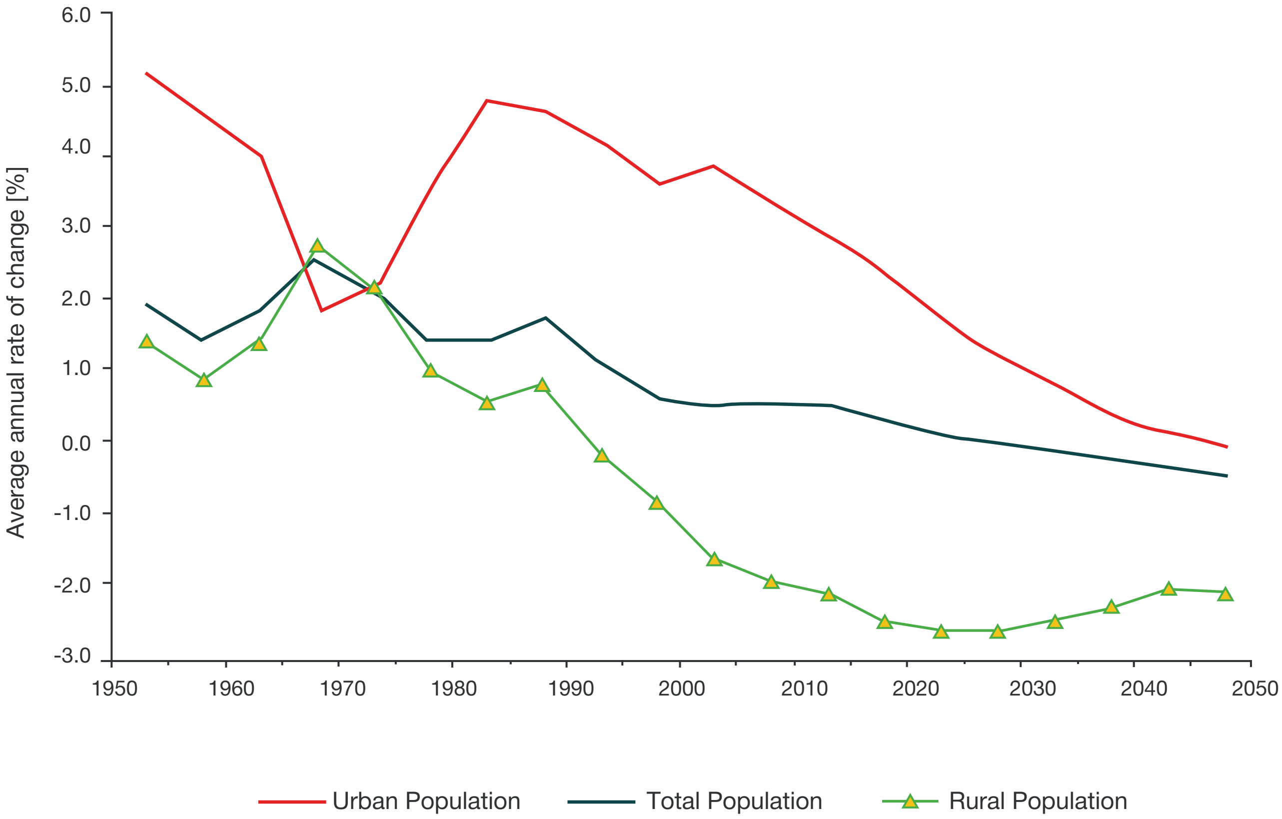


Figure 18. Change in population and urban population in China (1950-2050)

Source : World Urbanization Prospects 2018, p. 39
UN - DESA (2018), p. 39

COUNTRY	2020 CEMENT PRODUCTION [Mt]	2030	2040	2050	PRODUCTION 1990-2020 [Mt]	PRODUCTION 2020-2050 [Mt]	% INCREASE
COLUMN#	1	2	3	4	5	6	7
China	2,555	1,670	1,310	950	41,900	47,325	139%
India	415	545	673	800	6,155	18,250	366%
Other Asia	479	585	743	900	9,880	20,170	227%
Latam	193	295	398	500	4,005	10,390	140%
Africa	199	520	710	900	2,540	17,795	593%
Global North	282	468	482	495	10,941	13,380	122%
Global	**4,123**	**4,083**	**4,314**	**4,545**	**75,421**	**127,310**	**169%**

COUNTRY	PRODUCTION past 30 yrs	PRODUCTION (%) next 30 yrs	CO_2 EMISSIONS [Mt]	CO_2 if all cement LC_3	POP 2030	REMAINING BUDGET [Mt]	CO_2 cem of rem budget	CO_2 IF LC^3 of rem budget
COLUMN#	1	2	3	4	5	6	7	8
China	41,900	47,325	35,494	21,296	1,497	70,060	51%	30%
India	6,155	18,250	13,688	8,213	1,504	70,366	19%	12%
Other Asia	9,880	20,170	15,128	9,077	1,893	88,603	17%	10%
Latam	4,005	10,390	7,793	4,676	706	33,051	24%	14%
Africa	2,540	17,795	13,346	8,008	1,688	79,008	17%	10%
Global North	10,941	13,380	10,035	6,021	1,259	58,913	17%	10%
Global	**75,421**	**127,310**	**95,483**	**57,290**	**8,548**	**400,000**	**24%**	**14%**

Table 21. Projected future cement production 2020 – 2050 and environmental footprint

Source: Same source as table 15 but more detailed

ANNEX 2 HOUSING NEEDS AND CEMENT CONSUMPTION

In this annex, we describe in detail how the housing needs and cement consumption were calculated.

ANNEX 2.1 METHODOLOGICAL ISSUES AND BASES FOR CALCULATION

Connecting housing to cement need can be achieved by considering residential space. The floor area per capita and/or average dwelling size represents a fundamental indicator of housing quality, but it is not collected comprehensively.[118 119] Information on 54 countries could be collected, in total, with a strong bias for the Global North. Unit sizes range from 43.8 sqm in South-East Asia to 164.5 sqm in Australia and New Zealand.[120] Following our differentiation of slum and non-slum housing needs, we also require unit sizes for slum housing units. Data remains a great challenge concerning slums.[121] The housing deprivation of insufficient living space is defined by UN-Habitat as an occupation of three people per room, and documentation of the Millennium Development Goals (MDG) set a minimum room size of four square meters.[122] This value would allow us to calculate more nuanced living realities by considering family sizes per country.[123] The world region with the largest household sizes and therefore largest estimated slum unit sizes is Western Africa (7.8 sqm) where four out of the eight highest values are to be found, such as Senegal (11.5 sqm for a household average of 8.66 people) and Gambia (11 sqm for 8.23 people). We want to stress that these room standards represent the absolute bare minimum (1.33 sqm per person) and are far away from what can be considered adequate housing.

Setting construction standards enables the quantification of cement need to achieve SDG 11.1. We estimate that all units will be built in concrete frame structures based on the technical specifications described below and in **table 21**.[124 125] The main difference between non-slum and slum housing is the level of finishing and the quality of the construction. Slum units are unfinished (no plaster), generally built with artisanal bricks that consume more mortar and the final ceiling/roof is often built from less costly materials than concrete.

