AUGUST 2022

Air Pollution from Global Cement Industry

An International Benchmarking of Criteria Air Pollutants Intensities

Ali Hasanbeigi, Navdeep Bhadbhade, Ahana Ghosh

Global Efficiency Intelligence

Acknowledgments

This report was made possible with the support from the BlueGreen Alliance Foundation and the Sierra Club. The authors would like to thank Justin Stofferahn, Charlie Martin, Ben Beachy, Elgin Avila, Roxanne Johnson, Ariel Pinchot, Suzanne Caflisch, and Charlotte Brody of BlueGreen Alliance Foundation, Isabel Estevez of the Sierra Club, Won Park of Lawrence Berkeley National Laboratory, Taro Sonobe and Bahareh Kamranzad of Kyoto University, Chris Nielsen of Harvard University, Linda Greer and Shanshan Ding of Institute of Public and Environmental Affairs, and Beysin Tekinel of Imnera for their valuable input to this study and/or their insightful comments on the earlier version of this document.

Disclaimer

Recommended citation: Hasanbeigi, A., Bhadbhade, N., Ghosh, A. 2022. Air Pollution from Global Cement Industry - An International Benchmarking of Criteria Air Pollutants Intensities. Global Efficiency Intelligence. Florida, United States.

https://www.globalefficiencyintel.com

Executive Summary

Global cement production is expected to increase in the next few decades. While a slowdown in cement production in China is expected, as countries like India and other developing economies in Asia and Africa build more infrastructure, an increase in cement demand in these countries is anticipated. This expected increase in demand and production could be accompanied by an increase in criteria air pollutant emissions and other hazardous emissions as well as greenhouse gas (GHG) emissions under the current policy and technology regime.

Air pollution contributes to a wide variety of adverse health effects (see section 1.1). According to the U.S. Environmental Protection Agency (EPA) exposure to criteria air pollutants can cause a variety of respiratory health effects, including inflammation of the lining of the lungs, reduced lung function, and respiratory symptoms, increased susceptibility to respiratory infection, premature mortality, aggravation of cardiovascular disease, decreased lung function growth, exacerbation of allergic symptoms, neurodevelopmental effects such as lowered IQ and behavioral problems, reduction in the capacity of the blood to carry oxygen, thereby decreasing the supply of oxygen to tissues and organs such as the heart, and many other negative health effects.

In addition to being one of the most energy-intensive industries, cement manufacturing also involves processing of raw materials that typically contain nitrogen and sulfur and depends heavily on fossil fuels as the primary energy source which leads to cement production being one of the major air polluting industries worldwide. This report focuses on comparing the criteria air pollutants emissions intensities for the cement industry in selected countries.

The aim of the international benchmarking is to offer a means of comparing the performance of a given industry across countries. Benchmarking can also be used to estimate the potential for the abatement of air pollutants through the implementation of pollution control technologies. At the national level, benchmarking of criteria air pollutants emissions intensities can help policymakers prioritize emission abatement of specific criteria air pollutants and design policies for the reduction of their emissions.

In this study, we performed a benchmarking for each of the four major criteria air pollutants for which data were available: Sulfur dioxide (SO_2), Nitrogen oxide (NOx), Particulate matter (PM), and Non-Methane Volatile Organic Compounds (NMVOC), emitted from the production of cement in 14 countries/regions. We have considered both direct and indirect sources of emissions i.e., onsite emissions related to process and fuel combustion in cement plants (direct emissions) and offsite emissions associated with electricity used by cement plants that is caused from electricity generation in the power sector (indirect emissions). Emissions related to the rest of the cement value chain are beyond the scope of this project.

Our results show that amongst the criteria air pollutants analyzed in this study, NOx was the highest emitted criteria air pollutant from the cement industry globally, whereas the NMVOCs are the lowest emitted criteria air pollutants from the cement industry (Figure ES1). Although the shares of direct emissions vary for each criteria air pollutant and country, the majority of emissions of criteria air pollutants can be characterized as direct emissions that happen onsite at cement plants and affect local communities near cement plants. To provide a sense of scale, we have also compared the global cement industry's criteria air pollutants emissions with EU-27's total emissions in 2019 in Figure ES1. The SO_2 emissions from the global cement industry in 2019 were 3% higher than the overall total SO_2 emissions of the EU-27 region. Emissions of NOx from the global cement industry were 36% lower than the EU-27's overall NOx emissions in 2019. The PM emissions of global cement industry were 27% lower than the overall PM emissions from EU-27 region in 2019.

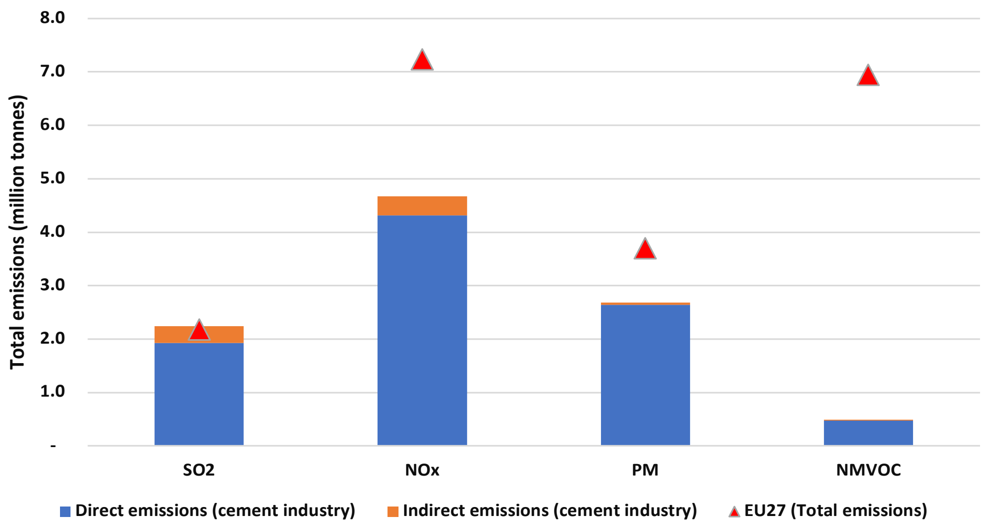

Figure ES1. Global cement industry's criteria air pollutants emissions compared with EU-27's total emissions in 2019 (source: this study, CEIP 2021).

China, Ukraine and Poland have the highest emissions intensities for almost all the criteria air pollutants analyzed in this study. Sweden and Austria have the lowest emissions intensities for most of the criteria air pollutants. This can be primarily explained by the air pollution regulations and adoption of pollution control technologies as well as the fuel mix of the cement industry among other factors. Figure ES2 shows SO_2 emissions intensity of cement industry for countries studied in 2019. Similar figures for NOx, PM, and NMVOC emissions can be found in chapter 5 of the report. Factors influencing criteria air pollutants emissions in the cement industry are discussed in detail in chapter 6 of this report.

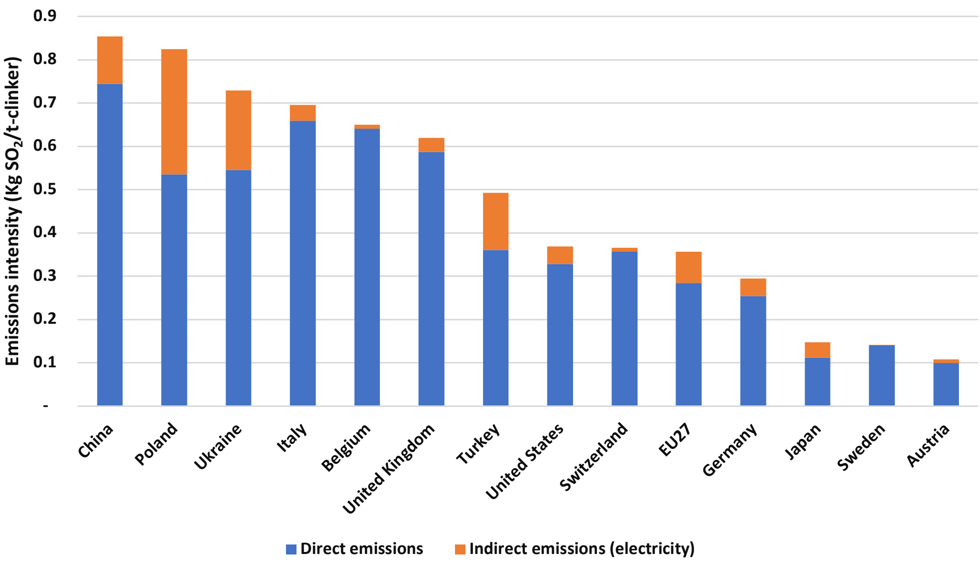

Figure ES2. SO_2 emissions intensity of cement industry for countries studied in 2019.

Industrial manufacturing facilities such as cement plants are often located close to low-income, disadvantaged communities exposing them to significant pollution. For example, in the United States, manufacturing generated 89% of all chemical waste in the country including 285 thousand tons of criteria air pollutants and over 40 thousand tons of hazardous waste from cement production according to Toxics Release Inventory data maintained by the United States Environmental Protection Agency. Lowering or eliminating criteria air pollutants can help mitigate the health risk and improve the quality of life for the communities located close to cement plants.

