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Product level embodied carbon flows in bilateral trade

Misato Sato*

Grantham Research Institute on Climate Change and the Environment London School of Economics and Political Science (LSE) Houghton Street London WC2A 2AE U.K. Tel: +44(0)2078523679. Email: M.Sato1@lse.ac.uk

Abstract

As increasingly complex modelling approaches to quantifying embodied carbon in trade have become popular, the lack of disaggregation has been identified as a key weakness. This paper quantifies embodied carbon in bilateral trade at the product level. This is done using the material balance approach, by collecting product carbon intensity factors from multiple data sources and combining with bilateral trade data in physical quantities. The dataset covers trades between 195 countries for 1080 products in 2006. The detailed mapping of trade embodied carbon provides detailed insights into the nature of the flows that were previously masked or under-reported. For example, it finds that the lion's share of global trade embodied emissions are concentrated in a relatively small number of product categories, suggesting that focusing mitigation efforts and trade-measures on these products would be an effective strategy to address potential carbon leakage, and to decarbonise international supply chains. The results also highlight that embodied carbon is focused in regional trade, thus regional harmonisation of climate mitigation policy will be effective in mitigating leakage.

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1 Introduction

The industrial sectors currently account for around a third of global energy demand and CO_2 emissions (IEA, 2007a). Decarbonising industrial production and consumption is therefore critical in achieving long term GHG stabilisation goals. However, in contrast to sectors such as transport, power generation and buildings, the geographic mobility of production facilities adds a layer of complexity to the issue of controlling industry sector emissions.

On one hand, the possibility to decouple production and consumption via international trade can facilitate carbon mitigation within production chains. Reducing emissions from the global aluminium sector, for example, could benefit from concentrating the electricity intensive primary aluminium smelting segment of the production chain in locations with ample zero-carbon power generation capacity such as hydro. On the other hand, trade also provides industries the opportunity to strategically choose production locations to avoid stringent environmental regulations. As countries introduce climate policy measures of varying stringency and global merchandise trade continues to grow[1], there are increasing concerns about the impact on production, investments and carbon leakage.

A large number of studies have quantified embodied emissions in trade (EET), using several different methodologies, as reviewed by a number of papers (e.g. Kitzes et al., 2009; Liu & Wang, 2009; Peters, 2008c; Wiedmann, 2009c; Sato, 2013; Wiedmann et al., 2011). Most studies use an input-output framework to capture indirect effects, either within a single region context (e.g. Druckman et al., 2008; Ferng, 2003), or a regional or multi-regional setting (e.g. Kanemoto et al., 2014; Atkinson et al., 2011; Davis & Caldeira, 2010; Peters & Hertwich, 2008a). Alternative approaches include simplified methods using average carbon intensity of GDP multiplied by trade balance (e.g. Helm et al., 2007; Wang & Watson, 2008) and material balance methods using physical rather than monetary data (e.g. Muradian et al., 2002). Computable general equilibrium models have been used to estimate how EET will change in response to a policy shock (e.g. Kainuma et al., 2000). [2]

The literature overall provides some broad conclusions. Studies find large and growing volumes of emissions embodied in trade, ranging from 4-7Gt CO_2 per year, equivalent to around a third of global annual CO_2 emissions during 2004-2006 (Peters et al., 2011b; Wiedmann et al., 2010). In general,

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[1] Merchandise trade grew 460% in value between 1991 and 2008, outstripping population and global GDP growth of 21% and 64% respectively (World Trade Organisation, 2012).

[2] Collectively, these approaches are grouped into the category of top-down methods, in contrast to the bottom-up methods used for the calculation of embodied emissions in products (e.g. Life cycle analysis (LCA)).

industrialised countries[3] are found to be net importers of EET, while the many emerging economies and resource rich countries are net exporters: "high density OECD countries had higher emissions embodied in imports than exports, while for materials exporters like Russia, Canada, Australia, Finland, Norway and South Africa, the situation was the reverse. Emerging economies specialising in manufacturing, like China and India also had higher emissions in embodied exports and in imports." (Hertwich & Peters, 2010, p.16).

However, thus far studies quantifying embodied carbon in trade have had limited impact on policy making for a number of possible reasons. As recent reviews highlight, there is considerable uncertainty surrounding the measurement of EET (Wiedmann et al., 2011), and comparing across studies reveals a large variation in EET estimates (Sato, 2013). This is largely due to the fact that underlying data, methodology and choice of methods all suffer issues with accuracy and different methods are used for EET quantification with varying definitions and application of trade balances (Kanemoto et al., 2012b). Moreover, so far the focus in this literature has been on country-level results while key policy issues such as carbon leakage is widely understood as a sectoral issue. While some studies use models with sector detail,[4] they are often not reported.