HOUSING STANDARDS	NON-SLUM UNIT	SLUM UNIT
Max Ceiling Field	5 x 5 m	3 x 3 m
Ceiling in concrete	Yes	No
Floor in concrete	Yes	Yes
Ceiling and Floor width	0.16m	0.12 m
Column	0.16 x 0.16m	0.12 x 0.12 m
Room Height	2.7m	2.2 m
Brick Size	Single line walls	Double line walls
Mortar Thickness	0.01 m	0.02 m
Wall Finishing	Plastered	Barren
Wall Openings	0.15% of the area	0.15% of the area
Wall Plaster	Yes	No
Plaster Thicknes	0.02 m	-

Assumptions on construction standards of slum - and non - slum housing units

The primary use of cement in housing construction is in concrete, mortar, and the final layer[126] which can all be translated into area-based consumption: how many kilograms of cement are needed per square meter built - up? We calculate the cement requirements by considering the housing built-up area per country, calculating the required ceiling fields, the columns to support them and walls (with openings) to create the spaces. From the perspective of the lower standards, slum housing has almost only half of the area-based cement consumption of non-slum housing. Considering that slum units are just a fraction of the built-up area of non-slum housing units, underscores the inequality in cement use in this world.[127]

CEMENT NEED [KG/SQM]	NON-SLUM	SLUM
Cement in concrete	101.4	60.4
Cement in Mortar	4.4	14.6
Cement in Plaster	39.2	0.0
Cement Total	**145.1**	**75.0**

Table 22 . Cement consumption per area for slum - and non-slum housing

How many kilograms of cement are needed per housing unit? Based on the previous calculations we arrive at the numbers presented in **table 23** below. While an average slum unit (6.5 sqm) requires 1,210 kg of cement, an average affordable house (25 sqm) would require 3,576 kg.

An average European housing unit (83 sqm) would consume 27,204 kg per unit. A minimum space standard of 25 sqm per family would multiply the cement need by a factor of five, and a minimum housing unit of 50 sqm by a factor of ten.

CEMENT NEEDS FOR DIFFERENT TYPES OF HOUSING UNITS	KG/UNIT	CO_2 EMISSIONS
Slum Housing Unit*	1,210	908
Affordable Housing Unit*	3,576	2,682
Housing unit as if built per European standards**	27,204	20,403

Table 23 . Cement consumption for different housing units

* Slum and affordable units are mentioned below as modest units

**European standard units are mentioned below as high-standard units

ANNEX 2.2 HOUSING NEEDS AND CEMENT DEMAND – GLOBAL OVERVIEW AND WORLD REGIONS

The following tables are excerpts from the **Housing Data Table (HDT**) mentioned earlier in chapter 2.3. The tables below show the cement needs for housing units in different regions, sub-regions and countries.

HOUSING NEEDS AND CEMENT DEMAND TO FULFILL SDG 11.1	WORLD	AFRICA	ASIA	LAC	EUROPE	NORTHERN AMERICA	OCEANIA	ROW#
COLUMN	1	2	3	4	5	6	7	
Population 2015 [million]	7,424.8	1,201.1	4,459.4	623.1	740.4	360.5	40.4	1
Population 2030 [million]	8,544.5	1,710.7	4,958.8	697.6	734.9	393.3	49.2	2
Population Growth 2015-30 [million]	1,119.6	509.6	499.4	74.5	-5.5	32.8	8.8	3
Population Growth 2015-30 [%]	15.1%	42.4%	11.2%	12.0%	-0.7%	9.1%	21.8%	4
Housing need 2015-30 [million] per year	38.6	7.8	23.3	3.4	2.3	1.8	0.1	5
Cement needs affordable units [Mt] per year	138.2	27.9	83.3	0.8	8.1	6.3	0.4	6
Cement needs high-standard units [Mt] per year	1,051.4	212.3	633.6	92.5	61.7	48.0	3.3	7
Cement production in 2021 [Mt]	4,360.2	226.1	3,541.9	193.4	278.9	107.3	12.6	8
Cement need of modest units [% of production]	3.2%	12.3%	2.4%	0.4%	2.9	5.9%	3.4%	9
Cement need of high-standard units [% of production]	24.1%	93.9%	17.9%	47.9%	22.1%	44.8%	26.0%	10
Total CO_2 emissions [2020] per year	32,320.8	1,274.1	19,584.8	1,438.1	4,768.4	4,837.4	418.0	11
CO_2 emissions for affordable units [Mt] (750kg/ton)	103.7	20.9	62.5	0.6	6.1	4.7	0.3	12
CO_2 emissions for high-standard units [Mt] {750 kg/ton)	788.6	159.2	475.2	69.4	46.3	36.0	2.5	13
CO_2 emissions for affordable units in % of total emissions	0.3%	1.6%	0.3%	0.0%	0.1%	0.1%	0.1%	14
CO_2 emissions for high-standard units in % of total emissions	2.4%	12.5%	2.4%	4.8%	1.0%	0.7%	0.6%	15
Remaining carbon budget [Mt]*	400,000.0	80,083.2	232,141.7	32,656.7	34,402.8	18,411.8	2,303.8	16
Emissions for affordable units (Mt in 15 years)	1,554.9	313.9	62.5	0.6	6.1	4.7	0.3	17
Emissions for high-standard units (Mt in 15 years)	11,828.5	2,387.9	475.2	69.4	46.3	36.0	2.5	18
CO_2 emissions modest units in % of remaining budget (15 years)	0.4%	0.4%	0.0%	0.0%	0.0%	0.0%	0.0%	19
CO_2 emissions high-standard in % of remaining budget (15 years)	3.0%	3.0%	0.2%	0.2%	0.1%	0.2%	0.1%	20

**The total remaining carbon budget of 400 billion tons is distributed as per the population of 2030

Table 24. Housing needs, cement demand and emissions in different world regions

Cement needs per housing unit are defined as in the previous **table 23.**

How to read the table 24? Table 24 shows the housing needs and the projected cement demand for the entire world, and for different world regions in the consecutive columns. Closing the global housing gap of 40 million units **(row 5)** per year would require some 138 million tons **(row 6)** of cement if only modest basic units were built. These 138 million tons represent 3.2 % **(row 9)** of the world production of 4.3 billion tons **(row 8)** if only very basic housing units were built, whereas some 1,051 million tons **(row 7)** per year if all houses were built as per European standards, or 24 % (row 10) of world cement production.

If we calculate the CO_2 emissions for this cement demand **(rows 12 and 13)** and compare it with the total CO_2 emissions of the world (row 11), we arrive at a relatively low percentage of only 0.3 % for the modest housing units **(row 14)** and 2.4 % if all units were made at European standards **(row 15)**. Similar numbers result if we compare the emissions from satisfying the housing needs with the Global Remaining Carbon Budget that the IPCC has estimated in 2021 at 400 billion tons if the 1.5^0 Celsius goal is attained **(row 16)**.[128] Building the modest housing units would use some 1.55 billion tons over 15 years **(row 17)** and if the units were built to European Standards 11.8 billion tons **(row 18).**

Percentagewise, the emissions would be in the order of 0.4 % and 3 % of the global remaining budget **(rows 19 and 20).**

As a general conclusion, we could already say: **Fulfilling the target of SDG 11.1 with modest housing units is possible in accordance with the Paris Agreement, even if no low-carbon cement were available.** This statement is, however, misleading because we only talk of very basic needs, and the housing units represent only a fraction of the total need for cement to build the infrastructure and especially the cities with their non-residential space needs. We have discussed this more in detail in **Chapter 2.8.**

Housing needs and cement demand by regions: These values differ significantly if we take a closer look at different world regions as presented in the **columns 2 to 7 in table 24.**

In Africa (column 2), even modest housing units would consume 12.3 % (rows 9) of the present cement production, and 93.9 % (row 10) if they were built to European standards. Nevertheless, the share of emissions from this cement demand compared to total emissions remains relatively modest with 1.6 % or 12.5 % of total emissions in 2019 (rows 14 and 15). That this number is higher than in other regions has also to do with the fact that Africa has very low per capita emissions compared to other countries.