In view of the projected continuing increase in absolute cement production and the need for reducing criteria air pollutants emissions, future reductions in criteria air pollutant emissions will require a combination of stricter adoption of pollution control technologies in cement plants as well as power sector and efficiency improvements for fuel consumption and switching to lower emissions fuels. Stricter air pollution control regulations and their enforcement for the cement industry are needed in China and other countries with high criteria air pollutants intensities to ensure the reduction of these emissions from the cement produced in these countries. This will result in cleaner and safer air for the people and the environment in these countries.

Table of Contents

Executive Summary 2

1. Introduction 6

1.1. Adverse health effects of criteria air pollutants 8

2. Global cement production and trade 10

3. Sources of criteria air pollutants emissions in the cement industry 12

3.1. SO_2 emissions sources 12

3.2. NOx emissions sources 12

3.3. PM emissions sources 13

3.4. NMVOC emissions sources 13

4. Global Cement Industry's criteria air pollutants emissions 14

5. Benchmarking criteria air pollutants emissions intensities of the cement industry 16

5.1. Benchmarking of SO_2 emissions intensity 16

5.2. Benchmarking of NOx emissions intensity 17

5.3. Benchmarking of PM emissions intensity 18

5.4. Benchmarking of NMVOC emissions intensity 18

6. Key factors influencing criteria air pollution emissions in cement industry 19

7. Conclusions 21

References 22

Appendices 24

Appendix 1. Methodology 24

Appendix 2. Criteria air pollution intensities based on cement production 26

1 Introduction

In addition to being one of the most energy intensive industries, because of the raw material used and process steps like clinker production, cement industry production is also one of the most air polluting manufacturing processes in the world. While CO_2 remains the most heavily emitted pollutant from the cement industry (2.3 billion ton of CO_2 in 2019 (Hasanbeigi 2021)), criteria air pollutants[1] are also emitted at a considerable amount.

While global cement production is expected to grow, a slowdown in cement production in China is expected. As countries like India and other developing economies in Asia and Africa build more infrastructure, an overall increase in cement demand is anticipated in coming decades (IEA, 2020). This expected increase in demand and production could result in an increases in the emissions of criteria air pollutants under the current policy and technology regime.

There are six most common criteria air pollutants emitted from the cement industry; acidic gaseous pollutants namely Sulfur dioxide (SO_2) and Nitrous oxides (NOx), pollutants emitted due to incomplete fuel combustion i.e., Carbon monoxide (CO), ground level ozone[2] precursors such as Non-methane organic volatile compounds (NMVOCs), toxic heavy metals like Lead (Pb) and Particulate matter (PM) (U.S. EPA, 2021). Residual materials from the fuel and raw materials and other hazardous pollutants that are products of incomplete combustion can also be emitted (Abu-Allaban et al., 2011). This study focuses on four of those pollutants (detailed later) because of data availability.

Figure 1 presents a simplified flow diagram for cement production. There are four broad steps involved in cement production (EEA,2019):

1. Extraction and pre-processing of raw material – Raw materials like limestone, chalk, marl and clay are crushed, ground and mixed together to specified fineness and chemical composition.
2. Pyro-processing for clinker production – Clinker is produced in a kiln where the raw materials are treated at a high temperature (up to 1500°C) leading to decomposition of calcium carbonate into calcium oxide and CO_2. Calcium oxide thus formed then reacts with silica, alumina and ferrous oxide to form silicates, aluminates and ferrites of calcium that constitute the clinker. Clinker can be produced via dry process, wet process, semi-dry process or semi-wet process.
3. Blending and grinding to convert clinker to cement – Clinker is then blended with additives to produce the cement.
4. Storage – Cement thus produced is stored into silos and transferred to either tanker or bagging stations.

1 Criteria Air Pollutants means an air pollutant for which acceptable levels of exposure can be determined and for which an ambient air quality standard has been set.

2 Ozone itself is not emitted. According to EPA: "Tropospheric, or ground-level ozone, is not emitted directly into the air, but is created by chemical reactions between oxides of nitrogen (NOx) and volatile organic compounds (VOC)." This happens when pollutants emitted by cars, power plants, industrial boilers, refineries, chemical plants, and other sources chemically react in the presence of sunlight." (U.S. EPA 2022).

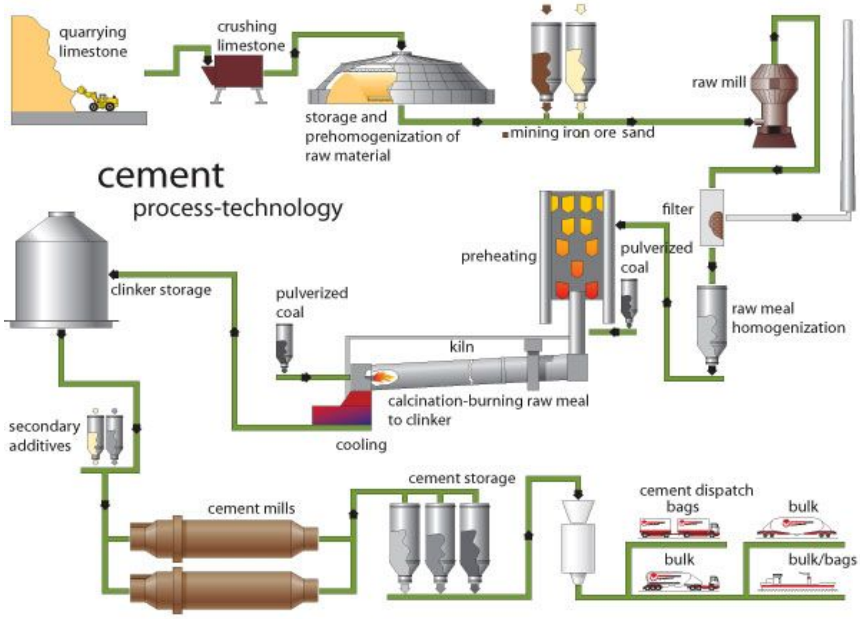

Figure 1. Cement production process (Constructioncost 2022).

Kilns used for the calcination are primarily responsible for criteria air pollutant emissions during cement production (European Commission, 2013; EEA, 2019). While the oxidation of sulfur and nitrogen content of the raw materials in the kilns during the clinker production is the largest source of SO_2 and NO_x emissions, incomplete fuel combustion and the combustion of organic compounds present in the fuels result in CO and NMVOC emissions. In addition to air pollutants, the calcination process also results in substantial amounts of CO_2 emissions (Lei et al., 2011). Processes involved in raw materials processing such as grinding, crushing and conveying are the source of PM emissions along with burning and cooling processes during clinker production.

The emission control mechanisms for the pollutants vary by country and depend on the environmental policies adopted by the countries. Limited information is available about the penetration of pollution control technologies in the cement plants for countries included in the report.

In this study, we have conducted benchmarking for each of the four major criteria air pollutants emitted from cement manufacturing (i.e., SO_2, NO_x, PM and NMVOC) in 14 major cement producing countries/regions. The countries included in the report represent about 64% of global cement production. The study methodology compares emission intensities of all criteria air pollutants (kg/t-clinker) for cement production in each country. We have considered both direct and indirect emissions i.e., onsite emissions related to processes and fuel combustions (direct emissions) and offsite emissions associated with electricity use in cement production (indirect emissions). CO and Pb - two chemicals hazardous to human health and ecosystems – are excluded from this study due to the lack of adequate and reliable data, revealing a need for further research and data collection.

1.1. Adverse health effects of criteria air pollutants

Air pollution contributes to a wide variety of adverse health effects. The U.S. EPA (2015) provides a brief description of health effects that have been associated with each of the criteria pollutants some of which are listed below:

1. **Particulate Matter (PM):** Effects associated with exposures to both $PM_{2.5}$ and $PM_{10-2.5}$ include premature mortality, aggravation of respiratory and cardiovascular disease, and changes in sub-clinical indicators of respiratory and cardiac function. Such health effects have been associated with short- and/or long-term exposure to PM. Exposures to $PM_{2.5}$ are also associated with decreased lung function growth, exacerbation of allergic symptoms, and increased respiratory symptoms (U.S. EPA 2015).

2. **Sulfur Dioxide (SO_2):** People with asthma are especially susceptible to the effects of SO_2. Short-term exposures of asthmatic individuals to elevated levels of SO_2 while exercising at a moderate level may result in breathing difficulties, accompanied by symptoms such as wheezing, chest tightness, or shortness of breath. Studies also provide consistent evidence of an association between short-term SO_2 exposures and increased respiratory symptoms in children, especially those with asthma or chronic respiratory symptoms. Short-term exposures to SO_2 have also been associated with respiratory-related emergency department visits and hospital admissions, particularly for children and older adults (U.S. EPA 2015).

3. **Nitrogen Dioxide (NOx):** Exposure to NOx has been associated with a variety of health effects, including respiratory symptoms, especially among asthmatic children, and respiratory-related emergency department visits and hospital admissions, particularly for children and older adults (U.S. EPA 2015).

