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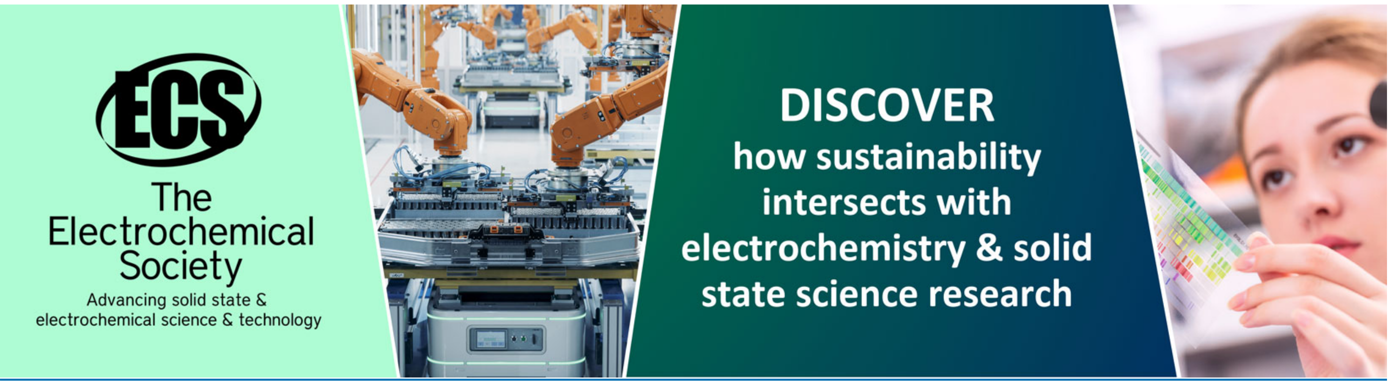

Greenhouse Gas Emissions of Global Construction Industries

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Abstract. The global construction industry is responsible for considerable effects on the environment and society. The construction and use of our built environment accounts for 39% of global greenhouse gas emissions. Population growth and rising standards of living are further exacerbating these problems. Understanding the contribution of construction industries and those activities responsible for the greatest share of greenhouse gas emissions is crucial in order to identify opportunities for emissions mitigation. This study uses multi-regional input-output analysis to analyse the embodied greenhouse gas emissions of global construction industries. A structural path analysis (SPA) was conducted for the construction sectors of 44 countries using top-down economic input-output data from EXIOBASE3. The findings were analysed to compare the embodied greenhouse gas emissions of each construction sector to ascertain their emissions intensity. The structural path analysis was used to disaggregate each sector into unique nodes or pathways, with each representing a single or group of activities and their associated emissions. This was used to identify critical hot spots of emissions within the various construction supply chains. The results show that there is wide discrepancy between the emissions intensity of the construction industry for the 44 countries, ranging from 0.165 $kgCO_2e$/Euro to 2.05 $kgCO_2e$/Euro. In addition, the most significant contributors to emissions for the most emissions intensive countries are the production of concrete and steel. This in-depth analysis of global construction industries using multi-regional input-output data provides critical information needed to identify opportunities for reducing global construction-related greenhouse gas emissions. This will help prioritise future emissions reduction efforts within the construction industry and target specific solutions to achieve the greatest improvements to the overall environmental performance of global construction industries.

Keywords: Construction sector, greenhouse gas emissions, multi-regional input-output analysis.

1. Introduction

The construction and use of our buildings and infrastructure contribute more than any other single sector to global energy use (36%) and greenhouse gas (GHG) emissions (39%) [1]. These have continued to increase, and in 2018, they reached record highs, up 7% from 2010 levels, despite global efforts to reduce them. Improvements to building envelopes and building energy systems have offset some of the growth in building related GHG emissions in recent years. However, GHG emissions have continued to rise due to increasing demand for electricity. Global population growth and rising living standards will put further pressure on these GHG emissions, fueled largely by an expected threefold increase in air conditioning use by 2050 [2] and increasing demand for materials. Buildings and infrastructure thus represent one of the most important and cost-effective options for mitigating global GHG emissions [3]. A critical part of this will be addressing embodied GHG emissions - those emanating from the manufacture of building materials and the construction process – as they account for around a third of all building-related emissions [4]. As our buildings head towards net-zero operational GHG emissions, these embodied GHG emissions will become even more significant. In response to this, the World Green Building Council [4] has called for a 40% reduction in construction-related embodied GHG emissions by 2030 and net-zero embodied GHG emissions by 2050.

