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Advancing Green Public Procurement of Steel and Cement in China

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Executive Summary

China spends trillions of yuan each year on public procurement: the purchase of goods, engineering, and services by the Chinese government. This large-scale purchasing power gives China's government huge leverage in driving markets towards the development of low-carbon products. Green public procurement (GPP) is a policy instrument where public entities seek to procure goods with a reduced environmental impact throughout their lifecycle relative to similar goods that provide the same function. GPP adoption is increasing around the world as national governments, sub-national governments, and multilateral entities develop policies to reduce their carbon footprints and create new low-carbon markets. Countries are competing to lead the way on low-carbon material innovations, and to meet growing trade requirements imposed by policies like the carbon border adjustment mechanism (CBAM). This report focuses on the use of GPP policies to reduce greenhouse gas (GHG) emissions associated with construction materials procured using government funds in China.

This report focuses on two energy- and carbon-intensive industries/products: steel and cement. Together, the two sectors account for around 18% of global carbon dioxide (CO_2) emissions and about 30% of national CO_2 emissions in China (Hasanbeigi 2021, 2022). In comparison, these two sectors account for about 2% of U.S. CO_2 emissions, demonstrating the particular importance of industrial decarbonization in China. In 2021, total steel and cement production in China were about 1 billion tonnes and 2.36 billion tonnes, respectively, each accounting for over half of the world's production for the steel and cement industries. According to our estimates in this report, around one-third of total annual steel and cement demand in China is used for public construction.

Around one-third of total annual steel and cement demand in China is for public construction. This is equal to 350 Mt of steel and 775 Mt of cement per year. This is around 3 times the total steel and over 2 times the total cement production in India in 2021.

We estimated the CO_2 emissions associated with steel and cement used in public construction projects and the potential impact of a GPP policy to reduce those emissions. Public procurement of steel and cement in China account for approximately 689 Mt CO_2 and 459 Mt CO_2 per year, respectively. Combined, 1,148 Mt CO_2 emissions in China is associated with publicly procured steel and cement. Figure ES1 shows the annual CO_2 emissions reduction potential resulting from GPP of steel and cement in China. For each scenario and product, we estimated the direct impact of GPP as well as the indirect impact if GPP led to the adoption of lower carbon steel and cement production for non-government funded procurement. The potential CO_2 emissions reduction impact of GPP could increase by nearly three-fold when taking indirect impacts into account, with a potential overall impact of 2,594 Mt CO_2 emissions reduction for GPP of steel and cement combined in a transformative scenario with a larger decrease in CO_2 intensity of steel and cement production relative to the baseline.

It should be noted that in the majority of cases, the government and its contractors do not purchase cement and instead purchase concrete (mainly ready-mix concrete), which is the final product used in construction projects. The values shown in this report include the cement used in concrete that is then used in construction projects.

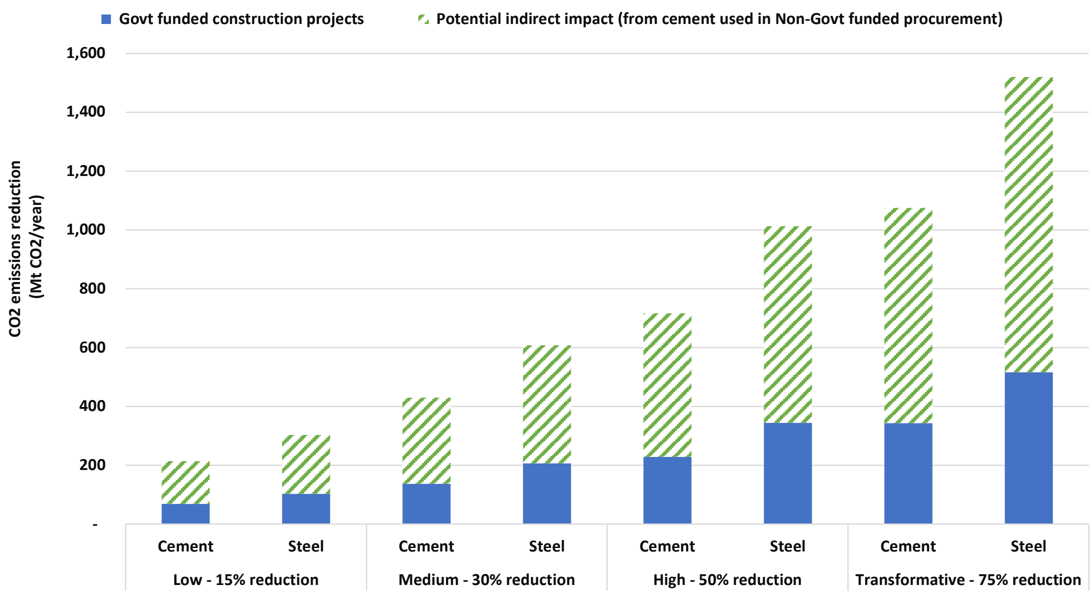

Figure ES1. Annual CO_2 emissions reduction potential resulting from GPP of steel and cement in China

Note: Potential indirect impact assumes that changes in steel and cement plants to reduce CO_2 emissions to meet GPP targets would impact the CO_2 intensity of all steel and cement produced and sold even to non-government-funded projects.

China has developed several policies related to GPP, particularly for the procurement of green building materials. Several governmental entities are involved, with the Ministry of Housing and Urban-Rural Development (MOHURD), Ministry of Industry and Information Technology (MIIT), Ministry of Finance, and the State Administration for Market Regulation (SAMR) playing crucial roles alongside key certification and standardization institutions. However, while China has made progress on GPP, there are currently no mandatory CO_2 intensity limits of steel and cement used in public construction projects.

Applying learnings from international best practices, we make the following recommendations for accelerating a national GPP policy for steel and cement in China:

- Prioritize the development of standardized and mandatory emissions reporting and industry-wide Environmental Product Declarations (EPDs) as necessary first step towards GPP.
- Given existing pilot programs and policies related to GPP, a national-level policy should be rapidly established to elevate standards and ensure harmonization and efficiency.
- To balance feasibility with innovation, a two-tiered approach is recommended: one with industry-average criteria and another for top low-carbon innovations.
- Instead of strict prescriptive measures, standards should emphasize performance and whole-project life-cycle assessments, offering bidders greater flexibility.
- Standards must be regularly updated to reflect technological advancements, with maximum emissions intensities caps tightened regularly.
- Investments in the procurement budget should complement investments in capacity building programs, addressing the knowledge and skills gap arising from the adoption of new materials and technologies.
- Continue to support industrial transformation through supportive industrial decarbonization policies such as TOP 10,000 enterprises, and financial aid, such as loans and grants

MOHURD	MIIT	SAMR	Ministry of Finance	Other/Multiple Ministries
Accelerate the development of emissions reporting standards and industry-wide EPDs.	Evaluate international best practices to encourage the adoption of GPP.	Create tools that can automate and simplify the implementation of GPP policy.	Encourage collaborative program design.	Invest in manufacturing dependencies.
Ratchet up standards over time.	Prefer performance-based standards over prescriptive standards.		Strengthen national GPP policies to avoid fragmentation.	Continue to invest in industrial transformation.
Use a two-tiered approach to promote innovation while maintaining feasibility.	Invest in programs to build capacity.			

Figure ES2: Recommendations to advance GPP policy for construction materials in China, and relevant ministries/government bodies

Note: MOHURD: Ministry of Housing and Urban-Rural Development, MIIT: Ministry of Industry and Information Technology, SAMR: State Administration for Market Regulation.

GPP in China can catalyze huge CO_2 emissions reductions in construction materials by acting as a signal to the industry of reliable large government demand. This complements China's ongoing investments in industrial decarbonization by demonstrating demand for the growing supply of low-carbon materials. Together, these policies can make China a green materials leader as domestic and global steel and cement markets shift and international climate policy strengthens.

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1 Introduction

As countries and institutions around the world work to achieve net zero emissions targets to combat climate change, deep decarbonization of heavy industries like steel, cement, aluminum, and chemicals is intensifying. These industries are key to climate change mitigation since they are energy-intensive, largely relying on fossil fuel sources and producing substantial carbon dioxide (CO_2) emissions. In addition, global demand for these materials is projected to grow as numerous countries pursue economic development and industrialization. Emissions from heavy industries need a drastic reduction if Paris Agreement goals are to be achieved. As the world's largest energy user and greenhouse gas emitter, and a major global economic powerhouse, China holds a vital position in determining the outcome of climate change mitigation efforts.

Government procurement of materials for infrastructure such as roads, buildings, and railways contributes to CO_2 emissions, largely driven by emissions associated with the production of steel and cement as construction materials. While enhancing energy efficiency and pivoting towards alternative materials will be instrumental in reducing these emissions, achieving deep decarbonization will also require substantial investments in strategies like large-scale fuel transition, electrification, carbon capture, utilization, and storage (CCUS), along with the adoption of other breakthrough technologies.

Public procurement expenditure as a percentage of gross domestic product (GDP) in many countries is significant. In Organization for Economic Cooperation and Development (OECD), public procurement spending has accounted for around 12% of GDP, and the COVID-19 pandemic led to an increase to around 15% of GDP in 2020 in 22 OECD-EU countries (OECD 2021). In Canada, public procurement amounted to about 27% of total government expenditure and slightly more than 13% of the national GDP in 2020 (Hasanbeigi et al. 2022). In other countries, the share of government expenditure in GDP is higher – 31% in India in FY2019-2020, nearly 39% in Japan, and 33% in South Korea (Hasanbeigi and Bhadbhade 2023).

When governments harness their substantial purchasing power to acquire goods and services that bear a minimal environmental impact, they not only steer markets towards more sustainable avenues but also shrink the carbon footprint of their activities and build markets for low-carbon products. Green public procurement (GPP) is a pivotal policy tool in catalyzing such a transformation.

The European Commission defines green public procurement (GPP) as "...a process whereby public authorities seek to procure goods, services, and works with a reduced environmental impact throughout their life cycle when compared to goods, services, and works with the same primary function that would otherwise be procured". Through GPP, public authorities engage in environmentally conscious procurement and send a stable market signal to manufacturers of low-carbon commodities. GPP can encompass a broad spectrum of environmental impacts, and in this study we focus on GPP policies that address embodied carbon (sometimes called "Buy Clean" policies). These policies emphasize the reduction of greenhouse gas (GHG) emissions that arise during the production, transportation, utilization, and disposal of materials.

This report emphasizes two primary materials: steel and cement. Together, these sectors contribute to approximately 18% of global CO_2 emissions, and more than half of the world's steel and cement are produced and consumed in China (Hasanbeigi 2022) (Hasanbeigi 2021). It should be noted that in the majority of cases, the government and its contractors do not purchase cement and instead purchase concrete (mainly ready-mix concrete), which is the final product used in construction projects. The values shown in this report include the cement used in concrete that is then used in construction projects.