In Asia (column 3), we can already observe a much lower population growth and thus a more modest increase in demand through housing compared with Africa. But still, building 23.3 million housing units per year is challenging and would consume 2.4 % or 18 % of the present cement production (Rows 9 and 10). Again, the share of emissions seems to be modest with 0.3 % or 2.4 % of total emissions (Rows 14 and 15).

In Europe and Northern America, we can observe – in line with the low population growth – a relatively modest cement demand for basic housing units and emissions. However, the emissions from housing are relatively high as a proportion of the remaining global carbon budget. This is because Europe and Northern America have a low share of the global population and thus also a low remaining carbon budget.

ANNEX 2.3 HOUSING NEEDS AND CEMENT DEMAND IN DIFFERENT COUNTRIES

The picture looks quite different if we look at selected countries, especially in Africa. There is an enormous need to catch up in selected poor countries. In Burundi or Ethiopia, 26,200 or 461,000 (row 7) units need to be built with cement requirements of 42.4 % or respectively 7.3 % of the present cement production, and an amazing number of almost 360 % or 132 % if the units were built to European standards. See **table 25 (rows 13 and 14)**

HOUSING AND CEMENT NEED TO FULFILL SDG 11.1 AFRICAN COUNTRIES	BURUNDI	EHIOPIA	KENYA	TANZANIA	BURKINA FASO	GHANA	NIGERIA	SENEGAL	ROW NUMBER
Population 2015 [million]	10.7	102.5	46.9	52.5	18.7	28.9	184.0	14.4	1
Population 2030 [million]	15.8	149.3	63.1	81.9	27.5	38.8	262.6	21.1	2
Population Growth 2015-30 [million]	5.1	46.8	16.3	29.3	8.8	9.9	78.6	6.8	3
Population Growth 2015-30 [%]	47%	46%	35%	56%	47%	34%	43%	47%	4
Total Housing needs in 000 units per year	26.2	461.0	260.7	336.5	78.1	193.2	1,404.5	53.6	7
Cement needed for affordable units (3'576 kg) (ktons/year)	76.3	691.8	298.9	304.0	51.2	171.4	1,881.8	63.1	10
Cement needed for high-standard units (27'204 kg) (ktons/year)	712.7	12,541.0	7,092.9	9,153.9	2,126.0	5,255.3	38,208.1	1,458.7	11
Cement production in 2021 in kt	180.0	9,500.0	9,248.0	6,500.0	3,040.0	5,600.0	29,000.0	7,473.0	12
Cement needs for housing (affordable units) in % of production	42.4%	7.3%	3.2%	4.7%	1.7%	3.1%	6.5%	0.8%	13
Cement needs for high standards units in % of production	395.9%	132.0%	76.7%	140.8%	69.9%	93.8%	131.8%	19.5%	14
Total CO_2 emissions in 2020 in kt per year	713.5	18,098.0	19,446.8	14,435.5	5,456.7	19,401.2	111,978.1	10,680.2	15
CO_2 emissions from cement for affordable units in kt per year	57.3	518.9	224.2	228.0	38.4	128.6	1,411.4	47.3	16
CO_2 emissions for high-standard units in kt per year	534.5	9,405.8	5,319.6	6,865.4	1,594.5	3,941.4	28,656.1	1,094.0	17
CO_2 emissions from cement for affordable units in % of total emissions	8.0%	2.9%	1.2%	1.6%	0.7%	0.7%	1.3%	0.4%	18
CO_2 emissions for high-standard units in % of total emissions	74.9%	52.0%	27.4%	47.6%	29.2%	20.3%	25.6%	10.2%	19

Table 25. Housing needs and cement demand in selected African Countries

A slightly less dramatic picture can be seen for selected Asian countries, but the challenge is also quite big: delivering every year 6 million housing units in India, 764,000 in Pakistan, almost a million in Bangladesh and 1.8 million in Indonesia is not a simple task.

However, the stress on cement production is more moderate due to the existing high capacity of cement production in Asia, as compared to Africa. See **table 26.**

HOUSING AND CEMENT NEED TO FULFILL SDG 11.1 ASIAN COUNTRIES	INDIA	PAKISTAN	BANGLADESH	THAILAND	INDONESIA	VIETNAM	PHILLIPINES	CHINA	ROW NUMBER
Population 2015 [million]	1,322.9	211.0	157.8	70.3	259.1	92.2	103.0	1,393.7	1
Population 2030 [million]	1,515.0	274.0	184.4	72.1	292.2	102.7	129.5	1,415.6	2
Population Growth 2015-30 [million]	192.1	63.1	26.6	1.8	33.1	10.5	26.4	21.9	3
Population Growth 2015-30 [%]	15%	30%	17%	3%	13%	11%	26%	2%	4
Total Housing needs in 000 units per year	6,027.6	764.0	991.2	207.7	1,383.8	337.0	602.4	8,140.5	7
Cement needed for affordable units (3'576 kg) (ktons/year)	8,328.3	1,382.3	1,435.6	33.3	636.5	40.7	490.8	2,573.8	10
Cement needed for high-standard units (27'204 kg) (ktons/year)	163,975.1	20,783.4	26,965.2	5,650.1	37,644.4	9,167.9	16,387.9	221,454.3	11
Cement productionin in 2021 in kt	350,000.0	49,600.0	34,200.0	39,200.0	65,000.0	114,686.0	27,000.0	2,360,000.0	12
Cement needs for housing (affordable units) in % of production	2.4%	2.8%	4.2%	0.1%	1.0%	0.0%	1.8%	0.1%	13
Cement needs for high standards units in % of production	46.9%	41.9%	78.8%	14.4%	57.9%	8.0%	60.7%	9.4%	14
Total CO_2 emissions in 2020 in kt per year	2,200,836.3	184,111.2	85,493.1	265,478.9	563,197.0	355,323.1	133,471.3	10,944,686.2	15
CO_2 emissions from cement for affordable units in kt per year	6,246.3	1,036.7	1,076.7	25.0	477.4	30.5	368.1	1,930.4	16
CO_2 emissions for high-standard units in kt per year	122,981.3	15,587.5	20,223.9	4,237.6	28,233.3	6,876.0	12,291.0	166,090.8	17
CO_2 emissions from cement for affordable units in % of total emissions	0.3%	0.6%	1.3%	0.0%	0.1%	0.0%	0.3%	0.0%	18
CO_2 emissions for high-standard units in % of total emissions	5.6%	8.5%	23.7%	1.6%	5.0%	1.9%	9.2%	1.5%	19

Table 26. Housing needs and cement demand in selected Asian Countries

ANNEX 2.4 HOUSING NEEDS AND CEMENT CONSUMPTION IN AFRICAN AND ASIAN REGIONS

This table is an excerpt from the global table that can be accessed on the LC³ website.