The construction industries of the world have a critical role to play in reducing the embodied GHG emissions of our buildings and infrastructure projects as they are ultimately responsible for their construction, including the specification of materials and components. To achieve these emissions reductions, an understanding of the source of emissions is critical. Construction companies have most control over activities involved in the construction process, which are mostly project site based. However, the majority of emissions occur upstream of these main site-based construction activities [5]. The role of designers, engineers and other consultants becomes even more important in this context due to their influence over the materials and construction approach used. A general understanding of the need to reduce the use of cement-based products, increase the use of sustainably sourced renewable materials and reuse existing materials is now well known. Despite this, a holistic understanding of the broad areas for emissions reduction across the entire construction supply chain is lacking. A key reason for this stems from the inability of commonly used emissions assessment techniques to capture supply chain wide processes and associated emissions.

In an attempt to address this issue, environmentally extended input-output models have been used. When used to disaggregate the supply chain of an entire industry, the most significant emissions sources can be easily identified, allowing them to be prioritised for future mitigation. These models have been used to analyse various environmental flows for the construction industry of several individual countries, such as China [6], UK [7], Ireland [8] and Australia [9]. In many cases, these analyses are limited to a single region, or connections to the global supply chain are aggregated at the highest possible level. As construction supply chains are increasingly globally connected, it is just as important to be able to interrogate imported sources of emissions as it is for those of locally sourced goods and services. This is made possible with a multi-regional input-output model, such as EXIOBASE [10], WIOD [11] or EORA [12].

The aim of this study was to compare the GHG emissions of selected global construction industries and identify critical hot spots for emissions reduction using a comprehensive MRIO analysis.

2. Research method

This section describes the method used to quantify the GHG emissions associated with the construction industry for 44 countries, including the identification of key emissions hotspots for the top five most emissions intensive construction industries.

2.1. Quantification of greenhouse gas emissions

This study uses an environmentally extended multi-regional input-output (MRIO) analysis to quantify greenhouse gas emissions. This section describes the MRIO model used, including the process for determining the GHG emissions for each country's construction industry. The process of conducting a structural path analysis is then described in order to identify the key emissions sources within each construction industry. It should be noted that the GHG emission values calculated are intensities, rather than absolute emissions. This enables a comparison between countries regardless of construction activity. In reality, absolute emissions will vary based on actual construction activity which will be non-identical for each country. However, as the value of construction activity per annum will likely change, sometimes significantly, an average intensity can be a much more useful indicator of environmental efficiency of construction activity in a particular country.

2.1.1. MRIO model

The MRIO model used for this analysis is based on the input-output tables from EXIOBASE3 [10]. This version includes input-output tables for 44 countries as well as five rest of world (ROW) regions, disaggregated into 163 industries per country/region (a total of 7,987 industries). These input-output tables provide information on the relationship within and between individual industries and products, such as the construction industry. The input-output tables are processed as per [13], with the direct and total GHG emissions associated with each industry determined.

2.1.2. Structural path analysis

In order to better understand the source of GHG emissions associated with each country's construction industry, a structural path analysis (SPA) was used to disaggregate their supply chains into individual nodes or processes. There are a potential maximum 32 quintillion nodes for each construction sector at just five stages upstream in the supply chain (7,987 industries at stage 1, $7{,}987^2$ industries at stage 2, $7{,}987^3$ industries at stage 3 etc.). The SPA was conducted as per [13] using the same user interface (GUI) and python package [14]. The input-output database is loaded into the GUI. The SPA is conducted for each construction sector, one by one. To meet current computing processing capabilities, nodes representing less than 0.0001% of the total emissions intensity for each construction sector were excluded and the analysis was performed to a maximum of five stages upstream. The output of the SPA is a series of mutually exclusive nodes, each representing a good or service provided from one stage to another within the construction supply chain analysed. A series of nodes, corresponding to a chain of transactions leading to the construction sector being assessed, is referred to as a pathway – for instance, iron ore purchased by the reinforcing steel bar sector, in turn purchased by the construction sector for an apartment building. Each node contains data on its associated GHG emissions intensity (in $kgCO_2e$/Euro). The model analyses multiple flows at the same time and automatically ranks nodes in order of importance. This helps identify emissions hotspots at various stages of the supply chain.