This study quantifies global embodied carbon in bilateral trade between 195 countries, disaggregated at the level of 1080 products for the year 2006. To the author's knowledge, the level of disaggregation in this study goes beyond previous work, and provides the most detailed mapping of EET flows yet. It does so by constructing and combining two large data sets: product level global bilateral trade in physical quantities and carbon intensities of products. The methodological principal of the material balance approach is applied to this data to estimate EET. This has been applied previously to analyses in ecological footprinting research (e.g. Moran et al. (2009)) and has the advantage of offering a transparent way of quantifying EET, retaining the detailed information available in the source data. It also overcomes a number of key sources of uncertainty implicit in the more commonly applied input-output methods. At the same time, for data reasons, this analysis relies on the use of world average emission factors (WAEF), defined in physical terms (kg CO_2/kg product). The extent to which using WAEF affects the accuracy of results is explored using a case study of cement.

This paper builds on recent studies, by further disaggregating estimations using high resolution bilateral

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[3] Industrialised countries are defined here as the countries included in Annex I of the Kyoto Protocol.

[4] Some exceptions include Weber & Matthews (2007), which examines sectoral EET but only for the US and Weber et al. (2008) that examines similarly for China. Peters et al. (2011b) provides a detailed analysis using a disaggregated model with 113 regions and 57 sectors, but his sectoral results are aggregated for global trade, or the trade between Annex I and non-Annex I of the Kyoto Protocol, whereby bilateral trade by country information is lost.

trade information at the product level (Weber & Matthews, 2007; Peters et al., 2011b). Doing so enables the identification of sectors, and products within sectors, where global EET flows are concentrated. It aims to provide insights into the nature of carbon flows that were previously masked under quantification exercises conducted using more aggregated models, or unreported by studies using detailed models but focusing on country level results. The complex picture emerging from the detailed analysis challenges the existing literature, which provides a more simplistic perspective which focuses on the exchange of embodied carbon between two large groups – Annex I vs non-Annex I.

This paper is structured as follows. Section 2 describes the methodology and the key assumptions, as well as the data collected and used to develop worldwide product level estimates of embodied emissions in trade. Section 3 presents results in terms of three key findings, with regard to the geographical and sectoral distribution of EET, the heterogeneity across countries (China, EU and US) as well as how countries can be characterised, in terms of their trade embodied carbon from a global supply chain perspective. Section 4 asks to what extent the results are sensitive to the WAEF assumption. The last section summarises the insights from the detailed quantification.

2 Material and methods

2.1 Quantification approach

The material balance methodology was developed within the ecological footprinting literature as an alternative to input-output methods (Kitzes et al., 2009). ’Footprint’ or ’intensity’ multipliers usually derived from life cycle analysis (LCA)[5] are combined with isolated values of imports and exports by sectors (weight or value), in order to estimate ecological footprints embodied in traded goods (e.g. Bicknell et al., 1998; Muradian et al., 2002; Bagliani et al., 2005; Turner et al., 2007):

$$EEE_j^{r,s} = \sum_{r \neq s} X_j^{r,s} * EF_j^w \tag{1}$$

Equation 1 states that the CO_2 emissions embodied in exports from country r to country s ($s =$

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[5] LCA is designed to evaluate the environmental impacts of a given product or service and is similar in philosophy to input-output analysis as a method to calculate embodied emissions in products, but differs in several important respects. It is a process-based bottom-up technique used to examine the production process of a specific product in detail, unlike the top-down input-output approach which obstructs from analysis of specific materials or products. The latter captures all indirect effects (e.g. within the economy) whereas LCA imposes boundaries. LCA guidelines are given by the ISO standards.

$1, 2, 3, ..., S$) is a product of country r's export matrix X of good j (where goods j = 1,2,3,..., J) expressed in physical quantities and a vector of world average emission factor, EF_j^w expressed also in physical terms (kg CO_2/kg). The CO_2 intensity factors are derived from engineering based techniques using large amounts of primary data. Specifically, intensity factors calculated using the *cradle-to-gate* system boundary are used, thus covering emissions from a partial product life cycle from manufacture (cradle) to the factory gate i.e., before it is transported to the consumer. $EEE_j^{r,s}$ thus reflects the *embodied* carbon emissions attributable to the production of the good throughout the production chain including the production of inputs. This is in contrast to carbon emission factors using alternative system boundaries such as *gate-to-gate*, *cradle-to-grave* (including the use phase and disposal phase of the product) and *cradle-to-cradle* (including recycling).

Mathematically, the material balance method represents a special case of a generalised physical input–output formulation. Yet in practice, data ability and necessary simplifying assumptions under both methods restrict their equivalence (Wiedmann & Lenzen, 2007). Importantly the *cradle-to-gate* carbon intensity coefficients under the material balance approach considers only domestic supply chains and exogenously includes trade in intermediate and final products. In other words, it assumes that all production inputs are sourced domestically. The implied system boundary under this method is akin that of the Bilateral Trade Input Output (BTIO) method which is also termed Embodied Emissions in Bilateral Trade (EEBT).