a) African Regions

HOUSING AND CEMENT NEED TO FULFILL SDG 11.1 AFRICAN COUNTRIES	AFRICA	EASTERN AFRICA	MIDDLE AFRICA	NORTHERN AFRICA	SOUTHERN AFRICA	WESTERN AFRICA	ROW#
COLUMN	1	2	3	4	5	6	7
Population 2015 [million]	1,201.1	393.3	157.4	228.4	63.7	358.3	1
Population 2030 [million]	1,710.7	574.4	248.3	293.3	74.3	520.3	2
Population Growth 2015-30 [million]	509.6	181.1	90.9	65.0	10.6	162.0	3
Population Growth 2015-30 [%]	42.4%	46.0%	57.7%	28.4%	16.7%	45.2%	4
Total Housing needs in 000 units per year (15 years)	7.8	2.2	1.9	0.9	0.4	2.4	5
Yearly Cement needed for affordable units (3'576 kg) in MT	27.9	7.7	6.7	3.4	1.5	8.6	6
Yearly Cement needed for high-standard units (27'204 kg) in MT	212.3	58.8	50.7	25.8	11.5	65.5	7
Cement production in 2021 in MT	226	39	11	103	13	60	8
Cement needs for affordable units in % of production	12.3%	19.8%	60.7%	3.3%	11.2%	14.4%	9
Cement needs for high standards units in % of production	93.9%	150.7%	461.8%	25.1%	85.1%	109.6%	10
Total CO_2 emissions in 2020 in kt per year	1,274.1	95.2	51.6	533.6	406.4	187.3	11
CO_2 emissions from cement for affordable units in kt per year	20.9	5.8	5.0	2.5	1.1	6.5	12
CO_2 emissions for high-standard units in kt	159.2	44.1	38.0	19.4	8.6	49.1	13
CO_2 emissions from cement for housing (slum and affordable units)	1.6%	6.1%	9.7%	0.5%	0.3%	3.4%	14
CO_2 emissions from housing, (high standards) in % of total emissions	12.5%	46.3%	73.8%	3.6%	2.1%	26.2%	15
Global CO_2 remaining budget per year (27 years)	87,287	29,309	12,668	14,967	3,794	26,550	16
Emissions for affordable units (2015-30)	418.52	115.86	99.99	50.90	22.60	129.16	17
Emissions for high standard units (2015-30)	3,183.83	881.42	760.65	387.24	171.95	982.56	18
Emissions affordable units as share of remaining budget	0.5%	0.4%	0.8%	0.3%	0.6%	0.5%	19
Emmisions high standard units as share of remaining budget	3.6%	3.0%	6.0%	2.6%	4.5%	3.7%	20

*The total remaining carbon budget of 400 billion tons is distributed as per the population of 2030

Table 27. Housing needs and cement demand in African regions

b) Asian Regions

HOUSING AND CEMENT NEED TO FULFILL SDG 11.1 ASIAN COUNTRIES	ASIA	CENTRAL ASIA	EASTERN ASIA	SOUTHERN ASIA	SOUTHERN EASTERN ASIA	WESTERN ASIA	ROW#
COLUMN	1	2	3	4	5	6	7
Population 2015 [million]	4,459.4	69.0	1,631.7	1,857.3	636.6	264.8	1
Population 2030 [million]	4,958.8	85.3	1,648.0	2,173.4	724.7	327.5	2
Population Growth 2015-30 [million]	499.4	16.3	16.3	316.0	88.0	62.7	3
Population Growth 2015-30 [%]	11.2%	23.7%	1.0%	17.0%	13.8%	23.7%	4
Total Housing needs in 000 units per year (15 years)	23.3	0.2	9.9	8.6	3.1	1.4	5
Yearly Cement needed for affordable units (3'576 kg) in MT	83.3	0.7	35.3	30.9	11.2	5.2	6
Yearly Cement needed for high-standard units (27'204 kg) in MT	633.3	5.1	268.6	235.2	85.3	39.3	7
Cement production in 2021 in MT	3,542	36	2,481	510	297	219	8
Cement needs for affordable units in % of production	2.4%	1.9%	1.4%	6.1%	3.8%	2.4%	9
Cement needs for high standards units in % of production	17.9%	14.3%	10.8%	46.1%	28.7%	18.0%	10
Total CO_2 emissions in 2020 in kt per year	1,274.1	95.2	51.6	533.6	406.4	187.3	11
CO_2 emissions from cement for affordable units in kt per year	62.5	0.5	25.6	23.2	8.4	3.9	12
CO_2 emissions for high-standard units in kt	475.2	3.8	201.5	176.4	64.4	29.5	13
CO_2 emissions from cement for housing (slum and affordable units)	4.9%	0.5%	51.4%	4.3%	2.1%	2.1%	14
CO_2 emissions from housing, (high standards) in % of total emissions	37.3%	4.0%	390.7%	33.1%	15.7%	15.7%	15
Global CO_2 remaining budget per year (27 years)	253,023	4,354	84,089	110,896	36,976	16,709	16
Emissions for affordable units (2015-30)	936.95	10.11	529.67	463.76	168.23	77.50	17
Emissions for high standard units (2015-30)	9,503.67	76.90	4,029.42	3,527.99	1,279.82	589.53	18
Emissions affordable units as share of remaining budget	0.4%	0.2%	0.6%	0.4%	0.5%	0.5%	19
Emmisions high standard units as share of remaining budget	3.8%	1.8%	4.8%	3.2%	3.5%	3.5%	20

*The total remaining carbon budget of 400 billion tons is distributed as per the population of 2030

Table 28. Housing needs and cement demand in selected Asian regions

c) Global North as a comparison

HOUSING AND CEMENT NEED TO FULFILL SDG 11.1 ASIAN COUNTRIES	EASTERN EUROPE	NORTHERN EUROPE	SOUTHERN EUROPE	WESTERN EUROPE	NORTHERN AMERICA	AUSTRALIA NEW ZEALAND	OCEANIA	ROW#
COLUMN	1	2	3	4	5	6	7	8
Population 2015 [million]	294.4	102.8	151.4	191.7	360.5	28.4	40.4	1
Population 2030 [million]	282.0	108.9	146.8	197.1	393.3	33.7	49.2	2
Population Growth 2015-30 [million]	- 12.3	6.1	- 4.6	5.4	32.8	5.3	8.8	3
Population Growth 2015-30 [%]	- 4.2%	6.0%	- 3.0%	2.8%	9.1%	18.6%	21.8%	4
Total Housing needs in 000 units per year (15 years)	0.8	0.5	0.4	0.6	1.8	0.1	0.1	5
Yearly Cement needed for affordable units (3'576 kg) in MT	2.8	1.9	1.4	2.1	6.3	0.4	0.4	6
Yearly Cement needed for high-standard units (27'204 kg) in MT	21.2	14.2	10.6	15.8	48.0	2.9	3.3	7
Cement production in 2021 in MT	121.1	23.8	62.5	71.5	107.3	12.3	12.6	8
Cement needs for affordable units in % of production	2.3%	7.8%	2.2%	2.9%	5.9%	3.1%	3.4%	9
Cement needs for high standards units in % of production	17.5%	59.4%	16.9%	22.0%	44.8%	23.4%	26.0%	10
Total CO_2 emissions in 2020 in kt per year	2,392.0	503.0	685.1	1,188.2	4,837.4	410.4	418.0	11
CO_2 emissions from cement for affordable units in kt per year	2.1	1.4	1.0	1.6	4.7	0.3	0.3	12
CO_2 emissions for high-standard units in kt	15.9	10.6	7.9	11.8	36.0	2.2	2.5	13
CO_2 emissions from cement for housing (slum and affordable units)	0.1%	0.3%	0.2%	0.1%	0.1%	0.1%	0.1%	14
CO_2 emissions from housing, (high standards) in % of total emissions	0.7%	2.1%	1.2%	1.0%	0.7%	0.5%	0.6%	15
Global CO_2 remaining budget per year (27 years)	14,390.2	5,559.1	7,491.4	10,056.8	20,068.0	1,719.4	2,511.0	16
Emissions for affordable units (2015-30)	41.88	27.93	20.83	31.10	94.74	5.68	4.85	17
Emissions for high standard units (2015-30)	318.60	212.46	158.44	236.56	720.72	43.17	49.22	18
Emissions affordable units as share of remaining budget	0.3%	0.5%	0.3%	0.3%	0.5%	0.3%	0.2%	19
Emmisions high standard units as share of remaining budget	2.2%	3.8%	2.1%	2.4%	3.6%	2.5%	2.0%	20
*The total remaining carbon budget of 400 billion tons is distributed as per the population of 2030								

Table 29. Housing needs and cement demand in the Global North as a comparison

ANNEX 3 THE THREE KEY FACTORS BEHIND CEMENT GROWTH: POPULATION, AFFLUENCE, AND URBANIZATION

KEY FACTOR 1 HOW AND WHEN DO POPULATIONS GROW?