Transitioning to net-zero emissions poses significant challenges for the steel and cement industries. In the cement sector, process-related CO_2 emissions from calcination — the thermal decomposition of limestone to quick lime and CO_2 within a kiln — constitute more than 50% of the overall CO_2 emissions. Consequently, traditional methods of enhancing energy efficiency and switching fuels fall short in achieving net-zero cement production. Additionally, decarbonizing steel in China presents unique challenges due to its massive production scale and reliance on the carbon-intensive blast furnace-basic oxygen furnace (BF-BOF) route.

China has already made progress in developing some GPP policies, including city-level pilots for green building materials, voluntary EPDs, and more. However, these policies do not include mandatory CO_2 emissions thresholds, and there is far more progress that can be made. This report investigates the scale of public procurement of construction materials in China to evaluate the potential impact of a GPP policy on GHG emissions from steel and cement. We estimate the scale of public procurement of steel and cement in China, model the potential impact of a GPP policy with different targets, and review existing national and sub-national policies related to embodied carbon. We identify common challenges to GPP implementation, as well as challenges unique to China. We close by surveying international best practices and making recommendations.

2 The Steel and Cement Industries in China

2.1. China's Steel Industry

In 2021, China accounted for 53% of global steel production, a significant increase since 2000 when its share was only 15% (Worldsteel 2022), even as world steel production more than doubled over that time period (Figure 1). The 2008 drop in world steel production shown in the figure was due to the global economic recession. The 2014 global production drop was mainly caused by a slowdown in the Chinese economy and measures to reduce steel production overcapacity, which resulted in shutting down illegal induction furnaces and old steel plants in China.

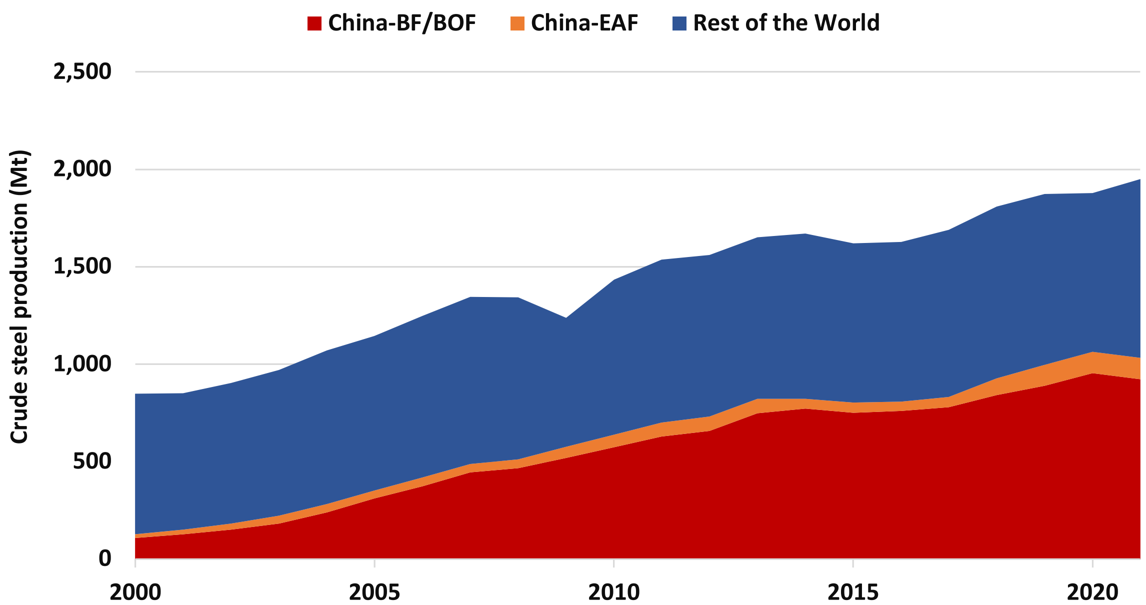

Figure 1: Crude steel production in China and the rest of the world, 2000-2021 (worldsteel 2021, 2022)

The Chinese steel industry produced 1,033 Mt of crude steel in 2021, of which 89.4% was produced by primary steelmaking plants using blast furnace-basic oxygen furnace (BF-BOF) and 10.6% was produced by the electric arc furnace (EAF) production route. China also imported 27.8 Mt and exported 66.2 Mt of steel mill products in 2021. Therefore, only 6% of the total steel produced in China is exported, and the remaining 94% of steel production in China is to satisfy China's domestic demand. The top 5 largest steel companies in China are China Baowu Group, Ansteel Group, Shagang Group, HBIS Group, and Jianlong Group (worldsteel 2022). The buildings sector is the largest consumer of steel in China (35%), followed by infrastructure and other construction (24%), machinery (16%), the automobile industry (6%), the energy sector (4%), and other steel products (14%) (Qianzhan Research Institute 2020; Guo and He 2021) (Figure 2).

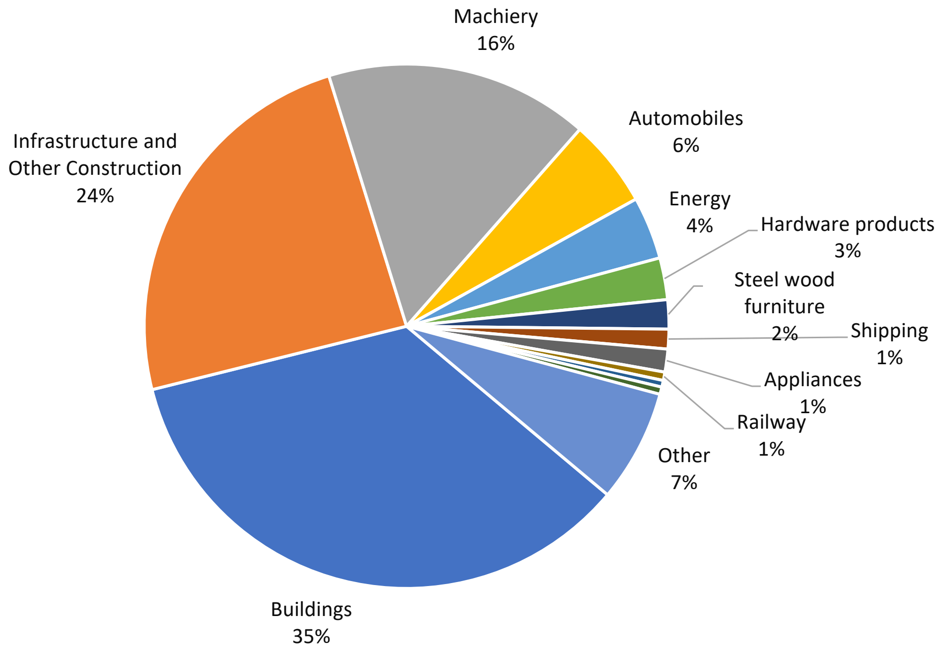

Figure 2: Steel Consumption in China by Source in 2020 (Qianzhan Research Institute 2020; Guo and He 2021)

China's steel industry accounted for around 34% of the total fuel used in the Chinese manufacturing sector in 2020 (NBS 2022). Coke, a coal-based fuel, accounted for 67% of the Chinese steel industry's final energy use in 2020. Process heating, especially in BFs, to convert iron ore into pig iron/hot metal, has the highest share of the end-use energy use in the steel industry in China.

In our previous study, we conducted benchmarking of the energy intensity and CO_2 emissions intensity of the iron and steel industry in 15 major steel-producing countries plus the EU-27 region (Hasanbeigi 2022). In Figure 3 below we show some key results from that study to highlight the position of the Chinese steel industry's energy intensity and CO_2 emissions intensity in an international context. China had the third highest CO_2 emissions intensity of countries studied.

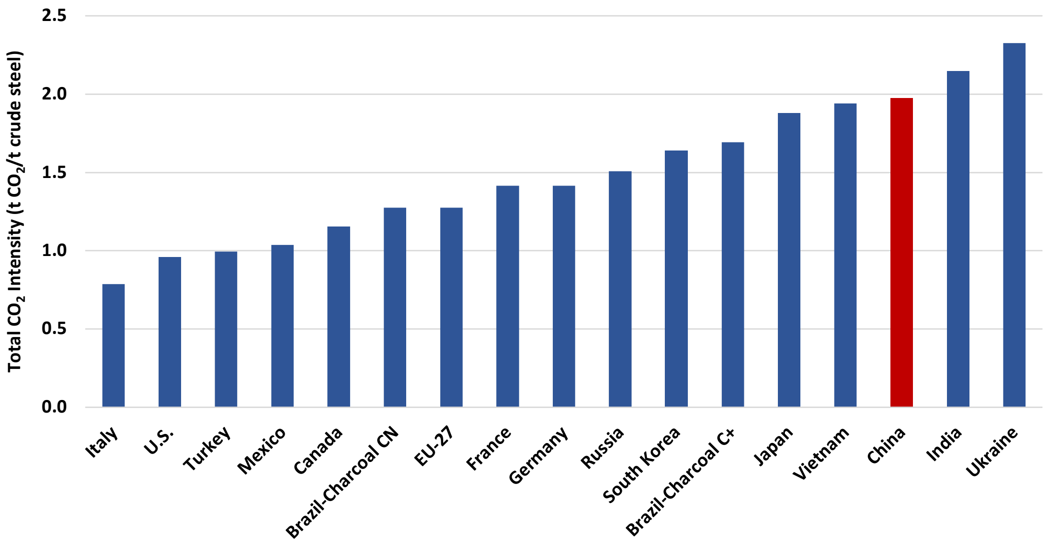

Figure 3: Total CO_2 emissions intensity of the steel industry in the studied countries/region in 2019 (Hasanbeigi 2022).

Note: Brazil-Charcoal CN refers to when charcoal is considered carbon neutral. Brazil-Charcoal C+ refers to when charcoal is not considered carbon neutral because of questions and concerns regarding the sustainability of biomass used in the steel industry in Brazil.

It is worth highlighting that although the very low share of EAF steel production in China results in a high total CO_2 intensity for its entire steel industry, more than 80% of the BF-BOF steel production capacity in China was built after the year 2000, with an average age of plants around 15 years (IEA 2020c). Many of these new plants are using more efficient production technology. In addition, in the past ten years, China has been aggressively shutting down old and inefficient steel plants.