One of the major limitations of the method relates to the chosen system boundary, which raises the problem of double-counting of emissions when looking at aggregate global emissions. As discussed in Kanemoto et al. (2012b), this approach is more suitable for comparing trade-adjusted emission inventories and indeed our aim here is to do so, at a detailed product-level. The alternative system boundary used under the MRIO framework which considers trade only into the final consumption is, instead, more suitable for consumption analysis. The problem of double-counting for the country-level results is bigger for countries with significant trade volumes relative to the country's economic size, and in particular those engaged in significant processing or intermediate goods trade such as Taiwan and South Korea. For large economies such as the US, the EU, Australia, Brazil and Japan, the import content of exports in the period mid-2000 was relatively low at around 10% to 15% (OECD, 2012). A second caveat relates to the use of world average emission factors (WAEF), and the results' sensitivity to this assumption will be examined in a sensitivity test using a case study of cement in Section 4. Finally, product-level EET estimates are difficult to verify using other studies' results except at the aggregated level. While effort is made throughout this paper to compare country-total estimates with accepted MRIO-based national carbon footprints where possible, nonetheless inconsistencies at the detailed level can occur as noted by Wiedmann (2009b).

The drawbacks are weighed against the key advantages of using this approach, which over comes some of the key error types identified in input–output analyses (Suh et al., 2004a; Lenzen, 2001a). It enables a more detailed examination of sectors, hence avoiding issues with coarse sector aggregation discussed in the literature (e.g. Lenzen et al., 2004b; Tukker et al., 2009). Moreover, by using physical trade data, it avoids inherent problems with using monetary data to approximate physical flows of goods, which are related to assumptions about valuation, prices and exchange rates among others (Maurer & Degain, 2012; Reinvang & Peters, 2008; Sato, 2013).

2.2 Data

2.2.1 Bilateral trade

The level of disaggregation used in this investigation in terms of sector and geography go beyond that of previous work. Trade data is taken from UN Commodity Trade (COMTRADE) statistics which contains detailed bilateral import and export statistics, via CEPII's BACI datatbase[6]. This database uses an original procedure to reconcile the issue of non-matching mirror statistics with the original COMTRADE data which involves evaluating the reliability of countries reporting. A variance analysis is used to decompose the absolute value of the ratios of mirror flows and this measure of the reliability of the reported information is used as weights in the reconciliation of non-matching bilateral trade flows as detailed in Gaulier & Zignago (2010). The sample data covers 1080 sectors (SITC revision 3 classification, 4 digit resolution) and 195 countries for the year 2006. This includes all traded commodities, including food and fuel but excluding electricity and live animals.[7]

In two cases, 4-digit sectors were further disaggregated to 5-digit level – the 4-digit sector 8841 which combines contact lenses, optical glasses, sunglasses and optical fibre, as well as sector 6610 to disaggregate Portland cement, lime and cement clinker. This was done to address the variation in the carbon intensity data for these products.

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[6] http://www.cepii.fr/CEPII/en/bdd_modele/presentation.asp?id=1

[7] Electricity is excluded because there is missing data for the majority of countries. Animals are excluded also because of missing data, and there are also limited estimates of their carbon intensity. The issue of car trade data is discussed below.

2.2.2 Carbon intensity factors

A key priority when using the material balance approach is to use robust product carbon intensity information (EF_j^w), ideally country-specific (Kitzes et al., 2009). Carbon intensities of products have been estimated for industrial and manufactured goods using bottom-up approaches such as LCA (Matthews et al., 2008b). An extensive data search was conducted to collect product carbon intensity factors from multiple data sources (see Table 1). These include the Global Footprint Network (GFN) which provides a comprehensive set of estimates of carbon intensity factors by 4-digit trade category (under SITC Revision 1)[8]; the European Union's ELCD which is a core database comprising of Life Cycle Inventory (LCI) data from various EU business associations and other sources, mainly for key materials and energy carriers; and the Carbon Footprint of Products database which is an initiative by the Japanese Ministry of Economy, Trade and Industry to improve data availability and transparency for LCA, and covering a range of heavy industrial sectors. Altogether, some 700 carbon intensities were found for around 400 products.

The literature has highlighted the limitations of existing footprint and LCA data (Kitzes et al., 2009). Due to the costly nature of bottom-up analysis, estimates are available, only for select years, countries and products. Moreover, differences in system boundaries remain a main source of variation in the measurement of carbon intensities in bottom-up methods, despite the many efforts to harmonise methods, for example by the International Organization of Standardization (ISO), the World Resource Institute (WRI) and the World Business Council for Sustainable Development (WBCSD).[9] In light of these issues and given the available data, the strategy adopted here to determine a best-available estimate of global average intensity factors EF_j^w is to collect as many available product level carbon intensities as possible strictly restricting to those using the *cradle-to-gate* system boundary, then taking an average excluding outliers.[10] [11]

The GFN is well known to be of poorer quality (Kitzes et al., 2009), hence a verification procedure was

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[8] Correspondence tables from COMTRADE were used to match carbon intensity estimates for SITC Revision 1 to Revision 3. They are global average figures, based on embodied energy estimates (from GFN internal data) and multiplied by "World Electricity and Heat Carbon Intensity" from International Energy Agency's CO_2 Emissions from Fuel Combustion Database 2007. The GFN data has been used for analyses on embodied emissions and ecological footprint in trade (e.g. Moran et al., 2009) and discussed in detail in (Kitzes et al., 2009).