3. Results and discussion

This section presents the total GHG emissions intensity associated with the construction industry of 44 countries, based in EXIOBASE3 data (Figure 1). This shows that the total GHG emissions intensity for these countries varies from 0.165 $kgCO_2e$/Euro to 2.05 $kgCO_2e$/Euro with the top five most GHG emissions intensive construction industries being in China, India, South Africa, Taiwan and South Korea. The least emission intensive construction industry was found to be that of the United Kingdom.

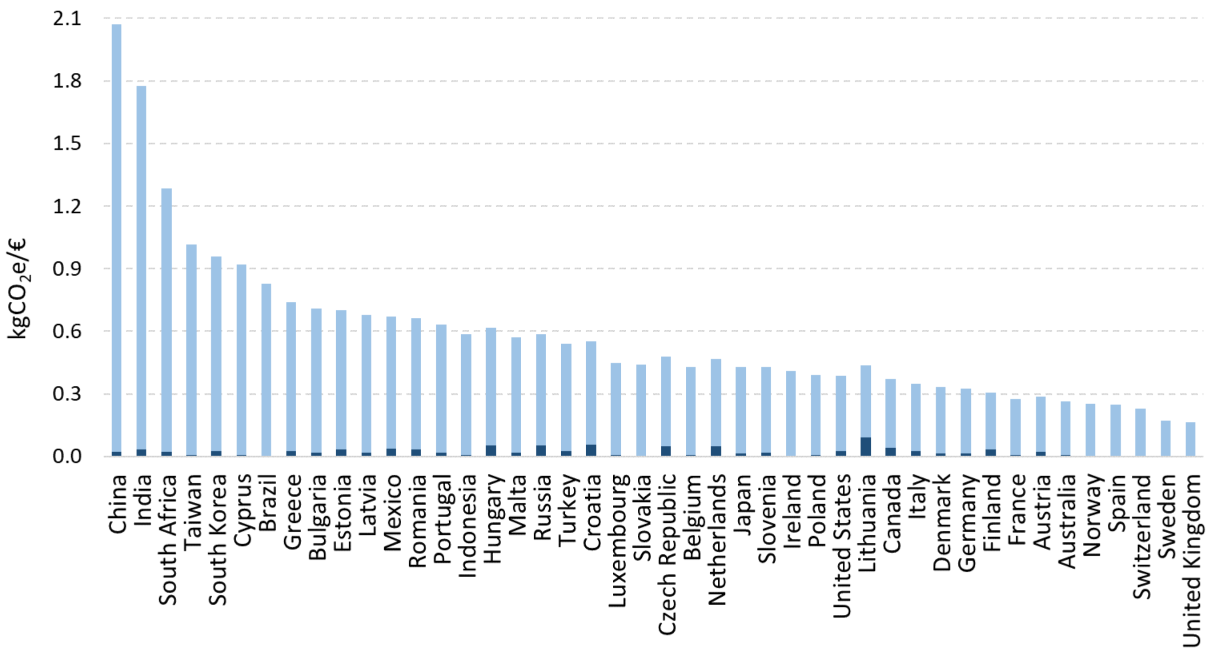

Figure 1 Direct and total GHG emissions intensity for the construction industry of 44 countries

Figure 1 also shows the direct emissions intensity for the construction industry of each country. Direct emissions, also known as scope 1 emissions, account for the emissions resulting from mainly site-based activities, such as the use of machinery and equipment that requires the burning of fuel. These direct emissions generally represent a small proportion of the total emissions of the construction industry due to the emissions intensive processes that occur further upstream in the construction supply chain (from the production of cement, steel and electricity, for example). The direct emissions were found to represent between 0.33%, or 0.0027 $kgCO_2e$/Euro (Brazil) and 26.6%, or 0.092 $kgCO_2e$/Euro (Lithuania) of the total emissions across the 44 country's construction industries (average of 5% or 0.023 $kgCO_2e$/Euro). A higher direct emissions intensity may mean a country relies on more emissions intensive construction processes, simpler construction with less materials, or uses materials with lower GHG emissions intensity.

There may be multiple reasons for a high indirect emissions intensity, such as that seen in China and India. This could include an emissions intensive local fuel mix, large reliance on products or services with emissions intensive manufacturing processes (e.g. transport and concrete), or large reliance on goods and services imported from countries with an emissions intensive fuel mix.

Table 1 provides the results of the structural path analysis of the top five most GHG emissions intensive construction industries, based on Figure 1. While a very large number of nodes were identified by the SPA, only the top five processes/inputs are shown, with the remainder representing less than 2.8% of the total emissions intensity for each country's construction sector, each. This shows that the manufacture of 'cement, lime and plaster' and steel products are responsible for the majority of GHG emissions for these most emissions intensive construction industries.