However, China has one of the highest CO_2 intensities of EAF steel production in the world, driven by the significant amount of pig iron (around 50% of EAF feedstock), which is produced via blast furnaces, used as feedstock in China's EAFs. Another important factor that influences the CO_2 intensity of EAF steel production is the power generation CO_2 emissions factor. Over half of the energy used in EAF steelmaking (including rolling and finishing) is electricity. China has a relatively high power generation CO_2 emissions factor due to the large share of coal used in electric power generation. Many of the other countries studied, such as the U.S. and Turkey, primarily use a scrap-based EAF production route that leads to lower emissions intensities, and/or have lower carbon intensity electricity grids.

2.2. China's Cement Industry

China accounts for over half of global cement production (Figure 4). In 2021, China produced 2.4 billion tons of cement, or 55% of global production, almost all of which was used to meet domestic demand (USGS 2023). China's cement production levels have been fairly stable since 2013. The top 5 largest cement companies in China are China National Building Materials Group, Anhui Conch Cement, Tangshan Jidong Cement, China Resources Cement, and Huaxin Cement, which combined made up 46.1% of China's installed clinker capacity in 2020 (Downie 2021).

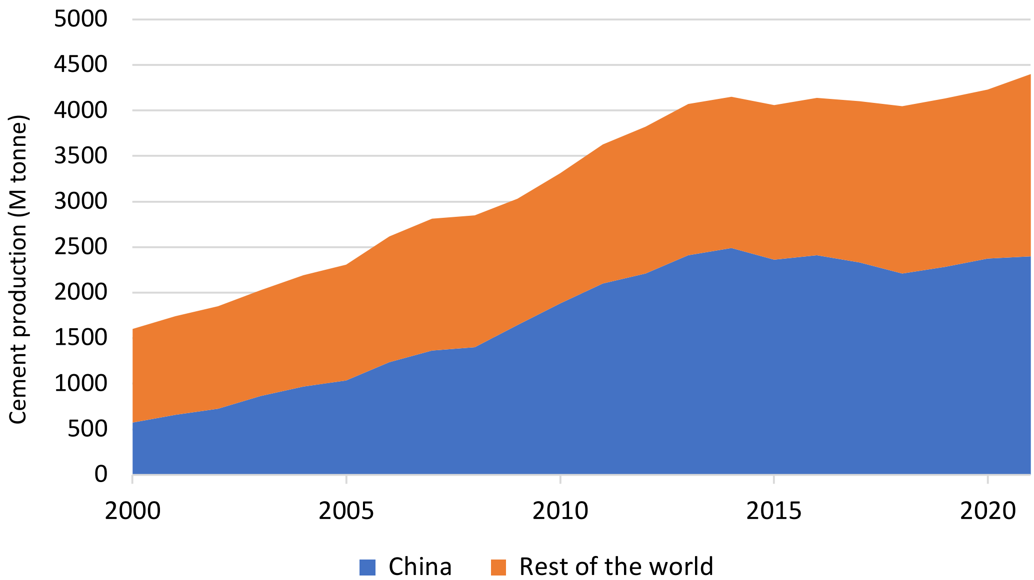

Figure 4: Cement production in China and the rest of the world, 2000-2021 (USGS, various years)

China's cement industry is highly dependent on coal, with coal representing 98% of fuel used for clinker production. China's cement industry has set a goal to peak emissions in 2023, and supply and demand are expected to decline thereafter, with demand reduction being the primary driver of lowered emissions (RMI and China Cement Association 2022) (Downie 2021).

In our previous study, we conducted benchmarking of the energy intensity and CO_2 emissions intensity of the cement industry in 14 major cement-producing countries and regions (Hasanbeigi and Springer 2019a). Of the countries and regions compared, China had the second lowest electricity intensity of cement production and the third lowest fuel intensity of clinker production. This is driven by the fact that China has some of the world's newest cement plants, installed in the past ten to fifteen years, which use more advanced and energy-efficient technologies. China's new cement plants use new suspension preheater-precalciner (NSP) kilns with relatively low fuel intensity, and have more efficient grinding mills with lower electricity intensity. In addition, the clinker-to-cement ratio in China was around 0.58 in 2015, one of the lowest in the world. Although the clinker-to-cement ratio in China rose to 0.65 in 2022, it is still one of the lowest in the world (International Energy Agency 2023) (Table 1). Since clinker production uses all fuel and the majority of electricity in a cement plant, a lower clinker-to-cement ratio means there is lower electricity and fuel intensity as well as CO_2 emissions intensity per ton of cement produced.

Table 1: Clinker-to-cement ratio in selected countries, 2019

Country	Clinker-to-cement ratio
China	0.65
Austria	0.70
Brazil	0.68
Canada	0.87
Czech Republic	0.80
Egypt	0.84
France	0.77
Germany	0.72
India	0.68
Italy	0.77
Philippines	0.77
Poland	0.74
Spain	0.81
Thailand	0.82
United Kingdom	0.88
United States	0.89

Note: This table displays the clinker to cement equivalent ratio based on a weighted average of grey and white clinker in Portland and blended cements. Source: GCCA 2019

Taken together, steel and cement production in China account for around 30 percent of national CO_2 emissions. Thus, adopting GPP policies for steel and cement could stimulate demand for lower carbon steel and cement in China.

3 China's Procurement of Construction Materials and Associated Emissions

3.1. Scale of Public Procurement of Construction Materials

This section presents the spending on various construction sectors[1] as well as the procurement of steel and cement by the national government in China. The scale of public procurement for each construction material of interest is estimated for the construction sectors based on analysis of the Input-Output table (National Bureau of Statistics 2023) and national accounts for the year 2020 (National Bureau of Statistics 2022). The share of government expenditure for the construction sectors is estimated based on the shares of government and non-government investment in the formation of fixed assets.[2] The descriptions of the construction sectors analyzed in this report can be found in Table 2. It should be noted that later in the report for the emissions impact analysis of GPP in China, we only focus on steel and cement.

Table 2: Descriptions of construction sectors analyzed in this report (National Standardization Committee 2017)

Construction sector	Description
Residential housing	Construction activities of housing projects.
Stadiums and other housing	Stadium construction, sports and leisure and fitness centers construction and other housing construction activities.
Railway, roads, tunnels, bridges	Construction activities of railroads, highways, municipal roads, and urban rail transit systems.
Other civil engineering	Water conservancy, transportation and supply engineering construction, marine engineering construction, industrial and mining construction, pipeline construction, environmental protection engineering, power engineering.
Construction and installation	Activities after the completion of the main construction of the building such as installation of various equipment in the building, as well as the construction of wiring and piping installation activities
Building construction and renovation services	Post construction activities such as decoration, renovation and maintenance

Figure 5 presents the total private and public sector expenditure on five construction sectors in China in 2020. The figure also breaks down spending by construction material of interest. Residential housing building is the leading construction sector in terms of total construction expenditure, followed by railway, road, tunnel and bridge engineering construction.

1 Construction engineering and services are not included in this analysis.
2 Total investment in fixed assets refers to the volume of activities in construction and purchases of fixed assets of the whole country and related fees.

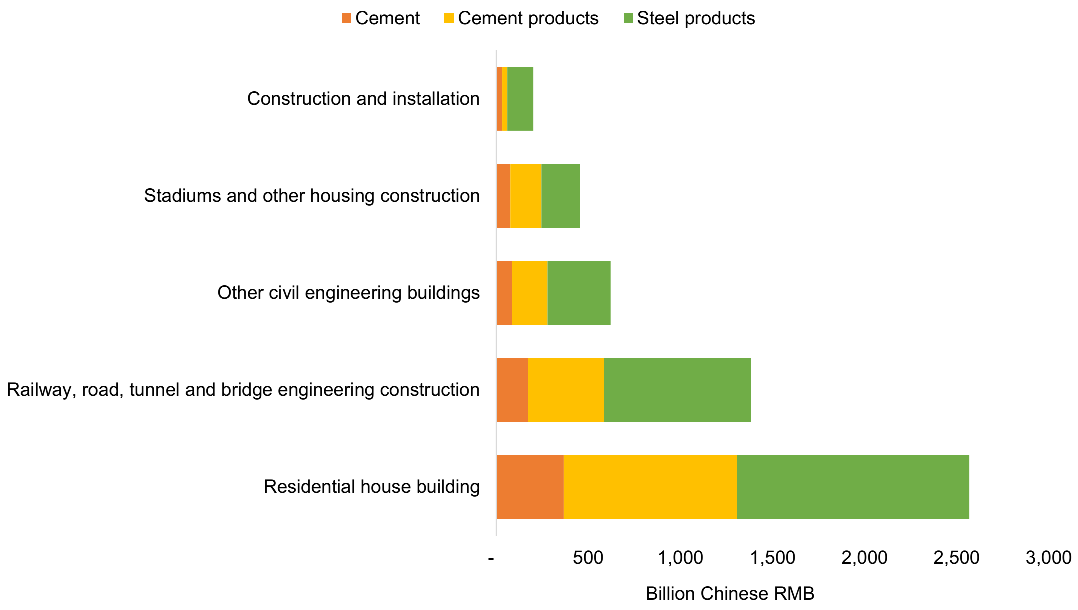

Figure 5: Total expenditure by construction sectors on cement, cement products, and steel products in China in 2020

Note: Cement refers to production of cement and clinker. Cement products refers to production of concrete, cement pipes, precast concrete components, bricks, tiles and other products.

Figure 6 presents the total public and private spending on the procurement of construction materials of interest at the national level in China. The total spending on the procurement of construction materials of interest (i.e., only cement and steel) in 2020 amounted to 5.2 trillion yuan, with public procurement representing 32.5% of this total. Amongst the construction materials of interest, the shares of public procurement were fairly similar, with steel products at 34% of total spending and cement and cement products at 32%. It should be noted that the overall spending on fixed assets may involve several other expenditure components such as acquisition of site, professional fees and other construction costs that are not related to the procurement of construction materials. Our estimates here in the report refers to only the procurement of cement and steel and not other project expenditures.