4. **Ground-level ozone (O_3):** Ground-level ozone, is not emitted directly into the air, but is created by chemical reactions between oxides of nitrogen (NOx) and volatile organic compounds (VOC). Exposure to ground-level ozone can cause a variety of respiratory health effects, including inflammation of the lining of the lungs, reduced lung function, and respiratory symptoms such as cough, wheezing, chest pain, burning in the chest, and shortness of breath. Ozone exposure can decrease the capacity to perform exercise. Exposure to ozone can also increase susceptibility to respiratory infection. Exposure to ambient concentrations of ozone has been associated with the aggravation of respiratory illnesses such as asthma, emphysema, and bronchitis, leading to increased use of medication, absences from school, doctor and emergency department visits, and hospital admissions. Short-term exposure to ozone is associated with premature mortality. Studies have also found that long-term ozone exposure may contribute to the development of asthma, especially among children with certain genetic susceptibilities and children who frequently exercise outdoors. Long-term exposure to ozone can permanently damage lung tissue (U.S. EPA 2015).

5. **Lead (Pb):** Lead accumulates in bones, blood, and soft tissues of the body. Exposure to lead can affect development of the central nervous system in young children, resulting in neurodevelopmental effects such as lowered IQ and behavioral problems (U.S. EPA 2015).

6. **Carbon Monoxide (CO)**: Exposure to CO reduces the capacity of the blood to carry oxygen, thereby decreasing the supply of oxygen to tissues and organs such as the heart. People with several types of heart disease already have a reduced capacity for pumping oxygenated blood to the heart, which can cause them to experience myocardial ischemia (reduced oxygen to the heart), often accompanied by chest pain (angina), when exercising or under increased stress. For these people, short-term CO exposure further affects their body's already compromised ability to respond to the increased oxygen demands of exercise or exertion. Thus, people with angina or heart disease are identified as at greatest risk from ambient CO. Other potentially at-risk populations include those with chronic obstructive pulmonary disease, anemia, diabetes, and those in prenatal or elderly life stages (U.S. EPA 2015).

Industrial manufacturing facilities such as cement plants are often located close to low-income, disadvantaged communities exposing them to significant pollution. The air pollution has a disproportionate effect on communities of color in the United States. The average exposure to industrial air toxins among low-income African Americans is 47% higher than that of low-income whites (Political Economic Research Institute, 2014). Communities of color are not only more likely to be exposed to industrial air pollution, but also less likely to reap the economic benefits of good manufacturing jobs. One study found that African Americans and Hispanics in communities neighboring industrial facilities receive 33% of the pollution exposure from those facilities, but just 21% of total jobs (PNAS, 2018).

2 Global Cement Production and Trade

With an average annual growth rate of 5%, global cement production has more than doubled from 2000 to 2020 (see Figure 2). Global cement production steadily grew until 2013 but has remained relatively flat from 2013 to 2020. China's cement production quadrupled during 2000-2020 resulting in China accounting for more than half of global cement production in 2020. With the projected increase in the demand from the construction industry, mainly driven by infrastructure projects in developing economies, cement production is expected to exhibit steady growth until 2030 (IEA, 2020).

Clinker is the main ingredient in cement manufacturing and clinker production process is one of the largest sources for criteria air pollutant emissions from the cement manufacturing (European Commission, 2013, USGS, 2009). After the initial drop in clinker to cement ratio until 2015, the average global clinker to cement ratio has been steadily increasing for the past five years at an average annual rate of 1.6% reaching to 0.72 in 2020. The main cause for the observed increase is the changes to cement standards, which have eliminated a grade of composite cement (IEA 2020).

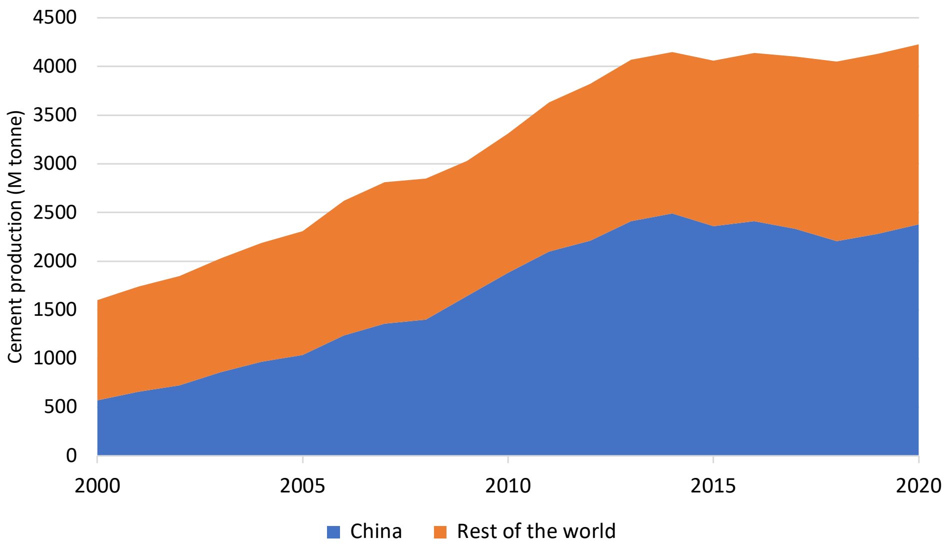

Figure 2. Cement production in China and rest of the world 2000-2020 (USGS, 2021).

Figure 3 shows the top 10 cement producing countries in the world. China is the global leader accounting for nearly 55% of the global cement production in 2020 followed by India accounting for 8% of the global cement production.

The top 20 cement exporting countries account for 83% of global cement exports in 2020, whereas the top 20 cement importing countries account for 80% of total global cement imports (see Table 1). Based on the cement trade data reported in the United Nations (UN) commodity trade database (UN comtrade database, 2021), Vietnam, Turkey, Japan, Indonesia, and Pakistan were the top five net exporters of cement globally, whereas U.S., Philippines, Sri Lanka, France and Australia were the top five net importers in 2020.

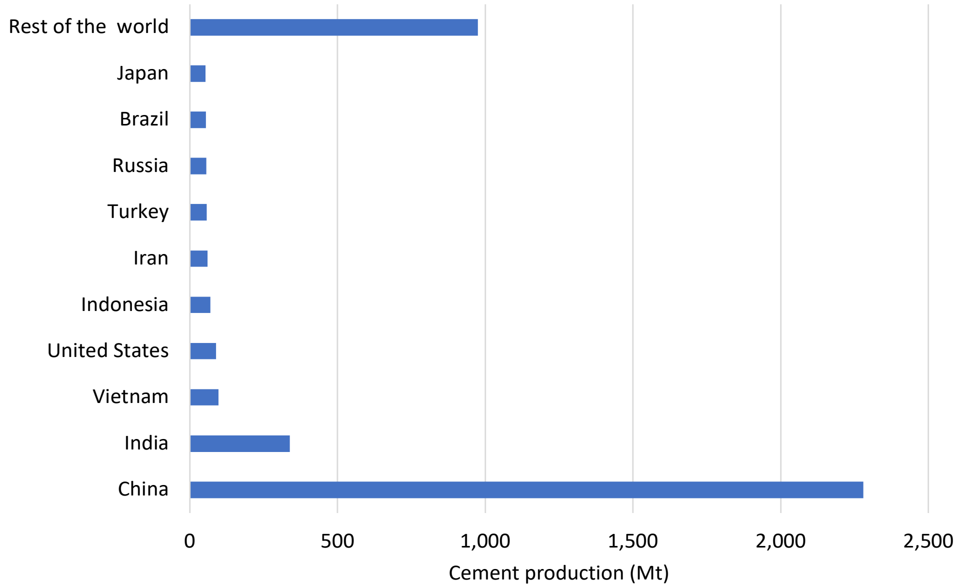

Figure 3. Top 10 cement producing countries in 2020 (USGS, 2021).

Table 1. Top 20 net exporters and importers of cement for 2020 (UN comtrade database, 2021)

Rank	Country	Net exports (kt)	Rank	Country	Net Imports (kt)
1	Viet Nam	359,818	1	USA	161,653
2	Turkey	338,762	2	Philippines	97,954
3	Japan	108,739	3	Sri Lanka	65,856
4	Indonesia	96,558	4	France	48,330
5	Pakistan	75,410	5	Australia	43,419
6	Saudi Arabia	55,703	6	China, Hong Kong	39,180
7	Rep. of Korea	53,435	7	Kuwait	32,812
8	Germany	47,342	8	Uzbekistan	23,447
9	Greece	37,564	9	Netherlands	22,867
10	Canada	36,663	10	Palestine	21,415
11	Belgium	32,752	11	Burkina Faso	17,945
12	China	31,284	12	Chile	17,419
13	India	27,596	13	Poland	13,788
14	Egypt	20,985	14	Romania	13,561
15	Kazakhstan	19,951	15	Uganda	11,414
16	Senegal	18,184	16	Peru	10,685
17	Ireland	18,002	17	Cambodia	10,186
18	Slovakia	17,644	18	Myanmar	9,229
19	Portugal	14,674	19	Colombia	8,322
20	Tajikistan	13,072	20	Tanzania	7,626

3 Sources of Criteria Air Pollutants Emissions in the Cement Industry

In addition to GHG emissions, the main emissions from cement manufacturing are PM, NOx, SO_2, CO. In addition, small quantities of volatile organic compounds (VOCs), ammonia (NH3), chlorine, hydrogen chloride, and heavy metals (as particulate or vapor) may also be emitted. Residual materials from the fuel and raw materials and other hazardous pollutants that are products of incomplete combustion can also be emitted (U.S. EPA 2009; European Commission 2013).