[9] Studies combining LCA with top-down input-output models have shown how results from LCA product analysis are sensitive to the inclusion or exclusion of certain flows (e.g. lack of upstream representation, transport and use phase emissions) (Suh et al., 2004a; Lenzen, 2001a; Kitzes et al., 2009).

[10] Where several estimates were available for one 4-digit product category, outliers are defined statistically using inter-quartile range.

[11] One way to address the lack of country and year specific carbon intensity data is to systematically adjust world average coefficients, according to weights that reflect a country's technology level. This is discussed in Section 4.

Table 1: Carbon Intensity Databases

	Authors	Database	Sector coverage
1.	Global Footprint Network	Carbon Footprint database	All SITC sectors at 4-digit level
2.	EU Commission, Joint Research Centre	European Life Cycle Database	Comprehensive
3.	CPM Chalmers	CPM LCA database	Comprehensive
4.	Aarhus University, Faculty of Agricultural Science	carbon footprint database	Food
5.	Hammond & Jones (2008)	Inventory of Carbon & Energy	Building materials
6	Bergmann et al. (2007)	Imposing a unilateral carbon constraint on European energy intensive industries and its impact on their international competitiveness - data & analysis	
7.	Moll et al. (2005)	Iron and steel - a materials system analysis	iron & steel
8.	GEMIS	Global Emission Model for Integrated Systems Version 4.6	comprehensive
9.	British Geological Survey	World Minerals Statistics	Industrial minerals, mine products
10.	U.S. Life Cycle Inventory Database	National Renewable Energy Laboratory	comprehensive

developed for determining the carbon intensity of products where an estimate is available from only one source (GFN). If for another 4-digit product in the same 3-digit category, the GFN estimates fall within ±25% of the available range, then the GFN estimate is deemed reliable for all 4-digit products in that category. Otherwise, the same test is conducted at the 2-digit level. If the test is rejected at 2-digit level, or if no other estimates are available at the 2-digit level product classification, then an average carbon intensity factor for all categories is used (2.58 CO_2 per kg product) as the best-guess estimate (the GFN estimates were found to lie at the upper-end of estimates). The latter average factor was applied to the majority of down-stream products such as electrical equipment and machinery, due to the lack of LCA estimates for these products. Summary statistics of the resulting vector of carbon intensities are provided in Table 4 in the Appendix.

3 Results

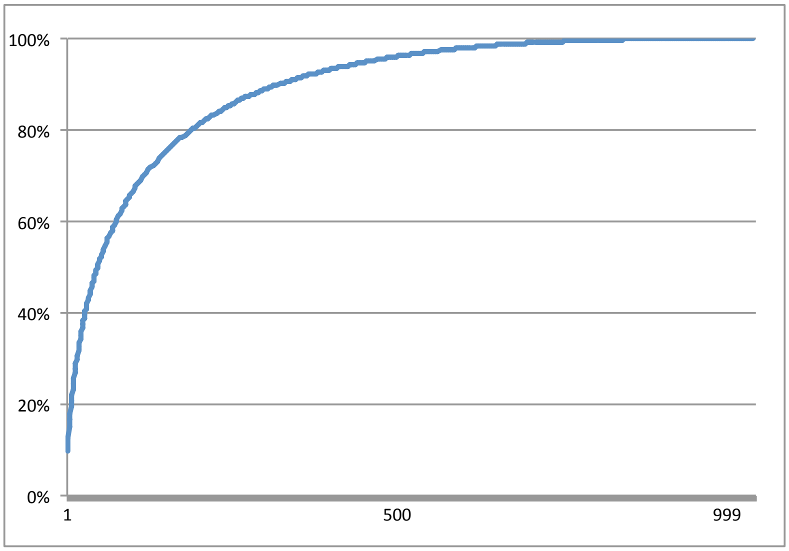
On a global level, this study explains 7.5Gt of CO_2 embodied in trade (including fuel and food),which represents roughly a quarter of annual global CO_2 emissions in 2006. This is in line with the estimates of EET found in the literature: Davis & Caldeira (2010) find approximately 6.2Gt of CO_2 (23%) for the year 2004, Xu & Dietzenbacher (2014) find 7.9Gt CO_2 (32%) for 2006 and Peters et al. (2011b) find around 7.8Gt CO_2 (26%) in 2008. This section presents the results from quantifying the product level embodied carbon in bilateral trade in terms of three key findings.

3.1 Around 10% of products account for 70% of global EET

To what extent is trade embodied carbon focused or dispersed across different products? Studies on the trade and carbon leakage effects of carbon pricing in Europe have shown that impacts will be focused on a few sectors (e.g. Hourcade et al., 2007; Demailly & Quirion, 2008) and arguments have been made in favour of policy measures tailored specifically to each sector, rather than generalised solutions, to address trade-related effects from climate policy (Dröge & Cooper, 2010). The product level evaluation of embodied carbon in this analysis finds that, of the 1080 products examined, around 10% of the products account for around 70% of global EET (Figure 1), and only 5% of products accounts for around 50% of EET. This suggests that focusing mitigation efforts and trade related measures on certain products would be an effective approach to address potential carbon leakage. The top 25 products contributing to global EET are listed in Table 2. The single most contributing product is motor spirits and light oils (gasoline) which are traded in vast quantities globally. Main exporters are Kuwait, Canada, Russia and importers include USA and the Netherlands. Flat rolled steel is the second highest contributing product, with significant exports originating in Japan, China, Ukraine and USA imported by South Korea, France and Turkey. These products are followed by crude oil, aluminium alloys and passenger cars.