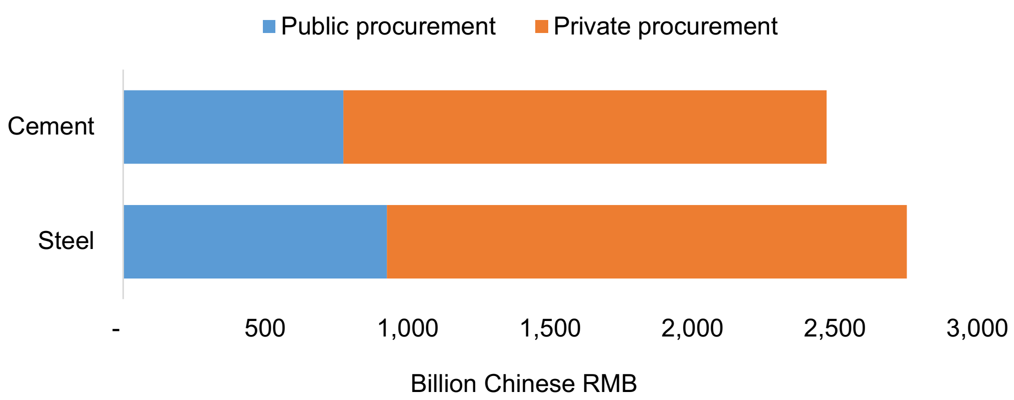

Figure 6: Scale of public and private procurement for cement and steel in China in 2020

3.2. Scale of Public and Private Procurement of Steel and Associated CO_2 Emissions

The Chinese steel industry produced 1,027 Mt of crude steel in 2020 and only 6% was exported. Our above estimates show that around 34% of steel was used in government-funded construction in China, or around 349 Mt. Figure 7 shows the total steel procurement by both the public and private sectors in China. We apply the share of government spending to annual production of the construction material of interest in China to obtain the estimated volume of annual procurement. It should be noted that the government also procures other products that contain steel (e.g. vehicles, equipment, etc.).[3] The values on the graphs for "Government-funded construction projects" only contain the steel procured for public construction. The "Non-Government-funded procurement" refers to the rest of the steel consumed in China other than for public construction.

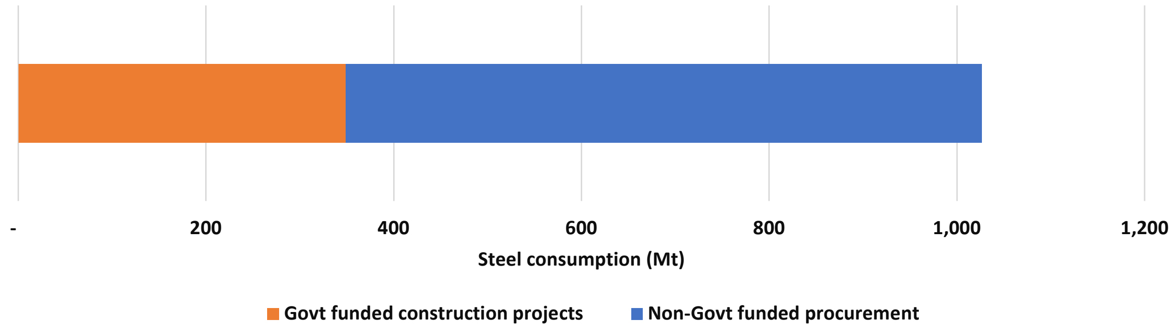

Figure 7: Public and private procurement of steel in China, 2020

Figure 8 shows annual CO_2 emissions associated with steel procured by the public and private sector in China. Because the majority of steel used in China is domestically produced, we used the CO_2 intensity of steel produced in China (1.97 t CO_2/t steel) (weighted average of both primary steel and electric arc furnace (EAF) steelmaking) to calculate annual CO_2 emissions associated with steel consumption in China. 689 million tons of annual CO_2 emissions are linked with steel consumption from government-funded projects in China, demonstrating that government procurement can be a strong driver of demand for low-carbon steel. In fact, India, the world's second largest producer of steel at roughly 230 million tons per year, produces substantially less steel overall that the amount procured annually by the Chinese government for public construction projects. Therefore, GPP policies in China have the potential to be transformative at the global scale.

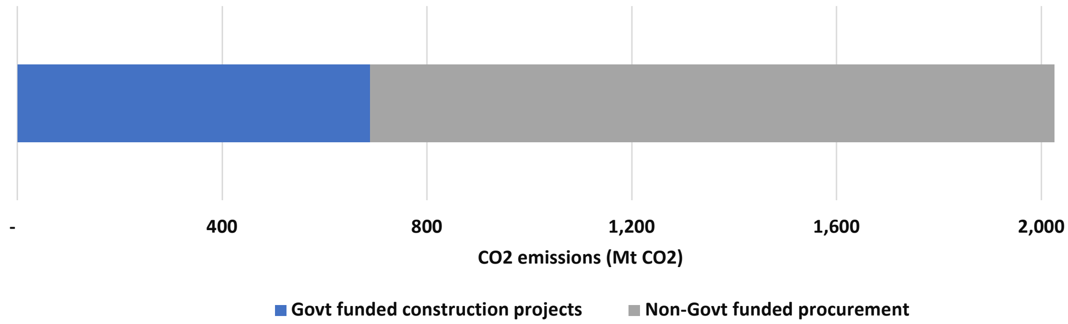

Figure 8: Annual CO_2 emissions associated with steel used in China in 2020

3 According to the data published in China's input-output table, steel is always procured in the form of steel rolled products by the construction sectors in China. As a result, raw steel is not considered in the analysis.

3.3. Scale of Public and Private Procurement of Cement and Associated CO_2 Emissions

In 2020, China produced 2.42 billion tons of cement, and total cement consumption in China was around 2.38 billion tons (RMI and China Cement Association 2022). Our above estimates show that about 32% of cement demand was used in public construction projects. It should be noted that in the majority of cases, the government or its contractors do not purchase cement and instead purchase concrete, the final product used in construction projects. The values shown in this chapter include the cement used in concrete that is used in construction projects. Figure 9 shows the total cement consumption in both public and private construction in China in 2020. We apply the share of government spending to annual production of the construction material of interest in China to obtain the estimated volume of annual procurement.

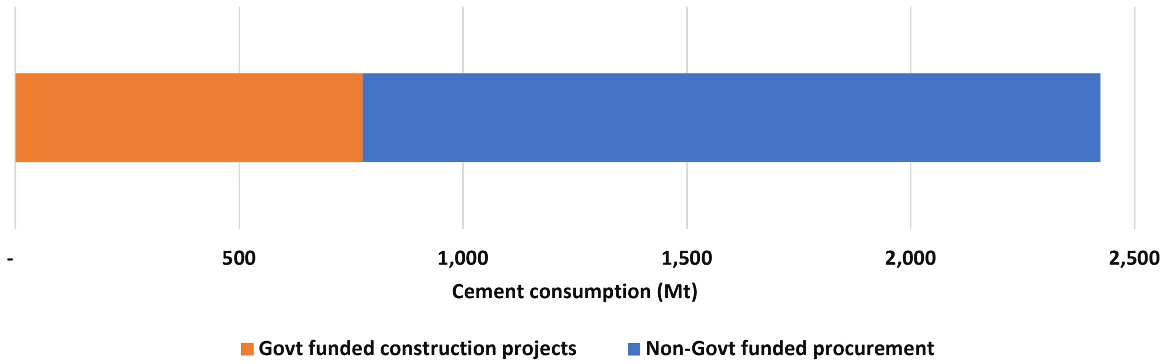

Figure 9: Total cement consumption in both public and private construction in China in 2020

Figure 10 shows annual CO_2 emissions associated with cement used in China in 2020. Since essentially all cement used in China is produced domestically, we used the CO_2 intensity of cement produced in China to estimate annual CO_2 emissions associated with cement consumption. Around one-third of the annual CO_2 emissions linked with cement consumption in China are associated with public construction, which was around 459 Mt CO_2 in 2020. Therefore, government procurement has significant leverage in incentivizing the decarbonization of cement production.

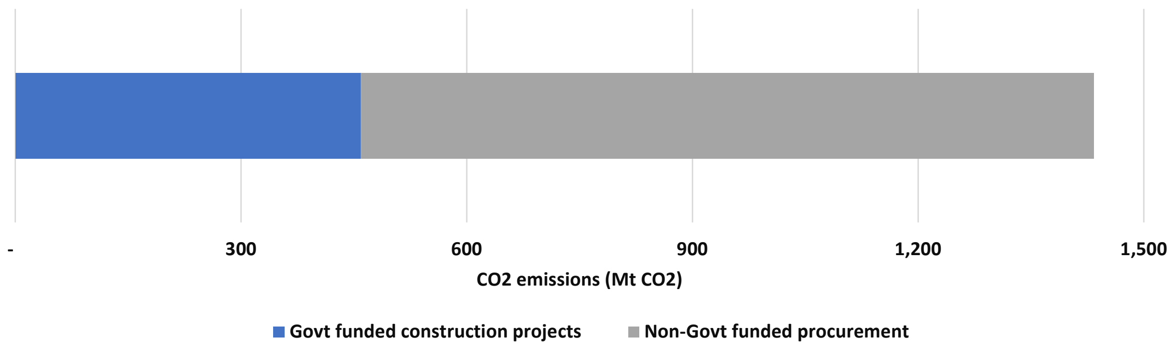

Figure 10: Annual CO_2 emissions associated with cement used in China in 2020

4 Potential Impact of GPP on CO_2 Emissions in China

In this section, we present the results of our analysis to estimate the potential impact of a GPP policy on the CO_2 emissions associated with cement and steel procured by the government in China.

4.1. Potential Impact of GPP on the Steel Industry's Emissions

4.1.1. Setting GPP Targets for Steel

To estimate the potential impact of GPP on CO_2 emissions associated with steel consumed in China, we developed several scenarios with various targets for CO_2 intensity of steel set by a GPP policy (Table 3). Since the majority of steel used in China is domestically produced (worldsteel 2022), we used the CO_2 intensity of steel produced in China (1.97 t CO_2/t steel 2019) (weighted average of both primary steel and electric arc furnace (EAF) steelmaking) as the baseline for target setting for steel GPP policy.

GPP targets shown in the table below are industry-level targets and not for a specific steel product. In actuality, GPP policy is likely to set product-specific intensity targets rather than industry-level targets. However, because of the lack of information and the existence of so many different steel products, it is not possible to do such industry-level impact estimation using product-level targets. Therefore, we used industry-level intensity targets to show the potential impact of GPP of steel.

4.1.2. Strategies for Decarbonizing China's Steel Industry

Major strategies to decarbonize the steel industry include energy efficiency, fuel switching to lower or zero-carbon fuels, electrification, CCUS, and adoption of transformative technologies such as green hydrogen-direct reduced iron (H_2-DRI). On the demand side, material efficiency and circular economy practices can lessen steel industry's carbon footprint. This next few paragraphs summarize decarbonization activities across the steel sector (Hasanbeigi et al. 2023, Bataille 2019, Net-Zero Steel Initiative 2021, Fan and Friedmann 2021, ArcelorMittal 2021, International Energy Agency 2020, Mission Possible Partnership 2022).

Energy Efficiency: The steel industry in China can adopt various energy-efficient technologies. Examples include waste heat recovery and the Top-Pressure Recovery Turbine Plant (TRT). Additionally, emerging technologies harnessing smart manufacturing and the internet of things (IoT)—like predictive maintenance and digital twins—can enhance process control and save energy in existing processes.