3.1. SO_2 emissions sources

Sulfur dioxide can be generated from the sulfur compounds in the raw materials, as well as from sulfur in the fuel that is combusted in a kiln during clinker production, which varies from plant to plant and with geographic location. However, the highly alkaline internal environment in the cement kiln system creates good conditions for direct absorption of SO_2 into the product, thereby mitigating the quantity of SO_2 emissions in the exhaust stream. Depending on the process and the source of the sulfur, SO_2 absorption ranges from about 70 % to more than 95 % (U.S. EPA 2022).

SO_2 emissions can be primarily controlled by process optimization techniques such as optimizing the clinker burning process, uniform distribution of hot meal in the kiln riser, choice of raw material and prevention of reducing conditions in the kiln. In addition to optimization techniques SO_2 emissions can be controlled by end-of-pipe techniques like absorbent addition, wet scrubbers or by using an adsorbent like activated carbon (European Commission, 2013).

3.2. NOx emissions sources

Oxides of nitrogen are generated during clinker production by oxidation of chemically bound nitrogen in the fuel (fuel NOx) and thermal fixation[3] of nitrogen in combustion air (thermal NOx). High temperatures in the kiln result in increasing the emissions of thermal NOx whereas increases in the nitrogen content in the fuel results in higher fuel NOx emissions. The burning zone of the kiln as well as the burning zone of pre-calciner are typical sources of NOx emissions during cement manufacturing. NOx emissions can be controlled by low NOx burners or selective non-catalytic reduction, both of which are commercially available technologies (Liu et al, 2021).

3 High process temperature during clinker production causes Nitrogen present in combustion air (which is inert at low temperature) to combine with oxygen to form NOx.

3.3. PM emissions sources

The main sources of PM (PM_{10} and $PM_{2.5}$) emissions at a cement plant are: (1) quarrying and crushing, (2) raw material storage, (3) grinding and blending (in the dry process only), (4) clinker production, (5) finish grinding, and (6) packaging and loading. The largest PM emission source at cement plants is the pyro-processing system, which includes the kiln and clinker cooler exhaust stacks. Often, kiln dust is collected and recycled into the kiln, where clinker is produced from the dust. However, if the alkali content of the raw materials is too high, some or all the dust is discarded in stockpiles or landfills or leached before being returned to the kiln. Other sources of PM are raw material storage piles, conveyors, storage silos, and unloading facilities (U.S. EPA 2022).

Particulate matter emissions from the kiln stack are controlled by fabric filters (reverse air, pulse jet, or pulse plenum) and electrostatic precipitators. Particulate matter emissions from clinker cooler systems are most often controlled with pulse-jet or pulse plenum fabric filters (U.S. EPA 2022).

3.4. NMVOC emissions sources

Emissions of volatile organic compounds (VOC) (along with CO) are mainly the result of incomplete combustion in the kilns during clinker production. VOC emissions mainly occur during the primary steps of preheating the feed material i.e., in the preheater and pre calciner. Emissions of NMVOCs can be low during the steady state of the kiln due to high residence time for the gases and high temperatures. Emissions of NMVOCs can be mainly controlled via choice of raw materials and fuels. In addition, adsorption on activated carbon can be used for the NMVOC emission control.

4 Global Cement Industry's Criteria Air Pollutants Emissions

The 14 cement producing countries and regions included in this report account for about 66% of global cement production in 2020. Although the analysis includes some of the largest cement producing countries, the selection of countries is also influenced by the data available.

Figure 4 presents emissions of criteria air pollutants caused by the global cement industry along with total emissions of criteria air pollutants from EU-27 countries. The four major criteria air pollutants analyzed in this report amount to about 10 million tons of annual emissions from global cement production in 2019. NOx is the highest emitted air pollutant globally from cement production amongst the air pollutants analyzed for this study, whereas the NMVOC has the lowest emissions. Approximately 95% of emissions from global cement production can be characterized as direct emissions (i.e., onsite fuel and process related emissions). While more than 95% of NMVOC and PM emissions are direct emissions, 90% of NOx and 85% of SO_2 emissions from global cement production can be attributed to direct onsite emissions. To get the perspective of order of magnitude of global cement industry's emissions of criteria air pollutants, we have also compared the emissions with total criteria air pollutants emitted from EU-27 countries in 2019 (Figure 4). The SO_2 emissions from the global cement industry in 2019 were 3% higher than the overall SO_2 emissions of EU-27. Emissions of NOx from the global cement industry were 36% lower than the EU-27's overall NOx emissions in 2019, while the PM emissions of the global cement industry were 27% lower than the overall PM emissions from EU-27 in 2019.

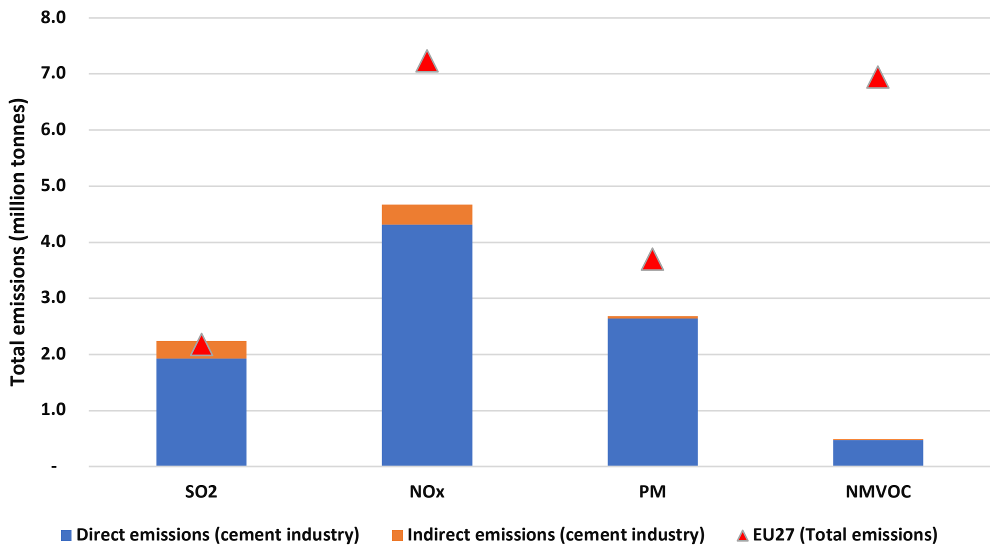

Figure 4. Global cement industry's criteria air pollutants emissions compared with EU-27 region's total emissions in 2019 (source: this study, CEIP, 2021).

Table 2 presents the total emissions of four major criteria air pollutants for each country studied for this report along with the shares of total global emissions of that criteria air pollutant from each country. China is responsible for more than half of global cement production, and thus the country's cement industry is also a leading emitter of SO_2 (57%), NOx (58%) and PM (60%), as well as NMVOCs (78%) globally.

Table 2. Total emissions of criteria air pollutants from the cement industry in the studied countries in 2019

Rank	Country	SO_2 emissions (kt)	Global share	Rank	Country	NOx emissions (kt)	Global share
1	China	1262	57%	1	China	2723	58%
2	Rest of the world	754	34%	2	Rest of the world	1566	34%
3	Turkey	73	3%	3	United States	114	2%
4	EU27	53	2%	4	European Union	78	2%
5	United States	29	1%	5	Turkey	70	1%
6	Poland	12	1%	6	Japan	41	1%
7	Italy	11	0%	7	Ukraine	15	0.3%
8	Germany	7	0.3%	8	Germany	14	0.3%
9	Japan	7	0.3%	9	United Kingdom	11	0.2%
10	Ukraine	5	0.2%	10	Italy	10	0.2%
11	United Kingdom	5	0.2%	11	Poland	7	0.2%
12	Belgium	3	0.1%	12	Belgium	7	0.1%
13	Switzerland	1	0.1%	13	Switzerland	3	0.1%
14	Austria	< 0.5	< 0.1%	14	Austria	3	0.1%
15	Sweden	< 0.5	< 0.1%	15	Sweden	1	< 0.1%
	World	2223			World	4663	

Rank	Country	PM emissions (kt)	Global share	Rank	Country	NMVOC emissions (kt)	Global share
1	China	1625	60%	1	China	279	78%
2	Rest of the world	920	34%	2	Turkey	24	7%
3	Turkey	84	3%	3	Rest of the world	23	6%
4	EU27	31	1%	4	European Union	12	3%
5	United States	31	1%	5	Poland	7	2%
6	Poland	8	0.3%	6	United States	6	2%
7	Italy	8	0.3%	7	Ukraine	3	1%
8	Ukraine	7	0.2%	8	Germany	1	0.4%
9	Japan	3	0.1%	9	United Kingdom	< 0.5	0.1%
10	Germany	2	0.1%	10	Switzerland	< 0.5	0.1%
11	United Kingdom	1	< 0.1%	11	Italy	< 0.5	0.1%
12	Switzerland	< 0.5	< 0.1%	12	Belgium	< 0.5	0.1%
13	Belgium	< 0.5	< 0.1%	13	Austria	< 0.5	< 0.1%
14	Austria	< 0.5	< 0.1%	14	Sweden	< 0.5	< 0.1%
15	Sweden	< 0.5	< 0.1%				
	World	2719			Word	356	

5 Benchmarking Criteria Air Pollutants Emissions Intensities of the Cement Industry

The aim of international benchmarking is to offer a means of comparing the performance of a given industry across countries. Benchmarking can also be used to estimate the potential for the abatement of air pollutants through the implementation of pollution control technologies. At the national level, benchmarking of criteria air pollutants emissions intensities can help policy makers prioritize emission abatement of specific criteria air pollutant and design policies for the curtailment of their emissions.