The table also indicates the broader sector group to which the product belongs, whereby the 1080 product categories (SITC Rev 3, 4-digit level) are aggregated to 60 sectors (3-digit level). The majority of high ranking products listed belong to heavy industry sectors. The iron & steel sector accounted for around 13% of all EET in 2006. This is followed by the Petroleum sector at 12%, then the primary plastic, organic chemicals and non-ferrous metal sectors, all at around 3-4%.

Figure 1: Distribution of EET by product category



Notes: These estimates include food and agricultural products.

3.2 The geographical distribution of EET reflects regional dependencies.

Large net embodied carbon flows from non-Annex I to Annex I countries have been highlighted in the EET literature. However, when examined at the level of country-pair bilateral trade routes, a rather different picture emerges. Figure 2 shows some key bilateral trade routes, ranked from left to right by net EET flows (red bar), indicating also the corresponding absolute volumes of embodied emissions in exports (EEE) and imports (EEI). For example, the US imports around 109Mt of embodied CO_2 in trade from China, and in return exports around 31Mt resulting in a net import of 78Mt CO_2. Figure 2 shows that significant volumes of EET are also trade within Annex I countries particularly between neighbouring countries, for example between the USA and Canada as well as Mexico.

To further explore the geographical dimension of embodied carbon in trade, Figure 3 describes the quantities of embodied carbon flows between (top part) and within (lower part) 11 regions (see Table 5 in the Appendix for grouping of countries). What is immediately striking is the large volumes of inter-regional trade within the EU region, as well as North America (Canada, USA and Mexico). At this level of aggregation, inter-regional trade accounts for around 39% of total embodied carbon trade. Second, in general trade embodied carbon tends to be higher between neighbouring regions. For example, Latin America's imports are highest from North America and followed by Europe, Central Asia's imports are highest from Europe and the Middle East, and China's imports are highest from Japan, Korea and Taiwan, as well as South East Asia.

Table 2: Embodied emissions in trade by product - Top 25

	Product name	Sector	EET (Mt CO2)
1	Motor spirit/light oils	petroleum	701
2	Flat rolled steel nes	iron_steel	213
3	Petrol./bitum. oil,crude	petroleum	176
4	Aluminium/alloys unwrt	nonferrous_metals	129
5	Motor vehicles for the transport of persons, n.e.s.	road_vehicles	113
6	Carbonates/peroxycarbona	inorganic_chemicals	99
7	Other ferro alloys	iron_steel	95
8	Ships/boats nes	nonroad_transport	92
9	Portland cement	cement_lime_nonmetallics	90
10	Nitrogenous fertilizers	fertilisers	90
11	Aluminium/alloys worked	nonferrous_metals	88
12	Aluminium ore/concntrate	metal_ore	81
13	Motor veh part/acces nes	road_vehicles	78
14	Semi-fin iron/stel<.25%c	iron_steel	76
15	Medicaments n.e.s.	pharmaceutical	71
16	Iron/steel bars nes	iron_steel	71
17	Wheat nes/meslin	cereals	69
18	Cyclic hydrocarbons	organic_chemicals	69
19	Polycarbonates/alk resin	plastics_primary	65
20	Propylene/olefin polymer	plastics_primary	61
21	Polyethylene	plastics_primary	61
22	Iron/steel articles nes	metal_manufactures	55
23	Alumina(aluminium oxide)	metal_ore	55
24	Acyclic monohyd alcohols	organic_chemicals	53
25	Cement clinkers	cement_lime_nonmetallics	52

Notes: These estimates include food and agricultural products.