Table 3: GPP target scenarios for the steel industry in China

GPP Target	% reduction in steel CO_2 intensity from baseline	Steel CO_2 intensity ($kgCO_2$/t crude steel)	Notes and potential actions for CO_2 emissions reduction *
Baseline	-	1,974	This is the level of China's current steel CO_2 intensity (Hasanbeigi et al. 2023)
Low	15%	1,678	Moderate improvements in energy efficiency and fuel switching with a small increase in share of EAF steelmaking can achieve this reduction in steel CO_2 intensity in China.
Medium	30%	1,382	Higher improvements in energy efficiency and fuel switching, combined with more switching to the EAF steel production route with decarbonized electricity can achieve this reduction in steel CO_2 intensity in China.
High	50%	987	Achieving this reduction in steel CO_2 intensity would require significantly higher energy efficiency improvement, more aggressive fuel switching to lower carbon fuels, substantially higher scrap-based EAF steelmaking, and some use of transformative technologies such as green hydrogen DRI-EAF in China.
Transformative	75%	493	All of the above, with more aggressive adoption of transformative technologies like green hydrogen DRI-EAF and CCUS in the Chinese steel industry.

* More detailed information on potential actions for CO_2 emissions reduction can be found at Hasanbeigi et al. 2023, Bataille 2019, Net-Zero Steel Initiative 2021, Fan and Friedmann 2021
EAF: electric arc furnace; DRI: direct reduced iron; CCUS: carbon capture, utilization, and storage.

Fuel Switching and Electrification: Coal or coke in the iron and steelmaking processes can be replaced with alternative fuels like natural gas, biomass, biogas, or eventually, hydrogen. A primary avenue for steel industry electrification is expanding the use of EAF steel production. Around 90% of steel produced in China uses the BF-BOF production route, indicating large potential for switching to the EAF route in the future. In addition, there will be a substantial increase in domestic steel scrap availability in China that could replace the need for the construction of new blast furnaces and instead provide scrap for new EAF steelmaking plants (Hasanbeigi et al. 2023) (Figure 11). Other methods for decarbonization via fuel switching and electrification include adopting transformative steelmaking technologies and using low-carbon electricity in process heating, with possibilities like electrified reheating furnaces or electric induction furnaces.

Transformative Technologies: Some technologies can transform the carbon footprint of steel production. Notably, hydrogen derived from renewable energy can replace natural gas in DRI production (green H_2-DRI). China is currently piloting several DRI projects. For instance, China's Hebei Iron and Steel Group (HBIS) collaborated with Tenova to develop a DRI plant using H_2-rich gases. Furthermore, Baowu Steel, the world's leading steel producer, is constructing a DRI facility in its Zhanjiang Steel location, representing a significant investment in this technology.

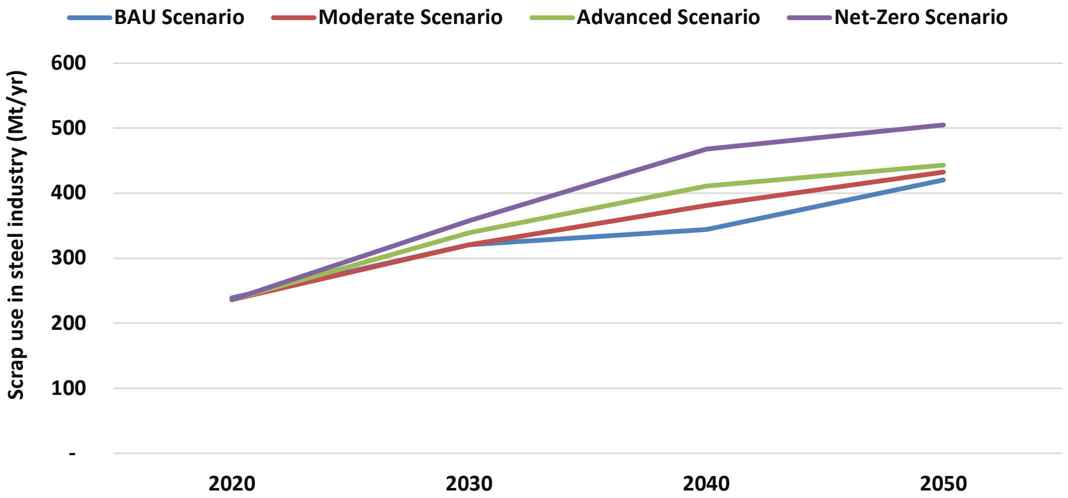

Figure 11: Scrap availability outlook for China's steel industry, based on estimates from selected studies. Source: Hasanbeigi et al. 2023

Notes: MPP = Mission Possible Partnership; BAU = business as usual; CISA = China Iron and Steel Association; IEA = International Energy Agency; STEPS = Stated Policies Scenario; SDS = Sustainable Development Scenario; MIIT = Ministry of Industry and Information Technology of China.

CCUS: Carbon capture, utilization, and storage (CCUS) can decarbonize steel production through various methods, such as post-combustion CCUS. While these techniques are in varying development stages, challenges lie in cost reduction and increasing operational efficiency. Captured CO_2 can either be stored underground, depending on geological factors, or repurposed for chemicals or fuel production.

4.1.3. The Potential Impact of Steel GPP in China

Using the annual CO_2 emissions associated with steel used in China presented in the previous chapter and the targets set in Table 3, we estimated the annual CO_2 emissions reduction potential resulting from GPP for steel in China (Figure 12).

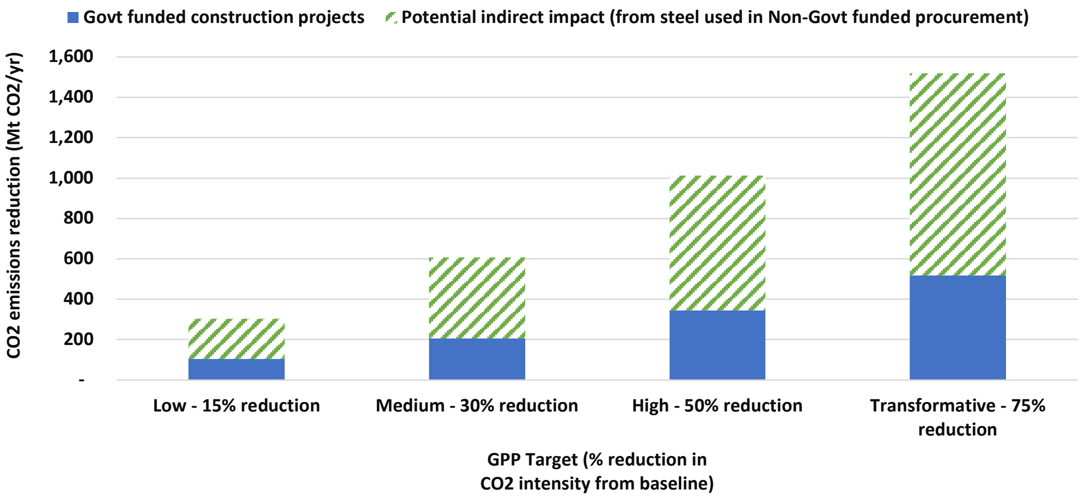

Figure 12: Annual CO_2 emissions reduction potential from GPP for steel in China

Under the Low scenario for a GPP target for steel, an annual emissions reduction of 103 Mt CO_2 per year can be achieved directly from public procurement of steel. This direct annual CO_2 emissions reduction potential would increase to around 517 Mt CO_2 per year under the Transformative scenario. The potential CO_2 emissions reduction impact of GPP for steel could increase by nearly three-fold if we consider the potential indirect impact from the steel sold to non-publicly funded projects since the changes that steel plants make for CO_2 emissions reduction applies to all steel they produced for market.

4.2. Potential Impact of GPP on the Cement Industry's Emissions

4.2.1. Setting GPP Targets for Cement

To estimate the potential impact of GPP on CO_2 emissions associated with cement consumption in China, we developed several scenarios with various GPP targets for the CO_2 intensity of cement set by a GPP policy (Table 4). Since nearly all cement consumption in China uses domestically produced cement, we used the average CO_2 emissions intensity of China's domestic cement industry as the baseline for the target setting for cement GPP. GPP targets shown in the table below are industry-level targets and not for a specific cement or concrete product.

Table 4: GPP target scenarios for the cement industry in China

GPP Target	% reduction in cement CO_2 intensity from baseline	Cement CO_2 intensity (kg CO_2/t cement)	Potential actions for CO_2 emissions reduction*
Baseline	-	592	This is the current CO_2 emissions intensity of China's domestic cement industry.
Low	15%	503	Can be achieved by moderate effort in energy efficiency improvement, fuel switching to lower carbon fuels, and a small increase in the use of supplementary cementitious materials (SCMs) instead of clinker.
Medium	30%	414	Can be achieved by maximizing energy efficiency improvement, more aggressive fuel switching to lower carbon fuels, and higher use of SCMs instead of clinker.
High	50%	296	Can be achieved by maximizing energy efficiency improvement, substantial phase-out of coal and pet coke and switching to lower carbon fuels, and substantially higher use of SCMs instead of clinker. Carbon capture, utilization, and storage (CCS) is also needed to achieve this target.
Transformative	75%	148	Will require CCUS to achieve this target. This will also require innovation and the adoption of transformative technologies.

* More detailed information on potential actions for CO_2 emissions reduction can be found at (Bataille 2019, Hasanbeigi and Springer 2019c, RMI and China Cement Association 2022, International Energy Agency 2018).

4.2.2. Strategies for Decarbonizing China's Cement Industry

In the cement industry, process-related CO_2 emissions from calcination accounted for around 50% of total CO_2 emissions. In other words, around half of the CO_2 emissions from the cement industry are not associated with energy use. Therefore, deep decarbonization in the cement industry (Transformative scenario) cannot be achieved even by the best available energy-efficient technologies or fuel switching alone. Clinker substitution and CCUS are imperative to achieve deep decarbonization in the cement industry in China. Material efficiency and circular economy measures can help to reduce the carbon footprint of cement and concrete used on the demand side. Below we briefly discuss major decarbonization levers for the cement industry (Bataille 2019, Hasanbeigi and Springer 2019c, RMI and China Cement Association 2022, International Energy Agency 2018).

Energy efficiency: Although many of China's cement plants are relatively new and energy efficient, there is still room for improvement. Many energy efficiency technologies are commercially available. These include waste heat recovery (WHR) technologies, high-efficiency clinker cooling and grinding processes, strategic energy management, smart sensors, advanced analytics, etc.