The following sub-sections present the results of benchmarking analysis for 14 countries and four criteria air pollutants (SO_2, NOx, PM, and NMVOC) emitted from the cement industry (direct and indirect emissions).

For this study, we compared the emission intensity of criteria air pollutants arising from processes and fuel combustion (onsite i.e., direct emissions) and electricity consumption (offsite i.e., indirect emissions) in the cement industry. Direct emission intensities are estimated using the emissions of criteria air pollutants reported in the respective national air pollution inventories, whereas indirect emission intensities are based on the criteria air pollutant emission factors estimated for the electricity generation and the country-specific electricity consumption intensities for cement production of the countries included in this study (detailed methodology presented in the Appendix 1).

5.1. Benchmarking of SO_2 emissions intensity

A large variation is observed for SO_2 intensities as well as for the share of direct emissions across the countries analyzed in this study (see Figure 5). China, Poland and Ukraine have the highest intensity of SO_2 emissions whereas Japan, Sweden and Austria have the lowest SO_2 emissions intensities amongst the countries analyzed for this report. High intensity of SO_2 emissions for China can be partly explained by a relatively high share of coal in the fuel mix (85%; IEA 2021). Countries such as the U.S. (20% natural gas share; IEA, 2021), Switzerland (14% natural gas share; IEA,2021) and Turkey (28% natural gas share; IEA, 2021) with higher shares of natural gas in the fuel mix, tend to have lower SO_2 emissions intensities due to substantially lower SO_2 emissions from natural gas combustion (see Figure 9). Due to higher SO_2 emissions intensities of power generation in Poland, Ukraine, Russia and Turkey, relatively larger shares of SO_2 emissions can be attributed to indirect emissions for these countries.

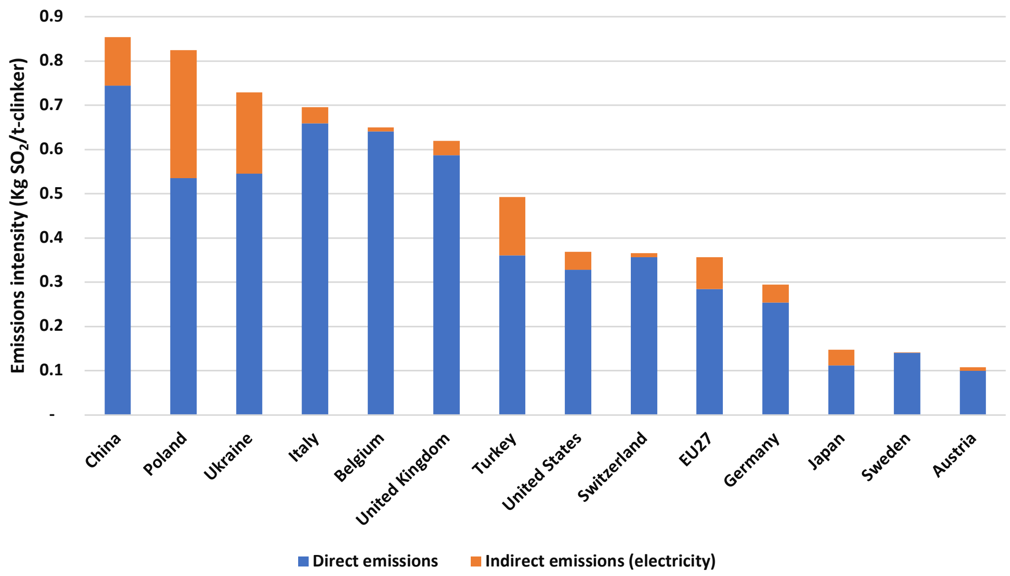

Figure 5. SO_2 emissions intensity of cement industry for countries studied in 2019.

5.2. Benchmarking of NOx emissions intensity

Figure 6 below presents the emissions intensity of NOx for cement production. NOx is the highest emitted criteria air pollutant globally from the cement industry amongst the criteria air pollutants analyzed in this report. The cement industries in Ukraine, China and the UK have the highest emissions intensities for NOx emissions. Poland, Turkey and Sweden have the lowest emissions intensity for NOx emissions. The higher intensity of NOx emissions can be partly explained by the higher share of petroleum products in the fuel mix used (see Figure 9) for kilns or higher share of coal or oil used in the fuel mix in the pre-calciner (European Commission, 2013). Despite the lowest overall NOx emission intensities, higher shares of NOx emissions can be characterized as indirect emissions for Poland and Turkey due to the relatively higher emissions intensities of NOx from the power sector in these two countries.

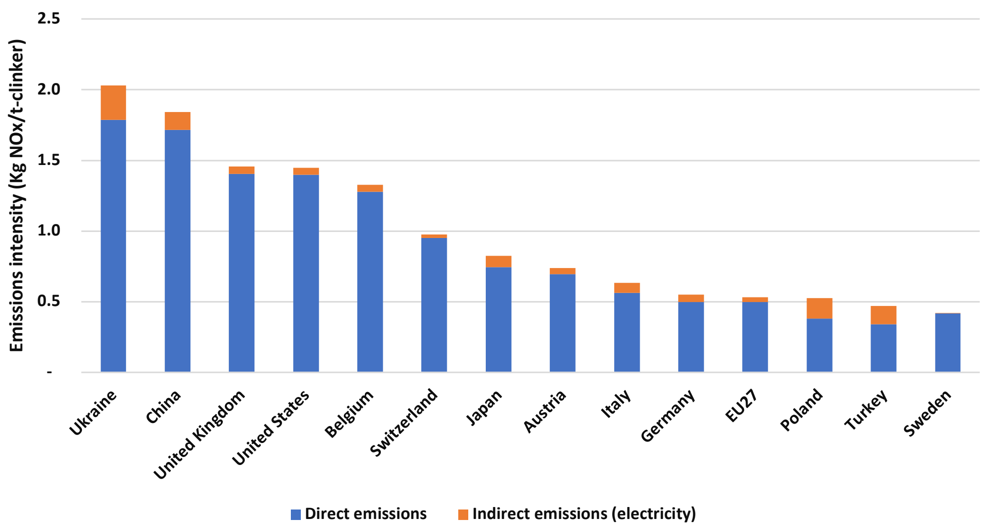

Figure 6. NOx emissions intensity of cement industry in countries studied in 2019.

5.3. Benchmarking of PM emissions intensity

A large variation can be observed for the PM emissions intensity from the cement industry (see Figure 7). China, Ukraine and Poland have the highest emissions intensities for PM whereas Japan, Austria and Sweden have the lowest emissions intensities. Almost all PM emissions from cement production can be characterized as direct onsite emissions. With the highest intensity of PM emissions from power generation, Poland has the highest share of indirect PM emissions amongst the countries studied in this report.

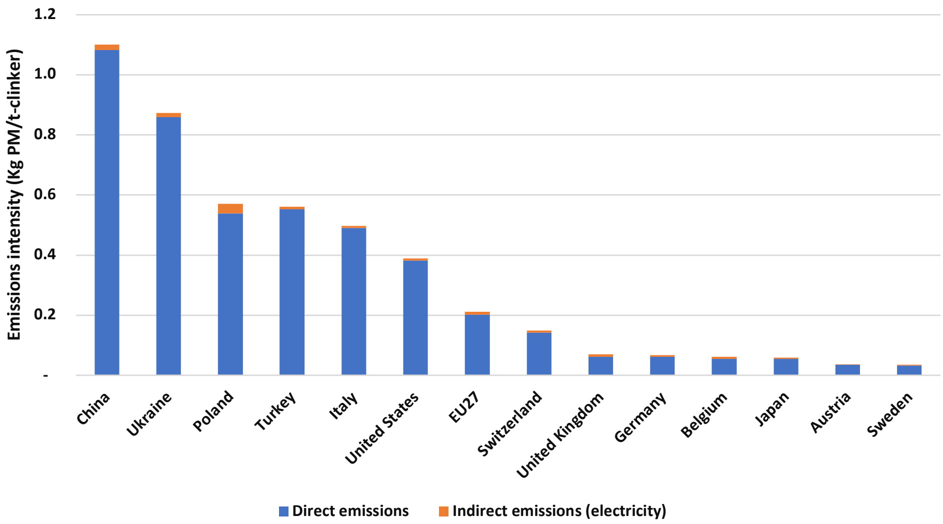

Figure 7. PM emissions intensity of cement industry in countries studied in 2019.