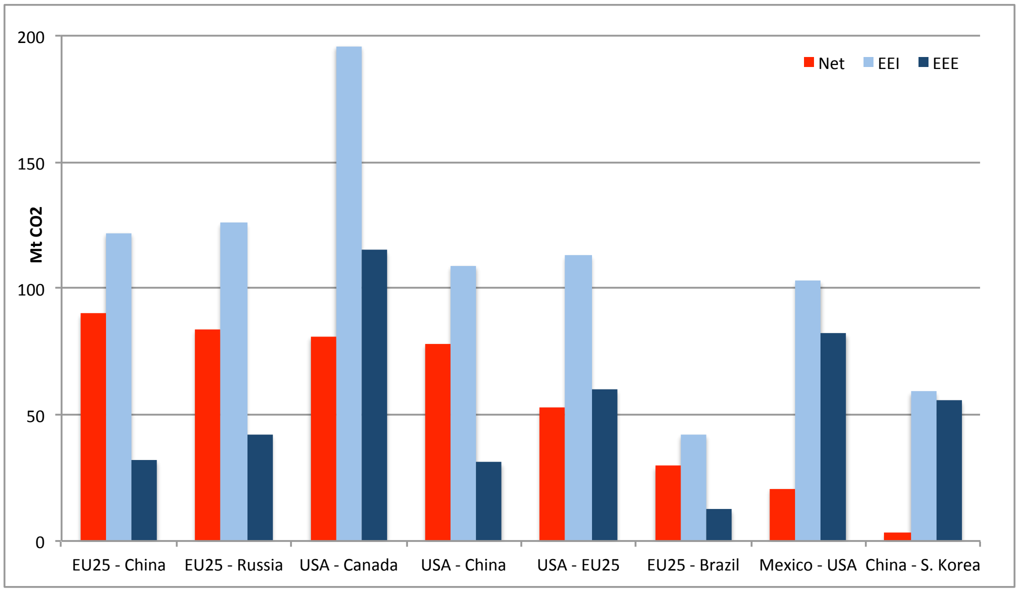
These results suggest that harmonising CO_2 mitigation policy across neighbouring countries with strong trade links will go a long way to address potential adverse impacts on trade. In Europe, differences in the rules of emissions allowance allocation during the first two phases of the EU ETS attracted strong criticism from industry, and the European Commission has sought to increase the degree of harmonisation through guidance notes (del Río González, 2006).

3.3 Based on differences in product compositions, three country types can be identified in terms of their position in the global supply chain

To examine cross-country differences in EET patterns, we look closer at China, the US and the EU. Table 3 lists for each of these three countries and regions, their top ten contributing products in terms of EEI and EEE as well as the main trading countries of those products. Represented in this table are products from those sectors that contribute substantially to both global trade and emissions, which are at the centre of the debate on carbon leakage and embodied emissions in trade (e.g. Pan et al., 2008; Liu & Wang, 2009; Peters & Hertwich, 2008a; Qi et al., 2008a).

The products via which China imports and exports embodied carbon, and the trading partners are strikingly different. Carbon imports tend to be embodied in primary products such as iron and

Figure 2: Net vs aggregate embodied carbon in bilateral trade – some key country pairs. 2006



Notes: For each pair, the first indicates importer and the latter, the exporter. For the pair USA-CHN, EEI is the US imports from China, and EEE is US exports from China.

aluminium ores (from Australia, Brazil and India, Indonesia), raw cotton (from the US, India and Uzbekistan), gasoline and other petroleum products (from S. Korea, Russia, Singapore, Saudi Arabia, Angola and Iran) as well as basic metals, chemicals and plastics (from S. Korea, Japan, Thailand etc). In contrast, carbon exports tend to be embodied in primary industrial products such as types of semi-finished steels, ferro-alloys, basic chemicals and cement clinkers, not surprising as China is the largest producer of many industrial commodities such as ammonia, cement, iron and steel (IEA, 2008a).[12] These are exported to large centres of consumption such as North America, Europe and Japan, as well as neighbouring countries such as S. Korea and South-East Asian countries.

In the case of Europe, the top ten EEE list includes a range of products from the refining sector as well as semi-finished industrial products in steel, aluminium and paper, as well as downstream products such as passenger vehicles and car parts. The USA is a major destination for Europe's EEE in the top ten products, as well as other countries in the region Turkey, Switzerland, Norway and Russia. The key products for Europe's imports of embodied carbon, on the other hand, include energy and mining inputs for production such as aluminium ores, as well as upstream industrial inputs such as