With a better life, mothers have first more (surviving) and then fewer children. Pre-industrial societies are characterized by high fertility but also high mortality rates. Mothers have many children, but many are dying, and the population stagnates. This situation changes when mortality rates, especially for child mortality, decrease.[129] The result is a growing - sometimes exploding - population due to a combination of better hygiene, education, and economic perspectives. This growth will slow down over time when more educated parents plan for smaller families based on the higher assurance that their children will survive.

This trend for families to have fewer children is prevalent now in most regions of the world, except in Africa. The process of a steep growth curve followed by a gradual flattening is a rather slow process - often occurring over 50 years and more - but it leads to enormous changes in the overall composition and structure (age pyramid) of the world's population. While fast-growing populations are rejuvenating, slow-growing or even declining populations are ageing.

This age structure has also consequences on the housing and labour market.

Population trends over time: strong growth is mostly happening in the Global South. It is expected that in 2050 some 5,293 million (55 %) out of 9,709 million people will live in Asia and 2,485 million (25 %) in Africa, as per the World Population Prospects of UN - DESA and its middle-growth scenario.[130] The table below shows these dramatic changes. The share of Europe and Northern America in the Global population was 27 % in 1960 (20 % and 7 %) and is declining to 11 % (7 % and 4 %) in 2050. The Asian population remains rather stable at 55 %. The most remarkable changes are happening in Africa, its share multiplies from 9 % in 1960 to 26 % in 2050 and to 38 % in 2100. This means that by 2050, every second citizen of this world will be Asian, every 4th citizen will be African; nine out of ten people will live in the Global South (Table 30). From 2050 to 2100 most populations will be declining, except in Africa, where a further growth from 2,485 billion to 3,924 billion may occur.

WORLD POPULATION BY REGION [MILLION CAPITA]	1950	1970	1990	2010	2030	2050	2100
World	3,035	4,458	6,143	7,795	8,546	9,709	10,349
Africa	283	476	811	1,341	1,711	2,485	3,924
Asia	1,705	2,650	3,741	4,641	4,959	5,293	4,674
Europe	605	694	726	748	737	703	587
Latin America and Carribean	220	361	522	654	698	749	647
Northern America	205	254	312	369	393	421	448
Oceania	16	23	31	43	49	58	69
WORLD POPULATION BY REGION [%]	**1950**	**1970**	**1990**	**2010**	**2030**	**2050**	**2100**
World	100%	100%	100%	100%	100%	100%	100%
Africa	9%	11%	13%	17%	20%	26%	38%
Asia	56%	59%	61%	60%	58%	55%	45%
Europe	20%	16%	12%	10%	9%	7%	6%
Latin America and Carribean	7%	8%	8%	8%	8%	8%	6%
Northern America	7%	6%	5%	5%	5%	4%	4%
Oceania	1%	1%	1%	1%	1%	1%	1%

Table 30. Population by world region (1960 – 2100)

Source: UN – DESA, 2022

KEY FACTOR 2 AFFLUENCE AND HIGHER GDP STIMULATE CEMENT CONSUMPTION

Cement has grown faster than the world GDP. While the world GDP was in 1960 USD 11 trillion (in 2015 Dollars), it has risen to USD 81 trillion in 2019, an increase of +688 %. Cement production – as we saw before – has grown twice as much. A higher GDP is also stimulating cement demand, as economic activities lead to more space, building and infrastructure requirements (Table 31).

We can also see from table 31 that the GDP per capita has risen by 268 % meaning that the overall affluence of the world population has almost tripled between 1960 and 2019. This does not mean that poverty has disappeared, but it indicates – overall – a reduction, especially in certain regions, with China being the most striking and most important example.

YEAR	WORLD CEMENT PRODUCTION [Mt]	WORLD GDP IN CONSTANT PRICES [TRILLION 2015 US$]	WORLD GDP / CAPITA [2015 US$]	GROWTH OF CEMENT PRODUCTION [%]	GDP GROWTH [%]	GROWTH OF GDP/CAPITA GROWTH [%]
1960	317	11,886	$ 3,916	100%	100%	100%
1970	606	18,882	$ 5,103	191%	159%	130%
1980	887	26,734	$ 5,997	280%	225%	153%
1990	1,148	36,369	$ 6,827	362%	306%	174%
2000	1,650	49,114	$ 7,995	521%	413%	204%
2010	3,280	66,869	$ 9,612	1035%	563%	245%
2020	4,210	81,830	$ 10,498	1328%	688%	268%

Table 31. World cement production and GDP (1960 – 2019)[131]

Source: Own calculations from US Geological Survey data on cement and from IMF for GDP

KEY FACTOR 3 URBANIZATION - AFRICAN CITIES GROW 10-TIMES FASTER THAN IN EUROPE

The third key factor for growth of cement demand is fast urbanization: overall, the cities in the Global North are already built, but there is a high pent-up demand in the Global South. Urbanization rates are especially high in areas that are still dominated by rural societies with high population growth. As the primary economic sectors (agriculture, fishery, forestry) cannot absorb the growing number of people and provide them jobs, people migrate to the cities in large waves.

We already mentioned the strong urbanization of the world population since 1950: while only 30 % of the total population lived then in urban areas, this share has gone up to 57 % in 2021 and will raise to 68 % in 2050 (Table 32).[132]

URBANIZATION	POPULATION 1950*		POPULATION 2021		POPULATION 2050		URBAN POPULATION [%]			GROWTH RATE
REGION	URBAN	RURAL	URBAN	RURAL	URBAN	RURAL	1950	2021	2050	IN %
Asia	246	1,158	2,408	2,253	3,479	1,778	18%	52%	66%	1.98
Africa	33	196	609	777	1,489	1,039	14%	44%	59%	3.56
Europe	284	265	558	185	599	117	52%	75%	84%	0.32
Latin America	70	99	546	125	685	95	41%	81%	88%	1.22
Northern America	110	62	308	64	387	48	64%	83%	89%	0.96
Oceania	8	4	29	14	41	16	63%	68%	72%	1.35
Total	**751**	**1,785**	**4,458**	**3,417**	**6,680**	**3,092**	30%	57%	68%	

*[Million Capita]

Table 32. Urbanization in different world regions (1950 – 2050)

Source: World urbanization prospects, 2019
UN - DESA (2019)

Very insightful are different regional trends: while the Global North was already highly urbanized in 1950, only 18 % of all Asians and 14 % of all Africans lived in cities. This picture will drastically change in 2050 when 66 % of Asians and 59 % of Africans will live in cities. The growth rate in Europe was 0.32 % from 2021 to 2050, **ten times less than in Africa at 3.56 %** and six times less than in Asia at 1.98 %. This means that African cities will grow ten times faster than the European ones.