Table 1 Source and proportion of total emissions for top five most emissions intensive construction industries

	Stage 1	Stage 2
China		
29.1%	Manufacture of cement, lime and plaster	
4.8%	Re-processing of ash into clinker	
3.6%	Manufacture of basic iron and steel and of ferro-alloys and first products thereof	
2.5%	Manufacture of other non-metallic mineral products nec	
2.2%	Manufacture of cement, lime and plaster	Mining of coal and lignite; extraction of peat
India		
17.9%	Manufacture of cement, lime and plaster	
9.2%	Manufacture of basic iron and steel and of ferro-alloys and first products thereof	
6.8%	Manufacture of basic iron and steel and of ferro-alloys and first products thereof	Mining of coal and lignite; extraction of peat
3.7%	Re-processing of secondary steel into new steel	
3.0%	Construction	Manufacture of cement, lime and plaster

	Stage 1	Stage 2
South Africa		
10.8%	Manufacture of other non-metallic mineral products nec	
5.6%	Manufacture of cement, lime and plaster	
4.8%	Re-processing of ash into clinker	
3.5%	Manufacture of rubber and plastic products	Production of electricity by coal
3.2%	Manufacture of other non-metallic mineral products nec	Manufacture of cement, lime and plaster
Taiwan		
8.4%	Manufacture of other non-metallic mineral products nec	Manufacture of cement, lime and plaster
7.8%	Quarrying of sand and clay	
5.0%	WA-Manufacture of other non-metallic mineral products nec	
4.6%	Manufacture of other non-metallic mineral products nec	Quarrying of sand and clay
4.6%	Manufacture of other non-metallic mineral products nec	Manufacture of cement, lime and plaster
South Korea		
16.7%	Manufacture of cement, lime and plaster	
3.8%	Re-processing of ash into clinker	
2.9%	DIRECT Stage 0	
2.6%	Manufacture of other non-metallic mineral products nec	
2.0%	Manufacture of cement, lime and plaster	Manufacture of cement, lime and plaster

While this study provides useful and detailed insight into the potential environmental effects of some of the world's major construction industries, it should be noted that relying on input-output data alone has major limitations. This data enables a more holistic, whole-of-economy perspective of the transactions between industries and their associated environmental flows. However, as it is based on financial, rather than physical quantities, and a number of assumptions are used in the compilation and use of this data, the reliability and relevance when applied to specific goods or services is limited. Further in-depth analysis of the SPA results is also needed to: identify trends across a larger number of countries; target more detailed analysis of construction supply chains using bottom-up data; and recommend appropriate GHG emissions reduction strategies.

4. Conclusion

The aim of this study was to compare the greenhouse gas emissions intensity of 44 countries and explore key areas for emissions mitigation. An environmentally extended multi-regional input-output analysis was conducted to identify the emissions intensity of each country. This found China and India to have the most emissions intensive construction industries, at 2.05 $kgCO_2e$/Euro and 1.74 $kgCO_2e$/Euro, respectively. The least emissions intensive construction industry was that of the United Kingdom at just 0.165 $kgCO_2e$/Euro. With direct emissions accounting for on average 5% of total emissions associated with construction activity across all countries, this indicates that the benefit in addressing these emissions is likely to be very minimal. Thus, the major emissions mitigation efforts should be focused on emission sources further upstream in the supply chain.

Previous studies and data on the GHG emissions of global construction industries generally provide emissions information on site-based activities and key related industries within the construction supply chain (e.g. concrete and steel production). However, this study is unique as it provides a more holistic analysis by including the entire supply chain, including emissions associated with both goods (e.g. materials) and supporting services. It also provides greater insight into the key areas for emissions mitigation, using a SPA to disaggregate the construction industry supply chains into discrete pathways and nodes for each of the top five countries in order to identify the upstream source of emissions for each country's construction industry. This showed that future emissions reduction efforts should focus on 'cement, lime and plaster' and steel products in order to achieve the greatest emissions reductions. Significant inroads have already made into reducing the GHG emissions associated with the production of cement, concrete and steel, with SCM as a substitute for cement and low emissions steel being increasingly used around the world. As the emissions intensity of these materials declines across the world, the MRIO and SPA techniques used in this study will be unvaluable for identifying the next GHG emissions hotspots and targeting future emissions reduction efforts.

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