Material efficiency and circular economy: For cement production, material efficiency through optimized concrete recipes and the recycling of cement and concrete can be a significant decarbonization lever. In fact, the Global Cement and Concrete Association estimates that efficiency in design and construction can reduce global cement and concrete CO_2 emissions by 22% by 2050 (Global Cement and Concrete Association 2022). Another study estimated that optimized concrete recipes can reduce CO_2 emissions by 8-30% (Karlsson et al. 2020). By creating better designs that reduce cement and concrete demand, and through innovations in cement recipes, substantial reductions in material use and associated emissions can be achieved. Such optimizations aim to reduce the demand for raw materials and energy in the cement manufacturing process, thereby contributing to overall decarbonization efforts in the sector. Concrete components (cement, sand, gravel and other aggerates) can be ground and recycled, thus reducing demand for new sand and gravel, which face supply limitations. In many cases, cement can also be reused as filler or reactive cement.

Fuel switching and electrification: Switching away from coal to lower-carbon fuels that are available in large quantities and can be easily used in cement plants with current technologies are the main fuel switching option in the near term. In China, current options include bio-based waste-derived fuels and biomass. In the long-term, near zero-carbon fuels (e.g. green hydrogen, renewable natural gas), or electrification of process heating could be considered.

Clinker substitution and alternative raw materials: All the fuel used and around 60% of the electricity used in a cement plant is consumed for clinker production (for raw material grinding, fuel preparation, and cement kilns). A higher clinker-to-cement ratio results in higher energy intensity per tonne of cement produced. Replacing clinker with supplementary cementitious materials (SCMs) such as fly ash, blast furnace slag, natural pozzolans, ground limestone, and calcined clay can help to significantly reduce CO_2 intensity per tonne of cement produced. While China has a lower clinker-to-cement ratio, there is still potential for 50% clinker replacement for some construction applications. In addition, there are alternative binding materials that use different raw materials besides Portland cement in order to reduce process-related CO_2 emissions. A number of these alternative binders are commercial or are being tested and developed by the cement industry (Hasanbeigi and Springer 2019b).

Carbon capture, utilization, and storage (CCUS): CCUS technologies are emerging for the cement industry that capture and compress CO_2 emissions and permanently store them underground or use the captured carbon to produce other materials. Carbon capture technologies are being piloted and demonstrated at several cement plants around the world. Carbon utilization technologies include using CO_2 for the concrete curing process, for production of aggregate and construction materials, to cultivate algae biomass, for production of chemicals and fuels by reacting it with hydrogen, and other applications, many of which are already commercialized. Given process emissions from cement production, CCUS will be a necessary part of achieving net zero cement production. However, it is also important to note that in developing countries like China, developers will be highly sensitive to potential cost increases driven by expensive technologies like CCUS, and policy incentives as well as increased emphasis on other decarbonization pillars, especially in the near- to medium-term, will need to be taken into account.

4.2.3. The Potential Impact of Cement GPP in China

Using the annual CO_2 emissions associated with cement consumed in China from the previous chapter and the targets set in Table 4, we estimated the annual CO_2 emissions reduction potential resulting from GPP for cement in China (Figure 13).

The potential indirect impact assumes that changes in Chinese cement plants to reduce CO_2 emissions to meet GPP targets would impact the CO_2 intensity of all cement produced and sold even to non-government-funded projects. The scale of such indirect impact is less clear; therefore, it is shown by striped bars on the charts (Figure 13).

Under the Low scenario for a GPP target for cement, an annual emissions reduction of 69 Mt CO_2 can be achieved directly from government procurement of cement for construction. This direct annual CO_2 emissions reduction potential would increase to 344 Mt CO_2 under the Transformative scenario. The potential CO_2 emissions reduction impact of GPP for cement would be more than tripled if we consider the potential indirect impact from the cement sold to non-public construction since the changes that cement plants make for CO_2 emissions reduction applies to all cement they produce.

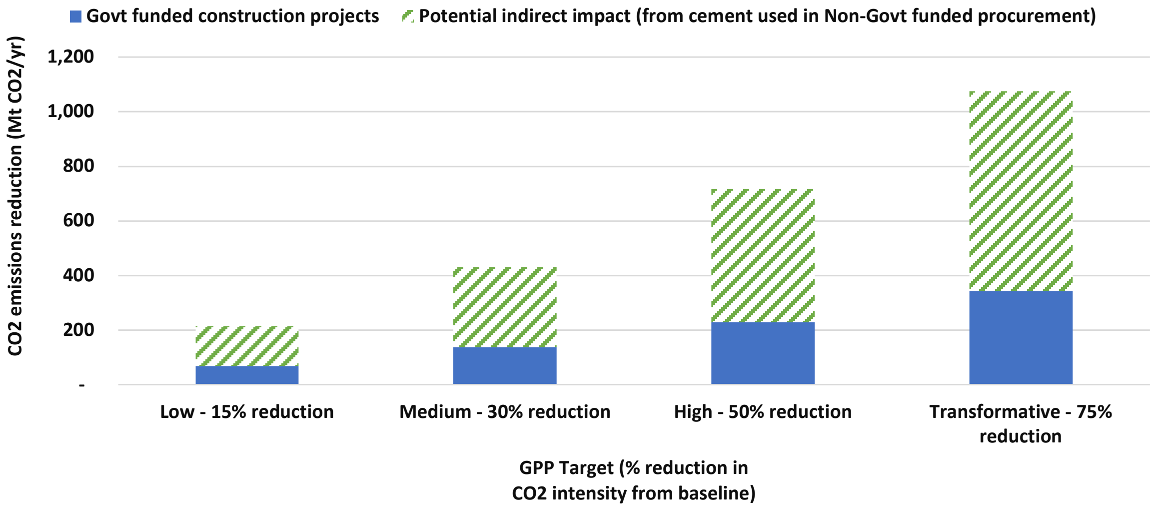

Figure 13: Annual CO_2 emissions reduction potential resulting from GPP for cement in China.

5 GPP and Relevant Policies in China

5.1. Relevant Policies for China's Steel and Cement Sectors

China has a national commitment to peak CO_2 emissions before 2030 and achieve net zero emissions by 2060, which broadly drives overall decarbonization trajectories in the country. In addition to the national 14th Five-Year Plan, China has also developed more sector-specific plans, including the Implementation Plan for Carbon Peaking in the Industrial Sector; the 14th Five-Year Plan for Raw Materials, which was released in 2021 by the Ministry of Industry and Information Technology (MIIT), the Ministry of Science and Technology, and the Ministry of Natural Resources; and MIIT's 14th Five-Year Plan for Green Development in Industry. These cover several carbon-intensive sectors, notably iron and steel as well as building materials. One of the major focal points of these plans is a strategic approach to industrial clustering. For instance, the plan recommends positioning EAFs close to cities, providing them easier access to scrap steel. Additionally, there's a shift towards low-carbon manufacturing technology. This includes a dedicated focus on R&D for pre-commercial hydrogen applications in both steel and cement, carbon capture in cement, and the integration of mature technologies, like the use of waste-derived fuel in cement kilns (Sandalow et al. 2022).

When it comes to specific targets, the plans aim for the cement industry to achieve a 2% decline in energy intensity and 3.7% for steel by 2025. The industry also plans to increase the usage of recycled steel from 260 million tons in 2020 to 320 million tons by 2025. Policies are being put in place to incentivize the adoption of EAFs, given their potential to significantly reduce carbon intensity of the Chinese steel industry.

The broader 14th FYP Outline encourages sectors to strive for emissions peaks before the national goal of 2030. For example, the cement industry is targeting its emissions peak by 2023, and the building materials industry aims for 2025. Similarly, the coking coal industry, a crucial component in steel production, has set its sight on a 2025 peaking target. Notably, several major state-owned enterprises in the steel and cement sector have announced peaking targets ranging between 2022 and 2025, including Baowu Steel, HBIS, Taiwan Cement, and Anshan Steel. The China Building Materials Federation announced a 2023 peaking target for the cement sector as part of a general 2025 peaking target for the whole building materials sector. A potential national emissions peaking action plan for the steel may set a 2025 target date for steel emissions peaking followed by a 30 percent reduction from peak levels by 2030 (Downie 2021).

It should also be noted that China recently established a national emissions trading system that aims to eventually cover emissions from the steel and cement sectors. China's national Emissions Trading System (ETS) is the world's largest carbon trading system by volume of emissions covered. Originally starting with the power sector, it is meant to cover more sectors over time. China's ETS takes the form of a tradeable performance standard, with the goal of eventually auctioning emissions permits to provide a financial incentive for regulated companies to reduce their emissions. The effectiveness of the ETS will depend on its stringency, demand for permits, and the robustness of monitoring, reporting, and verification systems.

5.2. China's GPP Policies and Stakeholders

China's journey towards Green Public Procurement (GPP) began with the Bidding Law of 1999, which laid down the basics for public procurement processes. A significant leap was made with the Government Procurement Law of 2003, urging the prioritization of environmentally friendly and resource-efficient products. This commitment was followed by a slew of specialized GPP policies over the next decade. For instance, 2004 saw the initiation of a preference for Energy Conservation Products (ECPs) in government purchases. By 2006, a list of "environmental labeling products" (ELP) was introduced for governmental use. Compulsory procurement of certain ECPs like air conditioners, televisions, and computers was implemented in 2007. The Ministry of Environmental Protection (MEP) began certifying low-carbon products in 2010. Additionally, GPP found mention in China's strategic 12th and 13th Five-Year Plans, emphasizing its integration into national development agendas (Hasanbeigi et al. 2019).

More recently, in 2019, four ministries issued "The Notice on Adjusting and Optimizing the Implementation Mechanism of Public Procurement for Energy-Saving Products and Environmental Labeling Products", which required priority procurement and mandatory procurement of green products based on new inventories and certificates, including for building materials such as cement and concrete. A number of 2022 carbon peaking implementation plans, formulating around achieving the 2030 carbon peaking goal, call for improvements in carbon footprint accounting, certifications and labels, and general support for GPP. The 2022 Implementation Plan for the Raw Materials Industry proposes to establish a life cycle-based inventory of carbon footprint for key products, and the Implementation Plan for Carbon Peaking in the Industrial Sector proposes to incorporate CO_2 emissions indicators for cement, among other products, into the green building materials standard (Guo et al. 2023).

While there aren't explicit quantitative CO_2 or GHG GPP targets at the national level, China's general approach spans multiple environmental goals, not just CO_2 emissions reductions. These encompass air pollution reduction, climate change mitigation, resource conservation, and public health protection, among others.

To aid GPP in China, lists of ECP and ELP have been made available to the public on various official websites. These resources, freely accessible, enable both procurers and the general public to be informed about green products. MOHURD has established a Green Building Materials Information Application database.[4] China's steel sector currently has a voluntary EPD platform known as the China Iron and Steel Industry EPD Programme, overseen by the China Iron and Steel Association and managed by Ouyeel Co. Operating as a non-profit, its primary funding comes from registration fees collected from organizations creating and registering their EPDs (CISA 2023). At present, there are very few steel product EPDs published on the platform.