Even more impressive and harder to grasp are the absolute numbers in **table 34**: while the urban population will grow by 40 million in Europe, Asian cities will grow by more than one billion, African cities will have 880 million more urban residents in the next 30 years.

REGION	ADDITIONAL URBAN POPULATION BETWEEN 2021 AND 2050
Asia	+1,070,740,174
Africa	+880,265,644
Europe	+40,403,169
Latin America	+139,086,700
Northern America	+78,992,603
Oceania	+11,850,719
Total	+2,221,339,009

Table 33. Additional urban population in absolute numbers (2021 - 2050)

Source: Own calculations based on US Geological survey data for the numbers of past production (1960 to 2020); for the projections, IEA & WBCSD Web (2009) World Urbanization Prospects (2009)

ANNEX 4 BIBLIOGRAPHY – REFERENCES

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WEBSITES AND ONLINE SOURCES

construction-gdp link	https://w3.unece.org/PXWeb/en/Table?IndicatorCode=8
bgs-link	https://www2.bgs.ac.uk/mineralsuk/statistics/worldArchive.html
cembureau-link	https://cembureau.eu/about-our-industry/key-facts-figures/#:~:text=Capital%20intensity%3A%20The %20cost%20of,the%20most%20capital%20intensive%20industries.
cia-link	https://www.cia.gov/the-world-factbook/field/budget/
clf-link	https://carbonleadershipforum.org
clf-ec-link	https://carbonleadershipforum.org/embodied-carbon-101/
clf-tvc-link	https://carbonleadershipforum.org/download-page/?dlm-dp-dl=35419construction-gdp link
dai-link	https://www.dailymotion.com/video/x7vhhbl
digital-link	https://digital.lib.usf.edu/SFS0052617/00001
dornob-link	https://dornob.com/how-much-is-enough-average-home-sizes-around-the-world
eu-cps-link	https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets_en
findmeafloor-link	https://www.findmeafloor.co.uk/where-in-the-world-do-you-get-the-biggest-home
folha-link	https://www1.folha.uol.com.br/mercado/2021/10/total-de-favelas-dobra-no-brasil-e-20-milhoes-estao-passando-fome.shtml
gdl-link	https://globaldatalab.oCg/aCeadata/hhsize/
gihub-link	https://outlook.gihub.org/
github-link	https://github.com/microsoft/GlobalMLBuildingFootprints
hofinet-link	http://www.hofinet.org
indicator-link	https://indicators.report/targets/11-1/
lc3-link	www.lc3.ch
microsoft-link	https://www.microsoft.com/en-us/maps/building-footprints
oecd-link	http://oe.cd/ahd
oecd-ahd-link	https://www.oecd.org/housing/data/affordable-housing-database
owd-link	https://ourworldindata.org/homelessness
pewresearch-link	https://www.pewresearch.org/fact-tank/2020/03/31/with-bilto-their-homes-worldwide-which-living-arrangements-are-most-common/
population-link	https://population.un.oCg/wpp/Download/StandaCd/Population
swisslife-link	https://www.swisslife.com/en/home/hub/what-is-the-lifespan-of-a-house.html
un-link	https://www.unfpa.org/data/demographic-dividend/EG
un-hh-link	https://www.un.org/development/desa/pd/data/household-size-and-composition
unh-link	https://unhabitat.org/topic/housing
unstats-link	https://unstats.un.org/unsd/methodology/m49
usgs-link	https://www.usgs.gov/centers/national-minerals-information-center/cement-statistics-and-information
vik-link	https://www.visualcapitalist.com/
wits-link	https://wits.worldbank.org/trade/country-byhs6product.aspx?lang=en
yt-hs-link	https://www.youtube.com/watch?v=Nore9EXNmjQ
yt-he-link1	https://www.youtube.com/watch?v=JQQ8Mla0qe4
yt-he-link2	https://www.youtube.com/watch?v=ZJ5l41jwYfY

INTERVIEWS

Donatien Buguy and Dennis Mwaniki, data specialists at UN - Habitat, on October 10, 2021.

ENDNOTES

[1] Payne (2022).
[2] A long value chain includes a high number of inter-related activities that are creating lots of jobs and added value in each step, allowing for a high economic multiplier effect.
[3] This high amount of cement compared to slum units can be explained with the following factors: The slum unit basically uses concrete for columns (thinner than in the formal construction) and mortar for bricks. It does not have a slab, nor a ceiling (which counts a lot) and also walls are not plastered.
[4] Masson-Delmotte V. (2019). This comparison of emissions of an industry with a country are problematic and just to illustrate the size of the problem.
[5] "By 2030, ensure access for all to adequate, safe and affordable housing and basic services, and upgrade slums." https://indicators.report/targets/11-1/
[6] IFC (2023), p. 11.
[7] ETC (2018), p.58.

[8] World Resources Institute (WRI) 2023: "So long as additional wood harvests follow existing patterns of wood use, an increase in the harvesting of secondary forests for construction use is likely to result in a net increase in GHG emissions, even when accounting for the effect of substituting wood for concrete and steel. One reason is that only a small proportion of harvested wood (and therefore the forest carbon lost due to increased wood harvesting) is typically incorporated into a long-lived wood product and stored in buildings. If we assume that 40 percent of wood harvested will be used to replace concrete and steel the results are still averse."
[9] WWF (2022).
[10] UN (1948).
[11] Payne (2022), p.3.
[12] UN-Habitat (2019), p.2.
[13] Malpezzi (2014), p.1.
[14] See also construction-gdp link.
[15] Tibaijuka (2013), p.87f.
[16] Savills (2021).
[17] See Buckley, et.al. (2016).
[18] The Minha Casa, Minha Vida (MCMV) is a national housing program that was launched by the Brazilian government in 2009. The program aimed at closing the housing backlog in the country (by that time 7 million) by using a combination of subsidies aimed at both supply and demand. The program underwent several phases, the first one ran from 2009 to 2011 with a total budget of 34 billion Reais (USD 19.3 billion) representing yearly spending of 1.5 % of the national budget. Segment 1 of the program focused on the poorest households and provided almost fully subsidized housing units (95 % of the final costs). The standards of these housing units (either apartment or house) were set with 35-42 sqm at a cost of a maximum of USD 21,600 to 29,000 In the first two years, over half a million of these housing units were constructed with an equivalent of 22 million sqm of built-up space. While over the years, alternative materials were approved for MCMV, the vast majority until today is built with concrete and bricks.
[19] UN - DESA (2018).
[20] Target 11.1 "by 2030, ensure access for all to adequate, safe and affordable housing and basic services, and upgrade slums" (indicator-link).
[21] UN - Habitat (2023). The Synthesis report prepared for the High-Level Political Forum in New York, July 2023 came to the – not very surprising – conclusion that except for some regions of the Global North, most countries are far or even very far from achieving the target of SDG 11. The situation is especially bad in Asia and Sub-Saharan Africa.
[22] Most of the literature provides infrastructure spending as part of the national GDP. Oxford Economics calculates actual and required investments to meet the SDGs. Actual investments grow from 2.3 trillion to 3.8 trillion USD per year, while the average gap is 600 billion USD, see Oxford Economics (2017), Saladin (2022), and gihub-link.
[23] UN - Habitat (2018), p.4.
[24] See pewresearch-link.
[25] Woetzel et.al. (2014).
[26] See the overview on unh-link.
[27] UN - Habitat (2008).
[28] See cia-link.
[29] UN - Habitat (2023).
[30] UN - Habitat (2023).
[31] We reproduced the world region division as per the original source (UN - Habitat 2023).
[32] The Housing Data Tables (HDT) can be downloaded from the LC^3 website, www.lc3.ch .
[33] The data table is not yet a user-friendly tool, but we wanted to make it accessible already in a crude form.
[34] See unstats-link.
[35] Earth observation is pushing the limits of data restrictions, and already releases automatically extracted building footprints, (github-link).
[36] Several families might live in one housing unit. This is often the case for newly formed households (children getting married) but might also be stemming from a more permanent living arrangement due to socio-economic constraints.
[37] The data on the urban population per country is made available by UN - DESA and can be translated into households by considering the average household sizes. National averages were used as there is no comprehensive overview of the difference between rural and urban household sizes (un-link).
[38] Housing is an important asset, and the entire real estate sector has experienced a financialization trend. Consequently, families might own more than one housing unit - however the ownership of units does not contribute per se to the housing shortage (as owned units might be rented out). A contributing factor to housing need is vacancy rates. Private strategies of wealth formation have been increasingly superposed by financial actors that buy houses all over the world to maximize returns on investment. These housing units and sometimes entire buildings can remain unoccupied. While the share of non-utilized housing units per total stock is strongly growing in many places, we lack aggregated data on this. The OECD Database on affordable housing confirms that countries are reporting the vacancy rate of the total housing stock. Malta, Japan, Cyprus and Hungary gave rates over 12 %, while the lowest rates can be found in the UK, Iceland and Switzerland (under 2 %, see oecd-link). Anecdotal evidence also suggests that these units situate mostly at the top end of local housing markets, where supply has a strong tendency to outstrip demand.
[39] A third component not considered in our calculations is the homeless population, while representing an important target for housing-related interventions, their numbers in relation to total households are low. There are different ways to measure homelessness and cross-country data is not available. The countries with better data on the issue suggest values in the range of 0.1-0.5 % of the total population (owd-homeless-link).

