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National carbon emissions from the industry process: Production of glass, soda ash, ammonia, calcium carbide and alumina

Zhu Liu *

Resnick Sustainability Institute, California Institute of Technology, Pasadena, CA 91125, USA
John F. Kennedy School of Government, Harvard University, Cambridge, MA 02138, USA

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ABSTRACT

China has become the world's largest carbon emitter. Its total carbon emission output from fossil fuel combustion and cement production was approximately 10 Gt CO_2 in 2013. However, less is known about carbon emissions from the production of industrial materials, such as mineral products (e.g., lime, soda ash, asphalt roofing), chemical products (e.g., ammonia, nitric acid) and metal products (e.g., iron, steel and aluminum). Carbon emissions from the production processes of these industrial products (in addition to cement production) are also less frequently reported by current international carbon emission datasets. Here we estimated the carbon emissions resulting from the manufacturing of 5 major industrial products in China, given China's dominant position in industrial production in the world. Based on an investigation of China's specific production processes, we devised a methodology for calculating emission factors. The results indicate that China's total carbon emission from the production of alumina, plate glass, soda ash, ammonia and calcium carbide was 233 million tons in 2013, equivalent to the total CO_2 emissions of Spain in 2013. The cumulative emissions from the manufacturing of these 5 products during the period 1990–2013 was approximately 2.5 Gt CO_2, more than the annual total CO_2 emissions of India. Thus, quantifying the emissions from industrial processes is critical for understanding the global carbon budget and developing a suitable climate policy.

1. Introduction

Climate change is one of the greatest challenges facing humankind today [1–3]. Human-induced carbon emissions are the major greenhouse gas emissions that drive anthropogenic climate change [2,4]. Carbon emissions can be generated by fossil fuel combustion, industrial production processes, waste treatment and land use change [5]. Fossil fuel combustion and cement production are the most significant sources of human-induced carbon emissions that have been reported by international datasets [6–9]. Cement production in particular is the largest source of industrial production emissions and has been widely reported. The amount of emissions from fossil fuel combustion and cement production are also considered baseline amounts for planning mitigation actions and allocating the mitigating responsibilities [10,11]. In addition to fossil fuel combustion and cement production, the manufacturing of mineral, chemical and metal products can generate carbon emissions [5], as chemical and physical transformations of materials can release CO_2. The IPCC lists several types of industrial products (see Table 1) the chemical or physical production of which can release carbon emissions. For example, global emissions from cement production were approximately 2000 Mt CO_2 in 2013 [9].

A more comprehensive understanding of the emissions from industrial processes is required (except for cement production, which has been widely reported; the calculation of emissions from the cement production process can be seen in our previous studies [12]). First, the sources of emissions from industrial processes can be diverse. In addition to the different types of industrial products that could produce CO_2, the different stages of the industrial process can emit CO_2. For example, carbon emissions from cement production refer to the direct emissions from the calcination process for clinker production (2A1 in IPCC classification). Direct primary energy combustion and indirect electricity consumption also occur during this process; emissions from these processes can be categorized as emissions from energy combustion (1A2 in IPCC classification). Carbon emissions from cement production arise from the production of clinker, which is the major component of cement. In the production of clinker, the calcination of calcium carbonate ($CaCO_3$) releases CO_2 emissions, but CO_2 can also be released during the calcination of cement kiln dust (CKD). Thus,

* Address: John F. Kennedy School of Government, Harvard University, Cambridge, MA 02138, USA.
E-mail addresses: zhuliu@caltech.edu, zhu_liu@hks.harvard.edu

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Table 1
Classifications of industrial process emissions by the IPCC.

IPCC classification	Calculated in this study
2: Industrial processes	
2A: Mineral industry	
2A1: Cement production	
2A2: Lime production	
2A3: Glass production	■
2A4: Other carbonation process	
2A5: Other process	
2B: Chemical industry	
2B1: Ammonia production	■
2B2: Nitric acid production	
2B3: Adipic acid production	
2B4: Caprolactam, glyoxal and glyoxylic acid production	
2B5: Carbide production	■
2B6: Titanium dioxide production	
2B7 Soda ash production	■
2B8: Petrochemical and carbon black production	
2B8a: Methanol	
2B8b: Ethylene	
2B8f: Carbon black	
2B9: Fluorides production	
2B10: Other	
2C: Metal industry	
2C1: Iron and steel production	
2C2: Ferroalloys production	
2C3: Aluminum production	■
2C4: Magnesium production	
2C5: Lead production	
2C6: Zinc production	
2C7: Other	
2D: Non-energy products from fuels and solvent use	
2D1: Lubricant use	
2D2: Paraffin wax use	
2D3: Solvent use	
2D4: Other	
2E: Electronics industry	
2G: Product is used as a substitute for ozone-depleting substances	
2H: Other manufacturing	
2H: Other	