With regards to green procurement of building materials specifically, China has developed several policies since 2016. From 2016 to 2019, several policies were issued regarding certification and labeling of green building materials products. In 2020, China issued the "Notice on the Issuance of an Action Plan for the Construction of Green Building", and a notice regarding pilots. Six pilot cities were announced in 2020, and by 2022, about 48 pilot cities were implementing green building material public procurement policies. These procurement policies largely considered environmental impacts other than CO_2 emissions (e.g. air and water pollution). In 2022, China issued the "Green Building and Building Material Public Procurement Requirements and Standards", which specified that GHG emissions calculation

4 https://www.shuzijiancai.com/database/

and analysis should take into account the full product life cycle, including emissions from the production of building materials, and the emissions reduction benefits of greener building materials should be analyzed. The technical standards for green building materials include energy use and CO_2 intensity thresholds for hot-rolled steel structures and ready-mixed concrete, among other products, but these standards are not binding.

Therefore, China's green building material public procurement policies do not yet have mandatory CO_2 intensity criteria for steel and cement used in public construction at the national level.

China's Green Public Procurement (GPP) framework is spearheaded by several key governmental and institutional entities. The Ministry of Housing and Urban-Rural Development sets benchmarks for buildings, supervises pilot projects, and manages product databases. MIIT provides technical guidance and establishes evaluation approaches. Simultaneously, the Ministry of Finance (MOF), which manages the overall procurement budget, is tasked with managing a centralized purchasing catalog and ECP and ELP lists. The State Administration for Market Regulation also play a role in labeling and approving certification bodies. The aforementioned ministries report to the State Council, the highest administrative authority in China.

Integral to this structure are committees like the Green Construction Material Product Certification Technical Committee, anchored at the China Development Strategy Institute for the Building Materials Industry, and the Green Construction Material Technical Standards committee, led by the China Association for Engineering Construction Standardization (Zhang et al. forthcoming). These committees provide technical support to the government ministries and other stakeholders.

Less involved though still important, the Ministry of Ecology and Environment (formerly Ministry of Environmental Protection) focuses on environmental labeling, issuing relevant standards. Partnering with MOF, the National Development and Reform Commission (NDRC) oversees the ECP list and regulates government procurement initiatives.

There are additional certification entities like the China Quality Certification Centre, China Environmental United Certification Centre, and the Environmental Development Centre that play a role in formulating, upholding, and promoting product certification schemes and environmental labeling standards, respectively. Some of these entities are also engaged in international exchange and collaboration.

In terms of procuring agencies, key purchasers include the State-owned Assets Supervision and Administration Commission, the Ministry of Transport, provincial versions of MOHURD and MIIT, and other provincial governments (Zhang et al. forthcoming).

6 Challenges and Policy Recommendations

6.1 Common Challenges to Green Public Procurement Policy

There are several challenges shared by all countries seeking to implement a GPP policy for construction materials such as steel and cement. The first set of common challenges is around establishing emissions reporting standards. Emissions reporting standards are essential for comparing products to one another in terms of environmental impact. This requires selecting one format of reporting, typically an environmental product declaration (EPD), and defining the system boundaries (i.e. which stages of production should be counted). Another challenge is ensuring the emissions data used to produce EPDs are reliable and comprehensive. In some cases, data is unavailable if one segment of the supply chain does not report its emissions. Reliability of data can be especially difficult in China, where quality of environmental data is generally low.

A second challenge is setting feasible yet ambitious targets for emissions reduction. The targets must be ambitious to incentivize low-carbon innovation, yet also reasonably achievable. As a result, developing targets requires close engagement with industry and other stakeholders, without compromising on ambition.

A third common challenge is the potential cross-border effects of a GPP policy. If an imported good is not subject to climate policy in its country of origin, it may have higher embodied emissions that are not accounted for by the domestic policy. Manufacturers may avoid the need to move towards lower-carbon production processes by selling to another nation with no embodied emissions policy, which could be a major challenge for China given its existing global market dominance. The second is a potential loss of market share to imported materials. If domestic manufacturers invest in R&D and facilities transformation to reduce emissions, their costs may go up. This could lead to a competitive disadvantage relative to imported materials which do not face these costs. For green public procurement to successfully drive innovation, it must be paired with policies that address the carbon loophole (Hasanbeigi and Darwili 2022), such as the emerging CBAM policy in the EU and similar proposed legislation in the U.S.

6.2. China-Specific Challenges to GPP

In addition to the challenges alluded to above, the magnitude and diversity of China's public procurement landscape present unique challenges in its pursuit of GPP for steel and cement. Firstly, the sheer scale of public procurement in China, a consequence of its vast population and state-centric economic model, introduces monumental logistical and managerial challenges, with the volume of transactions demanding innovative strategies for efficient oversight.

Secondly, the discrepancies in economic development and structure across China's provinces pose a particular hurdle. While metropolitan hubs like Beijing and Shanghai might have the resources and know-how to seamlessly adopt GPP, the less affluent regions may grapple with resource constraints and lack of expertise for implementation. These differences may be exacerbated by ongoing economic issues in China such as low growth rates, provincial debt, etc. In addition, certain provinces have far more steel and cement production than others. Hebei province alone produces nearly a quarter of China's steel, followed by Jiangsu (11%), Shandong (8%), Liaoning (7%), and Shanxi (6%) (Hasanbeigi et al. 2023). Shandong, Jiangsu, and Guangdong provinces lead the country in cement production, accounting for roughly 25%

of China's cement production (Xu et al. 2022). This distribution means that policy and technology choices in a few provinces may have an outsized influence on the total industrial emissions of the country. China frequently pursues subnational pilots as a way to test and improve policies, given the large variations across cities and provinces.

This uneven developmental landscape also ushers in the third challenge: the potential for a fragmented approach to GPP, where varying standards across provinces can lead to inconsistencies and inefficiencies. China's provincial and local governments also engage in public procurement, although we did not assess subnational procurement in this study. By some estimates, local-level government procurement spending on goods, engineering, and services was over ten times the amount spent at the central level in China (Ministry of Finance 2021). The large amount of local government procurement in China may theoretically limit the impact of a national GPP policy, but China has strength and experience in applying national policy frameworks to local government activity.

Developing expertise in green procurement is a challenge shared by all countries - procuring officials need to learn about embodied emissions, EPDs, lifecycle analysis, and new frameworks for bid evaluation. In China, this issue may be exacerbated by differences across localities in terms of budget and staffing to support building in-house expertise in green procurement.

Adding to the complexity is the pivotal role of State-owned Enterprises (SOEs) in China's economy. Of China's top ten steelmaking companies, seven are central or provincial SOEs. Of China's top ten cement producing companies, the top largest four in terms of installed clinker capacity are SOEs (Downie 2021). Balancing these entities' strategic national interests while steering them towards GPP compliance demands a politically sensitive approach. Already, some steel and cement SOEs have set energy and emissions-related targets, while others have not yet done so (Downie 2021).

Finally, given the complexity of China's regulatory structure, inter-ministry coordination emerges as a crucial challenge. Synchronized efforts between various governmental ministry, from the Ministry of Housing and Urban-Rural Development and the Ministry of Industry and Information Technology to the Ministry of Finance, are imperative for GPP's success, yet achieving this coordination within China's vast administrative structure can be challenging for any kind of policy.

6.3. International Examples and Best Practices

Governments worldwide have harnessed green public procurement as an effective policy instrument. Hasanbeigi et al. (2019) examined 30 such initiatives, with a focus on countries, cities, regions, and multilateral institutions. Some of the international best practices are explained in more detail below.

The Netherlands:

In the Netherlands, the GPP initiative introduces two distinct environmental criteria: quality criteria and performance criteria. Bids failing to meet the quality benchmarks are outrightly rejected. In contrast, the performance criteria prioritize green materials under the Most Economically Advantageous Tender (MEAT) evaluation without disqualifying bids. The program employs DuboCalc, a software tool which evaluates the environmental footprint of proposed projects based on materials usage. By analyzing 11 environmental parameters, the software produces a consolidated value: the Environmental Cost Indicator (ECI). To be considered, bids must adhere to a stipulated ECI, with further emissions reductions financially incentivized. Crucially, this holistic evaluation shifts the responsibility to the bidder, who then must balance cost, embodied emissions, and material longevity. To facilitate adoption, the Dutch public procurement expertise center, PIANOo, offers online tools and information to guide both procurement officials and bidders (Hasanbeigi et al. 2019). Another key feature of the Dutch GPP program is the CO_2 Performance Ladder scheme for procurement of construction works and materials. The CO_2 performance of suppliers participating in the scheme is certified at levels ranging from 1 to 5, and achieving better performance leads to a discount in the bid price, financially incentivizing emissions reductions.

European Union:
On the European front, the European Commission has established foundational GPP criteria that member states adopt. These guidelines encompass selection criteria, technical specifics, award stipulations, and contract performance clauses. They are divided into core criteria, addressing primary environmental concerns, and comprehensive criteria for those seeking a more aggressive environmental stance. The European model advocates a project-level evaluation anchored in a points system. Various environmental indicators, from global warming potential to acidification potential, are consolidated into a cumulative score. When traditional assessments are unavailable, alternatives such as carbon footprints or proxy data can be employed. However, the European system is currently voluntary (Hasanbeigi et al. 2019).

California and the United States:
The state of California pioneered the Buy Clean policy model in the U.S., mandating that state-funded projects weigh the global warming potential (GWP) of specific construction materials during procurement by setting intensity-based standards. Materials currently under this mandate include structural steel, concrete reinforcing steel, flat glass, and mineral wool insulation, with concrete likely to join the list soon. The policy roll-out was phased. Initially, for three years, material manufacturers needed to provide facility-specific EPDs with their bids. Then, from July 1, 2022, adherence to GWP limits became compulsory for securing state-funded projects. These thresholds, set at the industry mean for each material, undergo a review every three years, with potential adjustments mirroring industry advancements (California DGS 2022). Several other states have adopted similar policies in the U.S., namely Washington, Oregon, Colorado, and Minnesota (Hasanbeigi et al. 2021).