[40] The Datalab data is based on survey results but as the country values are considerably higher than the UN - DESA data, we use latter for the household sizes and the globaldatalab to calculate growth rates over time (gdl-link).
[41] UN - DESA means United Nations Department of Economic and Social Affairs.
[42] See population-link and un-hh-link.
[43] See swisslife-link.
[44] Based on expert interviews of international housing consultants.
[45] Boanada-Fuchs (2021).
[46] Inadequate housing is conceptually larger than slums (including location, cultural adequacy and housing costs) but data is not collected in a comprehensive manner. We will focus on slums, also because our study focused on the physical dimension of inadequacy. We are aware that the term "slum" may depreciate the daily situation of poor people.
[47] The official numbers of slums are collected and published by UN - Habitat. Slum numbers are not available for all countries. The UN - Stats website provides the share of the population living in slums for the years 2000, 2014, 2016, and 2018. The number of reporting countries increased from 52, 97, 199, to 125 respectively. We computed the year 2015 by interpolating the values for countries that provided slum shares for 2014 and 2016 (90 in total). Based on the available numbers we computed averages for regions and then applied them to the countries of the respective region with no value. The slum share is multiplied by the respective urban population and divided by the average household size.
[48] The UN - Habitat definition is based on five dimensions, but data on tenure security is currently not collected.
[49] For our calculation, only two dimensions are of relevance as the lack of improved water, and sanitation is related to the provision of infrastructure on the neighbourhood level and not related to the unit per se. A housing unit is considered a slum if it is made of non-durable materials and/or if the living area is insufficient, as to say more than 3 people are occupying the same room. The data on the level of each dimension of housing deprivation is not readily available UN - Habitat (2019). The only source to differentiate between different levels of housing deprivations is from a UN workshop presentation indicating global estimates: 65 % of all units are made of non-durable material and 60 % lack sufficient living space, see Mboup, G. (2004). As there is no way to assess the overlap between both, we use the larger share as a proxy for all slum units that need replacement.
[49] See folha-link.
[50] This number is the sum of the three housing needs and has been calculated by considering negative values in each deprivation. Excluding compatibility of housing needs, the number would grow to 608.6 million units.
[51] The total of 610 million units is slightly overrated due to double counting in the category Global North. The Global North includes countries with different characteristics in North America, Europe, Asia, and Australia. Consequently, some countries (e.g. Australia, Japan, South Korea) are included in this category as well as in their respective world region.
[52] See oecd-ahd-link.
[53] In Europe, the countries with the highest construction index are Poland (5.8), France (5.7), Belgium (5.5), and Norway (5.4), see Deloitte (2021).
[54] This high amount of cement for European standard units compared to slum units can be explained with the following factors: The slum unit basically uses concrete for columns (thinner than in the formal construction) and mortar for bricks. It does not have a slab, nor a ceiling (which counts a lot) and also walls are not plastered.
[55] As mentioned before, the total number of 38.6 million units per year is slightly lower than 40 million and is derived from a total of 579 million during the entire period of 15 years (the SDG period); the difference is explained in footnote 51
[56] IPCC (2021), chapter 2, p. 95ff.
[57] On a global level, it is estimated that floor space grew more than twice as fast than population between 2010-2019 (IEA 2019, p.16).
[58] IW (2021), p. 1.
[59] Different sources, mostly a TV talk show with the Minister for housing, Klara Geywitz on 20th December 2023, Markus Lanz, ZDF, 20th December 23. We are aware that many African countries are also hosting many refugees.
[60] Melchiorri M. (2018), p. 7.
[61] A note on the methodology of cement production and consumption:
Cement Production: In order to obtain the cement production numbers of the top producer countries, we consulted the International Minerals Statistics and Information website of the US government. These are online versions of the Mineral Yearbook (Volume III. -- Area Reports: International) and "annual reviews are designed to provide timely statistical data on mineral commodities in various countries." Excel data sheets are available for several countries for 2003 onwards. Additionally, we screened the historic yearbooks of the US Bureau of Mines Minerals Yearbook, which are available until the years 1993 and going back to 1932 (USA) and 1963 (Other countries). We downloaded and extracted the information on cement production by consulting reports in 5 (or 3) years period, depending on the time spam that was reproduced in the reports. We first extracted every country that has been among the top cement producers in the world and then extracted the production numbers for every year between 1960 and 2018 (last available year).
International Minerals Statistics and Information
https://www.usgs.gov/centers/national-minerals-information-center/international-minerals-statistics-and-information
Bureau Mines and Minerals Yearbook
https://www.usgs.gov/centers/national-minerals-information-center/bureau-mines-minerals-yearbook-1932-1993
Cement Consumption: Cement production is just a crude indicator of cement consumption but is often used, as consumption numbers are not readily available and, in most cases, can only be revealed by considering production, exports, and imports of cement. International trade numbers are collected by the World Integrated Trade Solution (WITS) is a joint initiative of the World Bank and the United Nations Conference on Trade and Development (UNCTAD) and in consultation of the International Trade Center (ITC), United Nations Statistical Division (UNSD), and the World Trade Organization (WTO). For cement there are different goods: cement clinkers, Portland cement, white/non-white, aluminous cement, hydraulic cement. This data is available from 1988 obtainable for export and import. Yearly date for import and export of cement clinker was downloaded to calculate the revealed consumption for all available countries.
World Integrated Trade Solution
https://wits.worldbank.org/trade/country-byhs6product.aspx?lang=en