Shaded cells are the industries that been calculated in this study.

precisely estimating the carbon emissions from cement production also requires the estimation of the carbon emissions from the production of clinker and the CKD, for which the complexity and difficulty of calculation increases. Second, the emission factors used for the calculation are highly dependent on the technology used for production, and this technology is specific to time zone and to region, thus causing difficulties for compiling the national emission factors for calculating emissions from industrial processes. Finally, the global relocation of manufacturing from the developed countries to the emerging economies introduces challenges for emission calculations, given the incomprehensive statistics system of industrial production and the lack of sufficient information regarding the technology level of developing countries.

This study aims to present a quantitative estimation of national carbon emissions from industrial production processes. We focus on China, now the world's top consumer of primary energy and emitter of carbon emissions. Its rapid economic development and industrialization processes [13,14] have made China the world's top consumer of primary energy and emitter of greenhouse gases [15]. In 2013, the total carbon emissions generated by China was already higher than the combined emissions of the U.S. and the EU [16]. Moreover, China has assumed the dominant position in global manufacturing [17], as its production of iron, steel, coke, cement and glass constitute greater than 50% of global production [18]. Emissions from cement production have been reported by international agencies such as CDIAC [19] and EDGAR [9]. However, to our knowledge, emissions from other industrial processes including those for mineral products (e.g., lime, soda ash, asphalt roofing), chemical products (e.g., ammonia, nitric acid) and metal products (e.g., iron, steel and aluminum), have not been reported in the literature.

Many types of industrial processes could release carbon emissions, including but not limited to the production of iron and steel, metallurgical coke, cement, aluminum, soda ash, titanium dioxide, lime, carbonates ammonia, petrochemicals, glass, zinc, phosphoric acid, lead, silicon carbide and nitric acid. We investigated the manufacturing of 22 industrial products (iron, steel, finished steel, titanium, coke, cement, plate glass, sulfuric acid, soda ash, caustic soda, ammonia, ethylene, calcium carbide, agrochemicals, nitrogen, phosphorus, chemical pesticides, non-ferrous metal, refined copper, aluminum, alumina and lima). We calculated the emissions of five industry processes based on the available data concerning both production and emission factors.

Supported by the nationwide investigation of the factory-level technologies that aim to calculate the emission factors, this research used the national emission factors reported by the National Development and Reform Commission (NDRC) [20] to calculate the emissions of 5 major industrial production processes, namely those of alumina, plate glass, soda ash, ammonia and calcium carbide. We also calculated the emissions resulting from the production of iron and steel; however, such emissions are categorized as emissions from energy consumption (1A2 in IPCC classification), given the fact that the emissions were generated during the coke combustion that was used as a reducing agent. Our calculation thus does not incorporate the emissions from iron and steel production.

2. Methodology

Carbon emissions from industrial production refer to the CO_2 released from the physical–chemical process of transforming raw materials into industrial products. The fossil fuels used in this transformation stage are considered the carbon emissions from fossil fuel combustion performed by the industrial sectors and are not considered as the industrial process emissions. For example, emissions from the calcination of calcium carbonate ($CaCO_3 \rightarrow CaO + CO_2$) are considered industrial process emissions. By contrast, emissions from fossil energy usage during the calcination process are considered energy-related emissions.

According to the IPCC's Guidelines for National Greenhouse Gas Inventories, industrial process emissions result from several types of industrial production: Mineral industry (2A), chemical industry (2B), metal industry (2C), non-energy products from fuels and solvent use (2D) and other industry (2H). The detailed classifications are provided in Table 1.

In this study, we calculated the emissions from 5 types of major industry production processes. On the one hand, these emissions are not reported in existing emission data sets; on the other hand, the openly accessible data sources can be supported by the calculation.

The IPCC [5] suggested three basic methodologies to estimate industrial process emissions. The Tier 1 approach, also known as the reference approach, is an output-based approach that estimates emissions based on the production volume and the default emission factors. The emissions factors refer to the emission amounts per production unit, which amounts vary depending on the production processes; the global average emission factors will be used in the Tier 1 approach, and the emissions are estimated by the mass production amount and the mass of emissions per production unit (global average value). The Tier 2 approach is also an output-based approach, but estimates emissions based on production and country-specific information for correction emission

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