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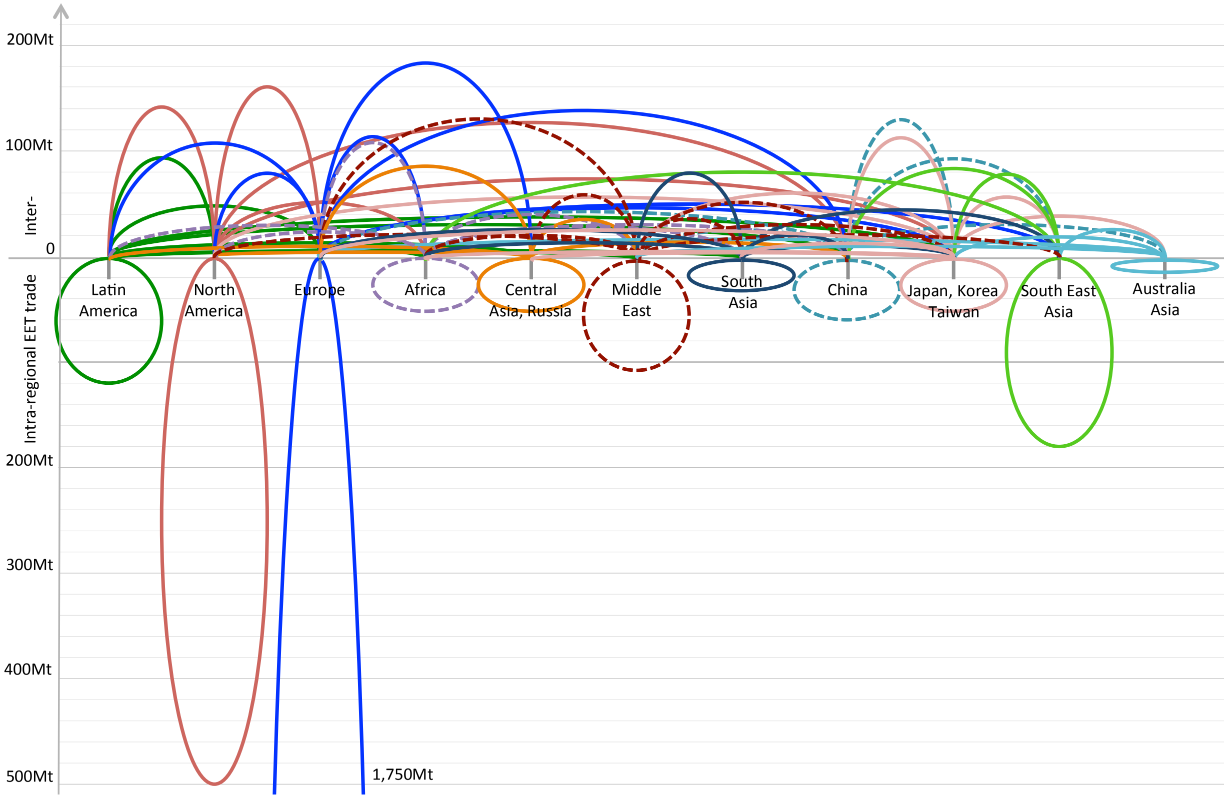
[12] Weber et al. (2008, p. 3574) analyses the change in China's sectoral composition of EEE over time, and reports: "Emissions embodied in primary product exports (including here: all mining, raw timber, raw chemicals, and basic metals) have decreased from between 20% to 24% in the early years of the analysis (1987–1992) to only 13% in 2002–2005 as the Chinese economy has developed into producing higher value-added items."

Figure 3: Inter- and Intra regional embodied carbon in trade by region in 2006



Source: Author's own calculations. Notes: The vertical axis indicates the volume of EET, for inter-regional trade (above the x-axis) and intra-regional trade (below x-axis). The colour coded lines above the x-axis indicate import flows. For example the dark blue lines are Europe's imports, the highest being from Central Asia and Russia. For country groupings, see Table 5.

aluminium alloys, basic chemicals and semi-finished steel products. These originate often from resource rich trade partners, near and far (e.g. Russia, Norway, Mozambique, South Africa and China). The table highlights Europe's import dependence for resource inputs, an issue which has gained significant importance in European Union policies in the past decade primarily motivated by supply chain security concerns.[13] In a study which quantifies the embodied resource content of trade from a North-South perspective, Giljum et al. (2008) finds that "trade pattern of net-imports to the North is particularly visible for the EU25, which faces the strongest dependence on resource imports of all investigated world regions, in particular regarding fossil fuels and metal ores."(p.18). This import dependence is reflected in Europe's embodied carbon trade balance, with more embodied carbon in imports relative to exports, with EEI at 959Mt and EEE at 695Mt CO_2.

Like Europe, the US also imports significant embodied carbon from its neighbouring resource rich countries such as Canada and those in Central and Latin America, but also from the Middle Eastern countries and Russia. Like Europe, the top 10 EEI list includes a range of products from the mining, refinery and upstream industrial sectors. What is striking in the EEI list is the presence of agricultural products such as maize, cotton and wheat. Therefore, in addition to the significant influence of regional trade dependencies in EET patterns, looking at the key EET products and countries also reveals the importance of resource rich countries in contributing to the global EET flows. The three large trading economies studied here import significant EET from resource rich countries such as Canada, Russia, Australia and Brazil.

To further examine cross-country differences in the sector compositions of EEE and EEI, each country's EEE and EEI are aggregated into three "supply-chain stages" – primary products, heavy industrial products and light industrial products[14] – and two simple indicators are developed and applied (Figure 4). On the horizontal axis is an index of a country's total BEET (total EEE minus total EEI), normalised (divided by the country's production-based emissions) to allow for comparison. It is expressed in natural logs, or in the case of net imports (negative) the natural log of the absolute value. On the extreme or 'unbalanced' ends, Singapore on the furthest left has the highest shares of net imports of EET relative to production emissions, and Brazil has the highest share of net exports relative to production emissions.

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[13] This is emphasised, for example, in the revised EU Sustainable Development Strategy, the Thematic Strategy on the Sustainable Use of Natural Resources and in the upcoming EU Action Plan on Sustainable Consumption and Production: "More than ever, Europe needs to import to export. Tackling restrictions on access to resources such as energy, metals and scrap, primary raw materials including certain agricultural materials, hides and skins must be a high priority. Measures taken by some of our biggest trading partners to restrict access to their supplies of these inputs are causing some EU industries major problems" (European Commission, 2006).

[14] See Table 6 in Appendix for sector groupings.