5.4 Benchmarking of NMVOC emissions intensity

NMVOCs are the lowest emitted criteria air pollutant from global cement production of the criteria air pollutants included in this study. Like other criteria air pollutants, a large variation can be observed for the NMVOC emission intensities for the countries included in this study. Poland, Ukraine and China have the highest NMVOC emissions intensities. Austria, Italy and Sweden on the other hand, have the lowest intensities for NMVOC emissions (Figure 8). Overall, about 95% of NMVOC emissions from cement production can be attributed to direct onsite emissions with countries like Austria and Italy having relatively higher shares of indirect emissions due to higher NMVOC emissions intensities of the power generation.

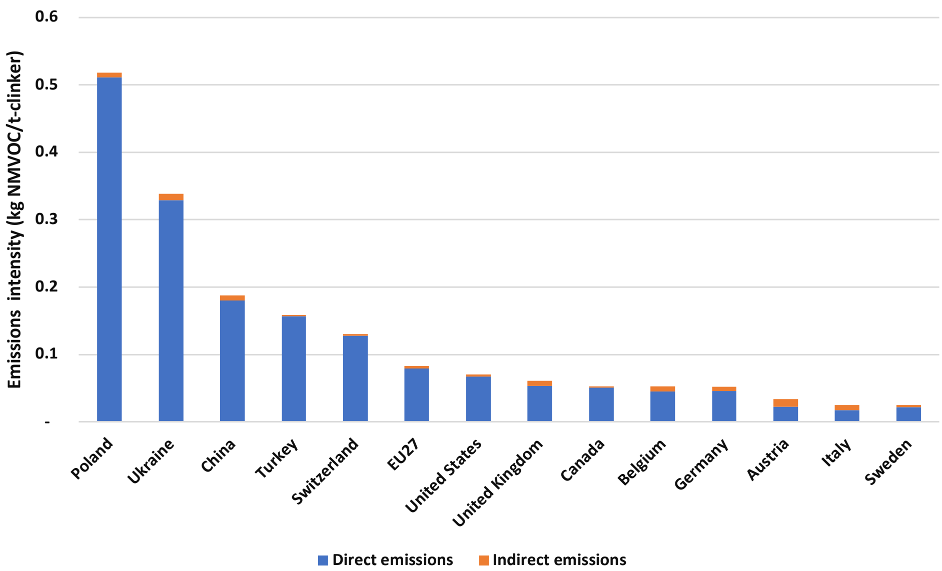

Figure 8. NMVOC emissions intensity of cement industry in countries studied in 2019.

6 Key Factors Influencing Criteria Air Pollution Emissions in Cement Industry

While a combination of several factors can explain variations in criteria air pollutant emission intensities of the cement industry across countries, some factors have larger impacts than others. It is often difficult to quantify the impact of each factor on criteria air pollutant emissions intensity of cement production across different countries. Nonetheless, even a qualitative discussion of these influencing factors can help the reader to better understand the reasons behind variations in criteria air pollutant emissions intensity among the countries studied. In this section we discuss key factors that could explain the variation observed in the intensities of criteria air pollutant emissions from cement production.

1. Air pollution regulations and penetration of air pollution control technologies
2. Types of kilns used in clinker production
3. Types of feedstocks and fuel mix
4. Clinker to cement ratio

Air pollution regulations and penetration of air pollution control technologies

Data on penetration of pollution control technologies for criteria air pollutant emissions for the countries included in this study is very limited. The level of information available for these countries differ, so direct comparison of the penetration of certain technologies is not possible. Some of the commercially available pollution control technologies are cyclones, wet scrubbers, electrostatic precipitators (ESPs), and bag filters (for PM emissions), low NOx burners, selective non catalytic reduction (for NOx emissions) (Liu et al., 2021).

The level of implementation of air pollution control technologies is often driven by the legislative standards set for the cement industries. Air pollution standards across the world vary in their scope and ranges. For example, all EU member states follow the same permissible air pollution limits with some exceptions whereas in countries like Canada the permissible air pollution levels vary for each province, or in the UK the permissible levels are set for each cement plant separately (Edwards, 2014). The stringency of air pollution regulations and permitted air pollution limits also vary widely from country to country.

Type of kilns used for clinker production

The SO_2 emissions from cement production primarily occur because of coal combustion in the kiln. A portion of the SO_2 that is released is absorbed back into the process via reaction with calcium oxide. The percentage of SO_2 absorbed depends on the type of kiln. The SO_2 absorption rate is 70% to 80% for pre-calciner kilns whereas for shaft kilns and other rotary kilns the absorption rate is 25% to 30% (Lei et al., 2011). NMVOC emissions intensities depend on the operating temperatures and oxygen availability in the kilns. Shaft kilns have higher NMVOC emission intensities because of lower temperatures and lower oxygen availability leading to incomplete combustion. NOx emissions also depend on temperature. Higher operating temperatures result in higher thermal NOx emissions (European Commission, 2013). Rotary kilns operate at higher temperatures than shaft and pre calciner kilns leading to higher NOx emissions intensities for rotary kilns (Liu et al, 2021).

Types of fuel mix and feedstock

Combustion of solid fuels like coal can produce more SO_2 emissions due to their high sulfur content whereas combustion of liquid fuels like petroleum products can cause more NOx emissions (see Figure 9). Countries with higher dependence on coal for cement production generally have higher emission intensities for SO_2 emissions, whereas the countries with higher shares of natural gas usually have relatively low intensities for SO_2 emissions. Combustion of biomass and organic waste is a major source for emissions of organic compounds (European Commission, 2013). As a result, countries with higher share of biomass and municipal waste in their cement industry's fuel mix have relatively higher emissions intensities for NMVOC.

SO_2 and NOx emissions are also affected by the sulfur and nitrogen content of the feedstock (European Commission, 2013). Higher alkali content of feed prohibits the reuse of dust in clinker production leading to higher intensities of PM emissions.

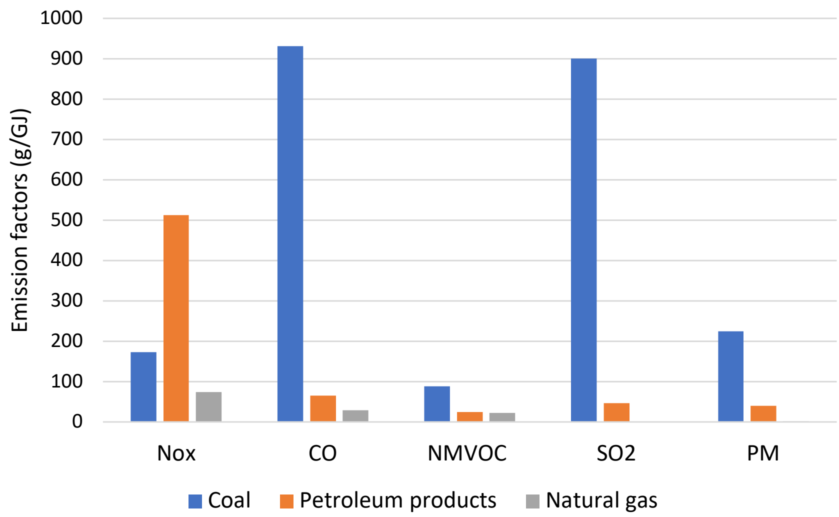

Figure 9. Unabated emission factors of major criteria air pollutants for fuels consumed in the cement industry (EEA,2019).

Clinker to cement ratio (clinker factor)

Kilns used to produce clinker are a major source of SO_2, NO_x and CO emissions (European Commission, 2013). The variation of total emission of criteria air pollutants from cement industries can be partially explained based on the comparison of the emissions per tonne of cement and the emissions per tonne of clinker. Emissions intensities based on the tonne of cement production appear lower for the countries with a lower clinker to cement ratio (see appendix 2) as compared to emissions intensities based on the production of clinker. In general, total emissions of criteria air pollutants are lower for countries with a lower clinker to cement ratio.

7 Conclusions

Our results show that amongst the criteria air pollutants analyzed for this study, the NMVOCs are the lowest emitted criteria air pollutants from the cement industry globally, whereas NOx was the highest emitted criteria air pollutant. Although some variation can be observed amongst the countries in terms of shares of direct and indirect emissions, approximately 95% of global criteria air pollutants for the cement production can be attributed to direct onsite emissions vs. indirect, offsite emissions associated with electricity used by cement plants that is caused from electricity generation in the power sector (emissions along the rest of the cement value chain are beyond the scope of the study). While Ukraine, Poland and China have the highest emission intensities for almost all criteria air pollutants, Austria and Sweden have the lowest emission intensities for most criteria air pollutants amongst the countries analyzed for this report.