It should also be noted that the U.S. is in a pilot phase for a federal Buy Clean program. The U.S. federal Buy Clean policy is governed by the Buy Clean Task Force and the Environmental Protection Agency (EPA), which are responsible for determining and updating the list of materials eligible for green public procurement. Additionally, the Office of Management and Budget (OMB) and the EPA offer overarching guidelines on these procurement policies. Agencies are mandated by the OMB to establish green procurement plans and provide yearly updates on their GPP activities. Materials covered under this policy include concrete, cement, glass products, asphalt mix, steel products, aluminum, and iron. Moreover, assemblies that consist of at least 80% of these approved materials, either by total cost or weight, are also recognized under this policy. While the impact of federal Buy Clean policy is still emerging, one highlight is that the Inflation Reduction Act has Buy Clean specifications for procurement of $2.15 billion worth of low-carbon construction materials for federal projects by the GSA, and a similar amount for the Department of Transportation, a significant investment with huge potential effects. The U.S. has also set aside $250 million for an EPD Assistance Program, as well as $5.8 billion to support capital investments at industrial facilities (U.S. Council on Environmental Quality 2023).

6.4. Recommendations

Based on our analysis of challenges to GPP and a review of international best practices in GPP policies, we propose the following recommendations to advance GPP policy for construction materials in China. Based on our analysis of existing GPP policies in China and associated stakeholders, we also tailor these recommendations to different government ministries and relevant bodies in China (Figure 14).

- Accelerate development of emissions reporting standards and industry-wide EPDs. Reliable data is central to the successful implementation of GPP. Embodied emissions reporting must be rooted in accurate, supply-chain-specific data. To compare products against one another and prior years' products, this data must be reported in a clear and standardized format. China has begun developing labels, certifications, and standards for green building materials, which can be expanded to cover cement and steel more broadly. In addition, China's voluntary steel EPD platform can be scaled up and expanded to other categories of products, like cement and concrete. Given the central role of this data in the GPP, these efforts should be prioritized in a coordinated manner through additional resources from MOHURD, which is responsible for managing product databases, and the State Administration for Market Regulation, which manages labeling and certification. From the perspective of sequencing, this is the first step in GPP; without life cycle emissions data, it is impossible to set quantitative embodied emission limits. Therefore, expanding these standards and making them mandatory is the highest priority task at present. Examples of existing international EPD platforms and tools that could be leveraged include the Embodied Carbon in Construction Calculator (EC3), an automated repository for EPDs, and the National Ready Mixed Concrete Association's EPD software.

- Evaluate international best practices to find novel ways to encourage GPP. The central government, especially MIIT, given its role in technical guidance, should examine international best practices and evaluate different models to promote or ensure the uptake of GPP at the central and local level, including novel business models. There are also a number of voluntary international platforms that Chinese stakeholders, including technical committees, can participate in or observe, such as ConcreteZero, SteelZero, the First Movers Coalition, and the Industrial Deep Decarbonisation Initiative.

- Strengthen national GPP policies to avoid fragmentation. Local pilots are actively exploring and implementing GPP policies. A national GPP policy should move quickly to establish common reporting standards to ensure harmonization and quality control across regions. In addition, there should be a strong coordinating mechanism at the national level to ensure that the relevant ministries and subnational stakeholders work together effectively. This would require support from multiple ministries, potentially with leadership from the Ministry of Finance, a key ministry that manages the overall procurement budget.

- Adopt a two-tiered approach to foster innovation without compromising feasibility. While setting only basic environmental standards can help enforce best practices, it doesn't necessarily encourage ground-breaking advancements. On the other hand, overly ambitious targets might be impractical, risking the domestic industry's competitiveness. Following the EU GPP model can strike the right balance: establish base criteria at the industry's average for practicality and introduce a higher tier targeting the top low-carbon innovators. As a strategy, policymakers (especially from MOHURD, which plays a role in testing and deployment) could mandate that this top-tier standard applies to 10% of all public procurement. Procuring agencies like the Ministry of Transport and provincial governments can then decide which projects align with this elevated criterion. Alternatively, while the basic criteria remain mandatory, projects adhering to the higher standards can be financially incentivized, offering them a competitive edge in pricing.

- Prefer performance-based standards over prescriptive standards. Taking lessons from the Dutch green public procurement program, GPP standards should use whole-project life-cycle assessment over product-level standards where possible. This allows for comparison across materials: rather than prescribing technical details, this gives the bidder the flexibility to consider trade-offs between cost, embodied emissions, and durability of materials. The benefits of such an approach could be evaluated by MIIT, which is in charge of establishing evaluation approaches and technical guidance.

- Ratchet up standards over time. As technological advancements are made over time, GPP targets should be adjusted to reflect new industry capabilities. This ensures that GPP continues to promote green development and innovation. Maximum emissions intensity standards can be lowered at two- or three-year intervals. Given MOHURD's role in implementation and piloting, performance feedback from these programs could be used to set new standards.

- Create tools that can automate and simplify the implementation of GPP. Such tools can be used by local governments and private entities that have low administrative capacity. Many local governments do not have the time and resources to invest in training for GPP procurement. This, paired with the significant amount of procurement that happens at the local level, underscores the importance of national GPP bodies such as the State Administration for Market Regulation investing in tools that automate and simplify the implementation of the GPP policy.

- Pair investments in the procurement budget with investment in programs to build capacity. The use of EPDs and whole-project life cycle analysis will require a change in long-standing construction and procurement practices. It will take training for engineers to become familiar with the appropriate use of new materials, for construction workers to update processes such as concrete curing, and for procurement officers to adapt to evaluation criteria that go beyond the least cost. National GPP policies in China should be accompanied by training materials and programs to build this capacity, including by MIIT in conjunction with ministries that manage workforce planning and training.

- Engage in collaborative program design: It is necessary to involve industry and other stakeholders from the beginning stages of GPP policy development. Industry experts should be involved in choosing targets to ensure that the standards are ambitious yet feasible for industry to meet. Given its overall role in procurement and its involvement in many of the relevant issued GPP policies, the Ministry of Finance could play a role in facilitating collaboration.

- Invest in manufacturing dependencies. Investments are needing for building ancillary infrastructure to enable industrial decarbonization, such as green hydrogen and renewable energy generation. These investments are part of China's broader decarbonization plans and involve a range of other ministries, including NDRC, MEE, and others.

- Continue to invest in industrial transformation. Both central and local governments in China should provide loans, grants, and financial support programs to help manufacturers pay the upfront costs required for retrofitting industrial facilities, building new facilities, and retraining workforces. In addition, government support for R&D can enable breakthrough technologies like CCUS, kiln electrification for cement production, etc. that will be necessary to fully decarbonize steel and cement production. As a leading producer of equipment for cement and steel production, China can build a competitive green advantage by leading in greener production technologies.

MOHURD	MIIT	SAMR	Ministry of Finance	Other/Multiple Ministries
Accelerate the development of emissions reporting standards and industry-wide EPDs.	Evaluate international best practices to encourage the adoption of GPP.	Create tools that can automate and simplify the implementation of GPP policy.	Encourage collaborative program design.	Invest in manufacturing dependencies.
Ratchet up standards over time.	Prefer performance-based standards over prescriptive standards.		Strengthen national GPP policies to avoid fragmentation.	Continue to invest in industrial transformation.
Use a two-tiered approach to promote innovation while maintaining feasibility.	Invest in programs to build capacity.			

Figure 14: Recommendations to advance GPP policy for construction materials in China, and relevant ministries/government organizations.

Note: MOHURD: Ministry of Housing and Urban-Rural Development, MIIT: Ministry of Industry and Information Technology, SAMR: State Administration for Market Regulation.

7 Conclusion

Public procurement accounts for a significant share of the Chinese economy, and China's national government exerts significant purchasing power. We estimate that the total spending on the procurement of steel and cement for construction in 2020 in China amounted to 5.2 trillion yuan, with public procurement representing 32.5% of this total. Around 34% of steel (350 Mt/year) and 31% of cement (775 Mt/year) was used in government-funded construction in China. We also estimated the scale of embodied emissions associated with this public spending. Public procurement of steel and cement in China account for approximately 689 Mt CO_2 and 459 Mt CO_2 per year, respectively.

More and more governments are using their purchasing power to drive energy and carbon-intensive industries towards more sustainable products and materials through green public procurement. China has already made steps towards various GPP policies. Using scenarios for emissions reduction targets, we estimated the impact of a national GPP policy focused on reducing embodied CO_2 emissions. Table 5 shows the annual CO_2 emissions reduction potential resulting from GPP of steel and cement in China. Taking into account indirect impacts if GPP drove adoption of lower carbon intensity steel and cement production, then the total impact of direct public procurement of low-carbon steel and cement could reach 861 Mt CO_2 per year or 2,594 Mt CO_2 per year under a transformative scenario.

Table 5: Annual CO_2 emissions reduction potential from GPP for steel and cement in China (Mt CO_2 per year)

	Steel		Cement	
GPP Target	Govt funded construction projects	Potential indirect impact (from steel used in non-Govt funded procure-ment)	Govt funded construction projects	Potential indirect impact (from cement used in non-Govt funded procurement)
Low - 15% reduction	103	201	69	146
Medium - 30% reduction	207	401	138	292
High - 50% reduction	344	669	229	487
Transformative - 75% reduction	517	1,003	344	731

The implementation and adoption of green procurement of construction materials in China has begun, but there is more progress that can be made. The foundation of China's GPP policy rests on robust emissions reporting standards. To facilitate effective GPP implementation, China needs to accelerate the development and standardization of embodied emissions reporting across the supply chain. This begins with expanding the existing labels, certifications, and standards, especially for core materials like cement and steel. The voluntary steel Environmental Product Declaration (EPD) platform serves as a prime candidate for scaling and should be extended to other essential product categories like cement and concrete. By allotting additional resources, China should prioritize these efforts, ensuring that they are coordinated across various sectors. Since local governments have started creating their GPP policies, a national GPP framework should be swiftly rolled out to ensure unified standards and prevent fragmented initiatives.

Next, China should adopt a holistic approach to GPP policy. By examining international best practices, China can innovate and adapt suitable models that align with its unique requirements. Adopting a two-tiered approach, as seen in the EU GPP model, can achieve a balance between innovation and practicality. Over time, as technological advancements occur, GPP targets should be adjusted, promoting continuous green development. Training and capacity-building programs are essential so that engineers, construction workers, and procurement officers can be equipped with new skills and knowledge. Collaborative program design involving industry experts ensures the feasibility of set standards. To support industrial transformation towards greener alternatives, China should invest in ancillary infrastructure, such as green hydrogen and renewable energy generation. Further, financial support in the form of loans, grants, and programs will aid manufacturers in covering the initial costs associated with facility upgrades, new constructions, and training.

GPP in China can catalyze huge CO_2 emissions reductions in construction materials by acting as a signal of a reliable large government demand. This complements China's ongoing investments in industrial upgrading by demonstrating demand for the growing supply of low-carbon construction materials. Together, these policies can make China a green materials leader as domestic and global steel and cement markets shift and international climate policy strengthens.

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