[62] "During the last decades, the increasing investment on buildings, roads, rails, water and gas pipelines has resulted in a soar of infrastructure level accompanied by the rapidly expanding cities and growing economy. Nearly half of the new buildings in the world were built in China annually for the last decade The total lengths of roads and railways have been tripled and doubled between 1990 and 2013, reaching 0.3 and 0.1 million kilometers in 2013 respectively (NBS, 2014). However, the infrastructure development was highly resource intensive. ….The embedded CO emission in China's infrastructures in 2008 was 26.6 billion tons, which was much higher than that of USA (18.1 billion tons) and other developed countries." (Cheng et. al 2017, p. 47).
[63] The hydro-electric plans are very ambitious as the following videos show (yt-he-link1 and yt-he-link2).
[64] A good description of planned high-speed train network can be seen in the following video (yt-hs-link).
[65] Own calculations from different sources, cement data from US geological survey (usgs-link) and British. geological survey (bgs-link). World population data from from owd-pop-link.
[66] The source for all tables on cement production is based on own calculations from annual statistics of US Geological Survey
[67] These three factors are also based on the study by UNEP (2018, p. 56ff).
[68] The source for all tables on cement production is based on own calculations from annual statistics of US Geological Survey
[69] Source: Own calculations based on US geological survey data and the very useful info-graphic to be seen at https://www.dailymotion.com/video/x7vhhbl
[70] This has also contributed to overheating of the construction sector that ultimately caused major collapses in the real estate sector. The Financial Times has covered the insightful story of Evergrande in a documentary, https://www.ft.com/video/2fce1e2e-52a1-4882-868e-c18802793e8a
[71] The source for all tables on cement production is based on own calculations from annual statistics of US Geological Survey
[72] Same as above.
[73] Source IEA (2009b). Unfortunately, a later release of projections by IEA could not be validated and we had to revert to this source.
[74] Source IEA (2009b).
[75] The reasons for the millions of unused houses are complex, but one of the reasons is the financialization of the housing markets and the speculative character of investments in housing. On the financialization, see Aalbers, M. (2016).
[76] IPCC (2021), chapter 2, p. 95.
[77] To distribute the remaining carbon budget as per population strength would of 2030 would mean that each world citizen has the same "right" to emit until 2050.
[78] GCCA (2021), p. 6.
[79] European Environment Agency (EEA): «More from less – Material resource efficiency in Europe" Luxembourg 2016, page
[80] Source for these figures and tables: vik-link based on data from different UN sources.
[81] Same source.
[82] UNEP (2018), p. 59.
[83] UNEP (2022), p. xxiic.
[84] Data sources: Embodied Carbon Benchmark Study and Commercial Buildings Energy Consumption Survey, assuming a medium-sized commercial office building. Assumes gradual grid decarbonization to zero by 2050. see clf-ec-link.
[85] Whereas the debate about green building was focused on operational emissions, the importance to address embodied carbon is now getting recognized. See for example clf-link.
[86] See clf-tvc-link.
[87] Scrivener et.al. (2019) p.42.
[88] LC^3 was developed at EPFL Lausanne in co-operation with various research organizations in Cuba and India and supported by SDC, the Swiss Agency for Development and Co-operation (lc3-link).
[89] Figure developed by the LC^3 project, see lc3-link.
[90] Scrivener, et.al. (2019), p.1.
[91] Scrivener et.al. (2019) p.6.
[92] EU ETS is the carbon pricing system of the European Union, for more information see eu-cps-link.
[93] Favier et.al. (2019).
[94] World Bank (2016), p.47.
[95] White (2015), p.124.
[96] Karst regions of the World (digital-link).
[97] Byers et.al. (2017), p. 8.
[98] The limestone deposits seem to be even more concentrated than in this list of countries; for example in Ghana and Burkina Faso, there are no viable deposits exploited.
[99] Choplin (2020), p.1986-87.
[100] Cembureau-link; CAPEX costs for LC^3 are based on estimates by an equipment manufacturer, but They may vary significantly depending on local conditions.
[101] Ito and Wagai (2017).
[102] World Bank (2016), p. 42ff.
[103] Maybe, this focus on lacking competition and monopolies is slightly biased, as it is from a study on competition in African economies. We think that other factors – mainly the lack of limestone, high cost and long transport routes as well as high energy costs – are more important. However, the high prices are a fact.
[104] Schmidt (2023).
[105] Lyal White is director, Centre for Dynamic Markets, Gordon Institute of Business Science and advisor of the World Economic Forum.
[106] White (2015), p.124.
[107] Le Cam (2015).
[108] World Bank (2015), p.12.
[109] Tibaijuka (2009).

[110] Bah (2018).

[111] The map shows how many people can afford a house of USD 20,000 some of the lowest-priced houses on the free market (CAHF 2021, p.8).

[112] Collier et.al. (2014) mentions 5 basic vulnerabilities why this market has been able to unfold in Europe but not in Africa: 1) formal housing was affordable, 2) there was clarity in legal rights, 3) formality and legality unleashed financial innovation, 4) the benefits of housing infrastructure (roads, water and sewerage) were available in advance, and 5) housing combined decent conditions for living with opportunities for income (p.2-3).

[113] https://www.afd.fr/en/sustainable-housing-initiative-shi

[114] Source: Own calculations based on US geological survey data and the very useful info-figure is to be seen at dai-link.

[115] The source for all tables on cement production is based on own calculations from annual statistics of US Geological Survey

[116] Same as above.

[117] Same as above.

[118] The OECD affordable housing database collects data on rooms per household, but these are an imperfect proxy for unit sizes. Our own research has shown that this indicator can differ within a single city housing area by a factor of 250 while the room number is just by a factor of 20, (see Boanada-Fuchs 2015). The Housing Finance Information Network is the most comprehensive source for providing average formal market-supplied housing sizes (hofinet-link). A report focused on the European situation (Dol and Haffner 2010) There were additional online sources consulted (dornob-link, findmeafloor-link) and averages computed in the case of several values per country.

[119] Available data is constantly evolving. Microsoft has released data on building footprints for different world regions. This open data was made available in late 2021 and 2022 and represents an interesting option to finetune the existing framework as housing unit sizes could be estimated from building areas (microsoft-link).

[120] In the perspective of the limited data points, we used the geographic closest region for areas that had not a single value (seven world regions).

[121] While UN - Habitat is working on improving current approaches and developing a more comprehensive framework (Thomson et.al. 2020), at the moment, many pressing issues cannot be answered, such as the fundamental question of how large slum units are. The IIED and SDI carry out settlement surveys, but these remain regionally confined to a few countries.

[122] There are comparable estimates from other sources. The metadata document of SDG Target 11.1 states that 9 sqm is the average slum unit size. This is also in line with our own experience as well as from peers.

[123] It is important to state that these are absolute minimum standards and mostly derive from the need that each person needs to be able to lie down for sleeping.

[124] These are assumptions but given the automatic calculations, standards could be adjusted per country or world region.

[125] For this calculation we only compute concrete use above the ground, as it would be very difficult to set standards for founda tions.

[126] Following material shares have been used: (i) per m^3 concrete, 350 kg cement needed, (ii) per m^3 mortar, 478.8 Kg cement needed, (iii) per m^3 plaster, 1,440 kg cement needed.

[127] As average non-slum housing units range from 31.9 - 164.5 sqm and slum units from 2.7 to 11.5 sqm, the respective cement need per unit is between 4,628 – 23,864 and 203 to 863 kg.

[128] IPCC (2021), chapter 2, p. 95.

[129] Paul Morland (2020) has described this process as if the same film was shown in different theaters at different times around the World.

[130] UN - DESA, World population prospects

[131] Same as above.

[132] Source: UN - DESA (2019) and UN - Habitat (2022).

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