Although it is often difficult to quantify the effects of key influencing factors on the emission intensities for criteria air pollutants, the large variations that are observed for all the criteria air pollutants amongst the countries included in this report can be mainly explained by a combination of factors such as the penetration level of air pollution control technologies and air pollution regulations, the type of kiln used, and the fuel mix of the cement manufacturing as well as of the power sector.

Benchmarking analysis presented in this study thus provides points of comparison to assess the performance of cement manufacturing in terms of air pollution caused by criteria air pollutants across countries. This comparison can be used to estimate potential reductions in criteria air pollutants. At national level, it can help policy makers identify and prioritize emission abatement of specific criteria air pollutants and design policies for the curtailment of their emissions, thus helping to improve health and quality of life for the low-income, disadvantaged communities that are frequently located close to industrial plants.

In view of the projected continuing increase in absolute cement production, future reductions in criteria air pollutant emissions will require a combination of stricter adoption of pollution control technologies in cement plants as well as the power sector, efficiency improvements for fuel consumption, and switching to lower emission fuels. Stricter air pollution control regulations and their enforcement for the cement industry are needed in China and other countries with high criteria air pollutants intensities to ensure the reduction of these emissions from cement production.

References

Air Environment Division, Water and Air Environment Bureau, Ministry of the Environment, 2017. Comprehensive survey of air pollutant emissions (FY2017 results). https://www.env.go.jp/air/air/osen/kotei/h30_2.pdf

Centre on Emission Inventories and Projections (CEIP), 2022. https://www.ceip.at/data-viewer

Constructioncost. 2022. Cement Production Process. Available at: https://www.construction-cost.co/cement-production-process.html

Edwards P., 2014. Global Cement Emissions Standards. Global Cement Magazine, 2014. https://www.globalcement.com/images/stories/documents/articles/eGC-Mar14-25web.pdf

Emissions Database for Global Atmospheric Research (EDGAR), 2022. https://edgar.jrc.ec.europa.eu/dataset_ap50

European Commission. 2013. Integrated Pollution Prevention and Control (IPPC), Reference Document on Best Available Techniques in the Iron and Cement Production.

European Environmental Agency (EEA), 2019. EMEP/EEA emission inventory guidebook. Technical guidance to prepare national inventories. https://www.eea.europa.eu/publications/emep-eea-guidebook-2019

Hasanbeigi, A. 2021. Global Cement Industry's GHG Emissions. Global Efficiency Intelligence. Available at: https://www.globalefficiencyintel.com/new-blog/2021/global-cement-industry-ghg-emissions

Hasanbeigi, A. and Springer, C. 2019. California's cement industry failing the climate challenge. Global Efficiency Intelligence.

IEA 2021. Electricity use per tonne of cement in selected countries and regions, 2018. https://www.iea.org/data-and-statistics/charts/electricity-use-per-tonne-of-cement-in-selected-countries-and-regions-2018

IEA, 2020. IEA tracking cement report. https://www.iea.org/reports/tracking-cement-2020

International Energy Agency (IEA), 2021. World Energy Statistic.

Lei Y., Zhang Q., Nielsen C., He K. 2011. "An inventory of primary air pollutants and CO2 emissions from cement production in China, 1990–2020". Atmospheric Environment. Volume 45, Issue 1, January 2011, Pages 147-154·

Liu J., Tong D., Zheng Y., Cheng J., Qin X., Shi Q., Yan L., Lei Y., and Zhang Q. 2021. "Carbon and air pollutant emissions from China's cement industry 1990–2015: trends, evolution of technologies, and drivers", Atmos. Chem. Phys., 21, 1627–1647, 2021.

ODYSSEE-MURE database, 2022. https://www.indicators.odyssee-mure.eu/energy-efficiency-database.html

Political Economy Research Institute, 2014. Regional Variation in Environmental Inequality: Industrial air toxics exposure in U.S. cities.

Proceedings of the National Academy of Sciences (PNAS), 2021. Racial disparities in pollution exposure and employment at US industrial facilities.

U.S. Environmental Protection Agency (U.S. EPA). 2022. Ground-level Ozone Pollution.

U.S. EPA, 2021. Air pollution inventory. https://www.epa.gov/air-emissions-inventories.

U.S. EPA. 2015. America's Children and the Environment-Third Edition. https://www.epa.gov/sites/default/files/2015-10/documents/ace3_criteria_air_pollutants.pdf

U.S. EPA. 2022. Air Emissions Factors and Quantification AP 42, Fifth Edition, Volume I Chapter 11: Mineral Products Industry.

U.S. EPA, 2021. Toxics Release Inventory (TRI) Program. https://www.epa.gov/toxics-release-inventory-tri-program

UN comtrade database, 2021. United Nations Commodity Trade Database. https://comtrade.un.org/

USGS, 2021. United States Geological Survey, Cement Statistics and Information. https://pubs.usgs.gov/periodicals/mcs2021/mcs2021-cement.pdf

Appendices

Appendix 1. Methodology

For this study, we have conducted benchmarking of the emissions intensity of four major criteria air pollutants released from the cement industry. We have compared 13 countries as well as the European Union to each other. Although the study includes some of the largest cement producing countries, the selection of countries is also affected by the data availability. We used 2019 as the base year for our analysis except for the U.S. and Japan, for which the latest official data available is for 2017.

A1.1. Direct onsite emissions from cement industry

The criteria air pollutants emission data for the cement industry were obtained from three major data sources. Centre on Emission Inventories and Projections (CEIP) was used as the primary data source for most countries studied in this report. These data were then corroborated by comparison with the data reported to the United Nations Framework Convention on Climate Change (UNFCCC) in the common reporting format (CRF) tables and National inventory reports (NIRs). The data from CRF and NIR were also used in few cases where data from CEIP were either missing or had some discrepancies.

Fuel-related emissions for the cement industry are reported together with other non-metallic minerals under the category 1A2.f in CEIP (except for the U.K. and U.S.). Emissions related to fuel combustion in the cement industry were estimated based on shares of fuel consumption of the cement production from the total fuel consumption of the entire non-metallic mineral industry. The process-related emissions for cement production (2A1) were adopted directly from the CEIP database.

For the U.S., the U.S. EPA uses the National Emissions Inventory (NEI) to estimate air emissions of criteria pollutants, criteria precursors, and hazardous air pollutants from air emissions sources and the required data was extracted from this source. In a few cases, a combination of sources was used for criteria air pollutants emissions data of the cement industry that resulted in more accurate intensity values. Criteria air pollutants data for Japan was obtained from the comprehensive air pollution survey conducted by the Ministry of environment in Japan (Ministry of environment Japan, 2017).

The production data for the cement industry are obtained from the United States Geological Survey (USGS) 2019. For the European Union, the production data was calculated by adding the production data of the member states. Clinker production data was obtained from the CRF tables of the respective countries.

Next, we calculated the emissions intensity for all the criteria air pollutants after standardizing the units. The emission intensities were obtained by dividing the emissions by the production and were reported in kg of emission/tonne of product (clinker or cement).

The total emissions for criteria air pollutants are reported in CEIP (and CRF) using the methods outlined in the EMEP/EEA emission inventory guidebook (EEA, 2019). The countries can adopt one of the three methods suggested in the guidebook based on the granularity of data available for that country. Air pollutant reporting methods are as follows:

1. Tier 1 method: This method is employed when there is a lack of detailed information about the production routes and technologies used for the given manufacturing sector. For tier 1 method, total emissions of criteria air pollutants are estimated using average emission factors for the entire manufacturing sector provided in the guidebook and the annual production.
2. Tier 2 method: This method is recommended when individual criteria air pollution data from production facilities are not available but the information about production technologies employed by those facilities as well as pollution control technologies is available. EMEP/EEA emission inventory guidebook provides technology specific emission factors for all criteria air pollutants. These technology-specific emission factors along with the data for annual production using that technology are used to estimate the total annual emissions of criteria air pollutants.
3. Tier 3 method: This method is used for reporting when the most detailed data for criteria air pollutants are available from the production facilities within the country.

The information of the method employed to report the air pollution data can be found in the NIRs of the respective countries. Most countries analyzed for this benchmarking study have employed the Tier 2 method or a combination of the Tier2 and Tier 3 methods.

A1.2. Indirect offsite emissions from cement industry

Indirect emissions related to the electricity used in the cement industry are calculated by first estimating the emission intensities for criteria air pollutants in the power sector (kg/kWh) in each country analyzed for this study.

Total emissions for all four criteria air pollutants for the power sector (category 1.A.1.a) are obtained from Emission Database for Global Atmospheric research (EDGAR, 2022). The latest data available from this source are for the year 2015. Therefore, emission intensities for each air pollutant are estimated based on the electricity generation data (kg/kWh) from the years 2010 and 2015 and the trend of the se five years (2010-2015) was used to extrapolate the intensities until the year 2019. Electricity generation data for the countries selected in this study were obtained from IEA (IEA 2021).

Emission intensities for criteria air pollutants for electricity generation are then combined with the electricity consumption intensities (kWh/tonne of cement or clinker) for the cement industry in each of the countries included in this study. Electricity consumption intensities for cement industry in the countries included in this analysis are obtained from a combination of sources (ODYSSEE-MURE database, 2021; Hasanbeigi, 2019; IEA, 2021).

Appendix 2: Criteria air pollution intensities based on cement production

In the main body of the report, we showed the criteria air pollution intensities per tonne of clinker. However, the clinker to cement ratio affects the emissions intensities. Emissions intensities based on the tonne of cement production appear lower for the countries with lower clinker to cement ratio as compared to emissions intensities based on the production of clinker. The graphs below show the criteria air pollution intensities per tonne cement.

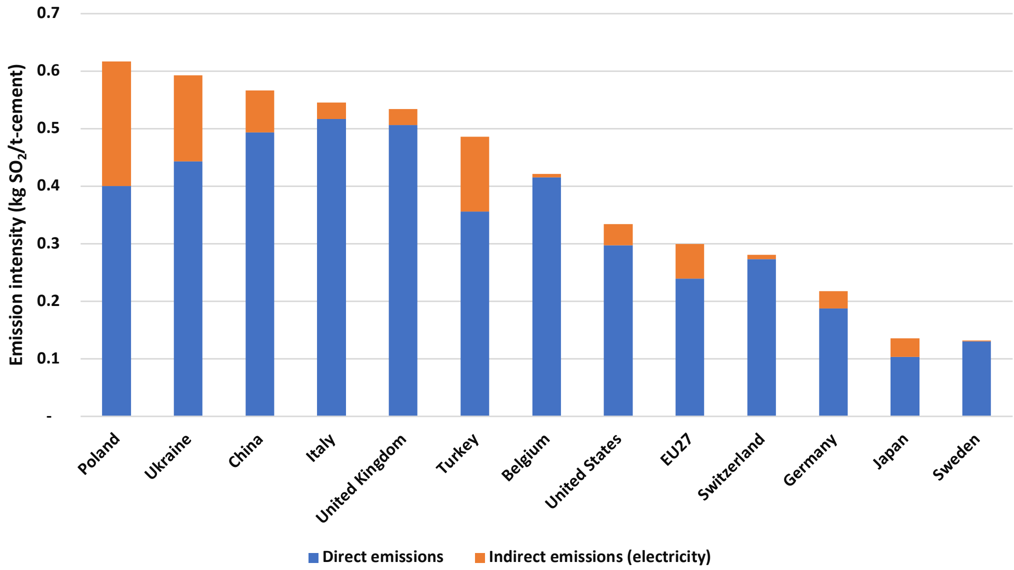

Figure A.1 SO_2 emission intensity based on cement production for countries studied in 2019.

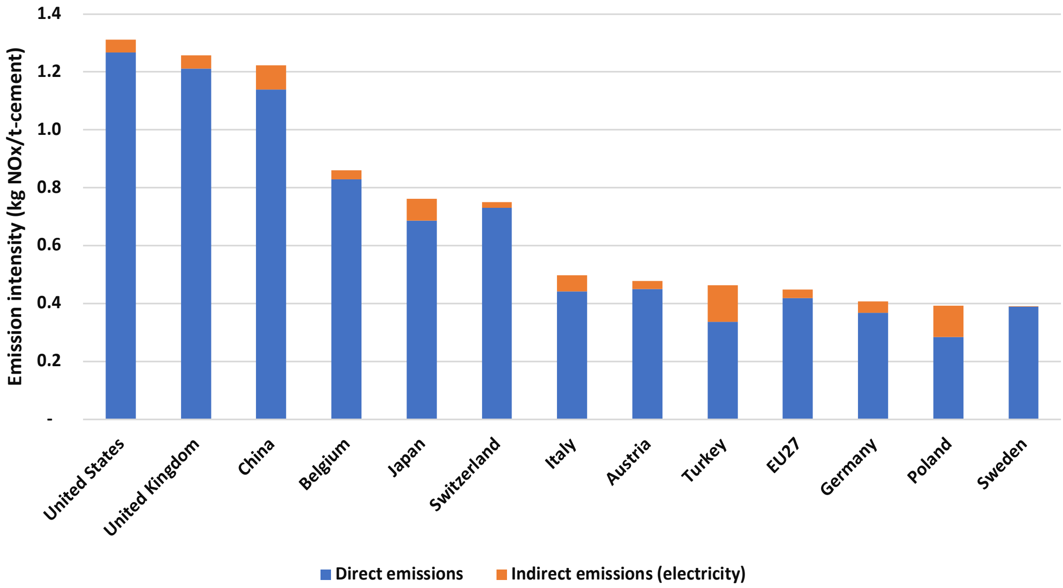

Figure A.2. NOx emission intensity based on cement production for countries studied in 2019.

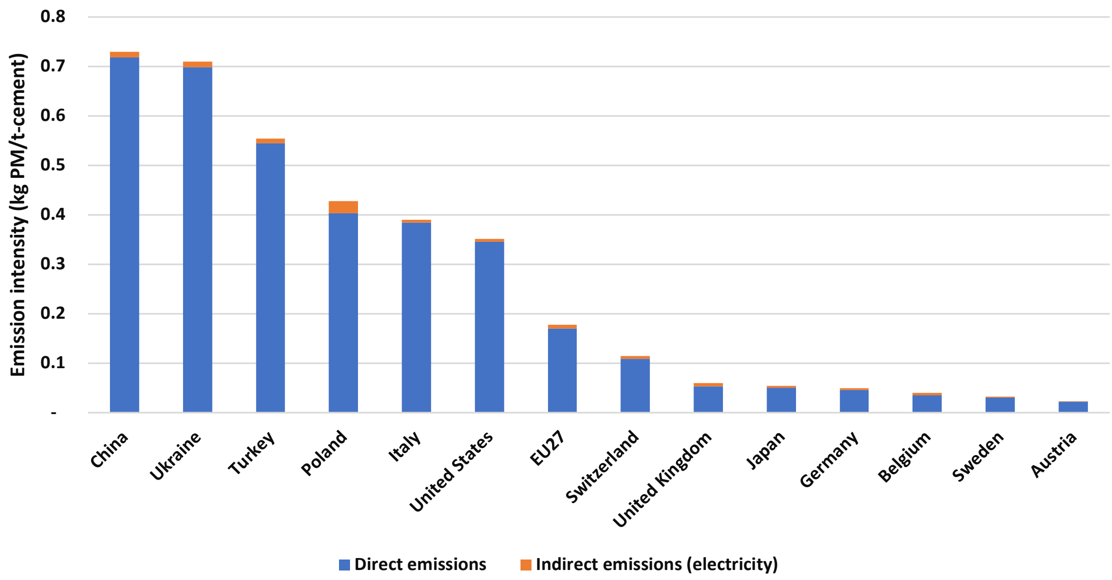

Figure A.3. PM emission intensity based on cement production for countries studied in 2019.

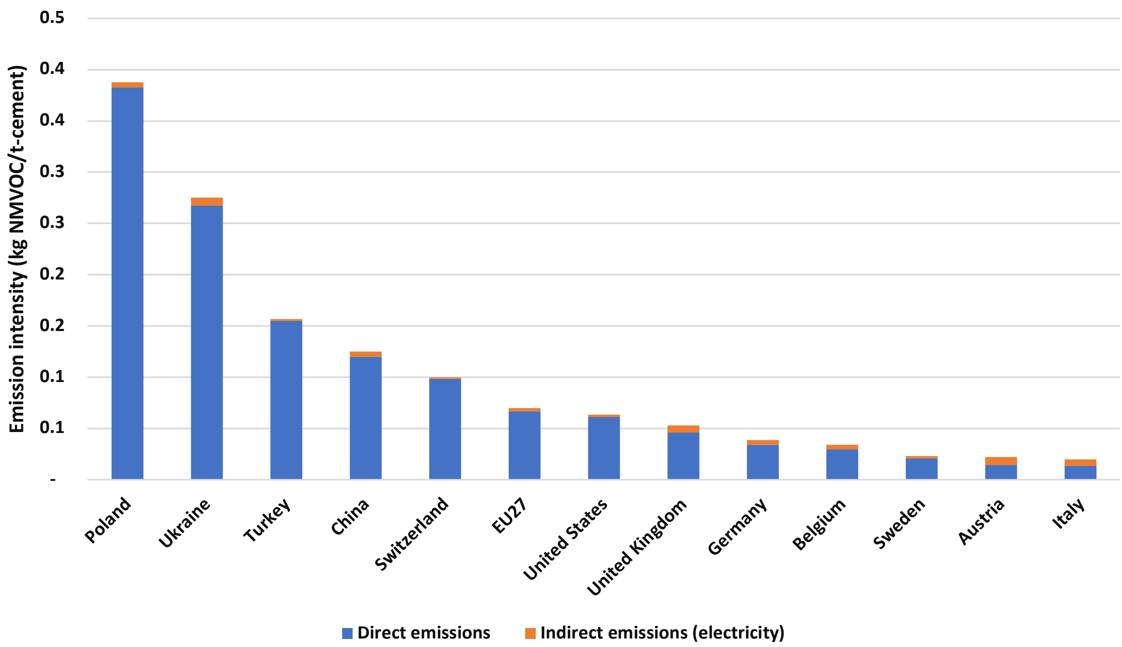

Figure A.4. NMVOC emission intensity based on cement production for countries studied in 2019.