Table 3: Key products and trading partners for China, the EU and USA's EEI and EEE in 2006

	Imports		Exports	
	Top 10 Products	Top 3 trade partners	Products	Top 3 trade partners
China	◆ Iron ore and concentrates, not agglomerated	Australia, Brazil, India	◆ Flat-rolled products of iron or non-alloy steel, not clad	S. Korea, Italy , Vietnam
	◆ Motor spirit (gasoline) and other light oils	S. Korea, Singapore, Russia	◆ Portland cement	USA, S. Korea, Nigeria
	◆ Aluminium ores and concentrates	Indonesia, India, Australia	◆ Other ferro-alloys (excluding radioactive ferro-alloys)	Japan, S. Korea, USA
	◆ Polycarboxylic acids, anhydrides, halides, peroxides& peroxyacids	S. Korea, Thailand, Japan	◆ Carbonates; peroxocarbonates; commercial ammonium carbonate	S.Korea, Indonesia, Thailand
	◆ Cotton (other than linters), not carded or combed	USA, India, Uzbekistan	◆ Cement clinkers	Spain, UAE, Italy
	◆ Cyclic hydrocarbons	S. Korea, Japan, Singapore	◆ Articles of iron or steel, not else stated	USA, Japan, S. Korea
	◆ Alumina (aluminium oxide), other than artificial corundum	Australia, Jamaica, India	◆ Semi-finished products of iron or non-alloy steel, <0.25% of carbon	Thailand, S. Korea, Vietnam
	◆ Petroleum oils and oils obtained from bituminous minerals, crude	Saudi Arabia, Angola, Iran	◆ Bars and rods, hot-rolled, in irregularly wound coils, of iron or steel	USA, S. Korea, Spain
	◆ Flat-rolled products of iron or non-alloy steel, not clad	Japan, S. Korea, Kazakstan	◆ Other bars and rods of iron and steel	S. Korea, Singap., Canada
	◆ Polymers of propylene or of other olefins	S. Korea, Singapore, USA	◆ Tubes, pipes and hollow profiles, seamless, of iron or steel	USA, Algeria, Singapore
EU	◆ Motor spirit (gasoline) and other light oils	Russia, Belarus, Norway	◆ Motor spirit (gasoline) and other light oils	USA, Swizerland, Mexiro
	◆ Petroleum oils and oils obtained from bituminous minerals, crude	Russia, Norway, Libya	◆ Motor vehicles for the transport of persons, n.e.s.	USA, Russia, Japan
	◆ Aluminium and aluminium alloys, unwrought	Mozambiq., Russia, Norway	◆ Flat-rolled products of iron or non-alloy steel, not clad	USA, Turkey, Saudi Arabia
	◆ Other ferro-alloys (excluding radioactive ferro-alloys)	S. Africa, Kazakstan, Russia	◆ Medicaments n.e.s.	Russia, Canada, Switzerland
	◆ Flat-rolled products of iron or non-alloy steel, not clad	China, Russia, Serbia	◆ Other wheat (including spelt) and meslin, unmilled	Nigeria, Algeria, Egypt
	◆ Aluminium ores and concentrates	S. Korea, China, Japan	◆ Aluminium and aluminium alloys, worked	USA, Switzerland, Malaysia
	◆ Carbonates; peroxocarbonates; commercial ammonium carbonate	Nowray, USA, Bulgaria	◆ Paper& paperboard, used for writing, printing/ graphic purpose	USA, Russia, Australia
	◆ Oilcake and other solid residues	Argentia, Brazil, Malaysia	◆ Tubes, pipes and hollow profiles, seamless, of iron or steel	USA, China, Algeria
	◆ Semi-finished products of iron or non-alloy steel, <0.25% of carbon	Ukraine, Russia, Mexico	◆ Other parts and accessories of the motor vehicles	USA, Turkey, China
	◆ Acyclic monohydric alcohols	Russia, Chile, Trinidad&T	◆ Paper and paperboard, uncoated, used for writing, printing	Argentina, USA, Australia
USA	◆ Motor spirit (gasoline) and other light oils	Canada, Netherl., Venezuela	◆ Motor spirit (gasoline) and other light oils	Mexico, Canada, Chile
	◆ Petroleum oils and oils obtained from bituminous minerals, crude	Canada, S. Arabia, Nigeria	◆ Maize (not including sweet corn), unmilled	Japan, Mexico, S. Korea
	◆ Motor vehicles for the transport of persons, n.e.s.	Japan, Canada, Mexico	◆ Carbonates; peroxocarbonates; commercial ammonium carbonate	Mexico, Canada, Brazil
	◆ Portland cement	China, Canada, Thailand	◆ Cotton (other than linters), not carded or combed	China, Turkey, Mexico
	◆ Aluminium ores and concentrates	Jamaica, Guinia, Brazil	◆ Wheat (including spelt) and meslin, unmilled	Japan, Nigeria, Mexico
	◆ Aluminium and aluminium alloys, unwrought	Canada, Russia, Brazil	◆ Fertilizers, n.e.s.	India, China, Canada
	◆ Flat-rolled products of iron or non-alloy steel, not clad	Canada, S. Korea, Russia	◆ Other parts and accessories of the motor vehicles	Canada, Mexico, Austria
	◆ Other parts and accessories of the motor vehicles	Canada, Mexico, Japan	◆ Aluminium and aluminium alloys, worked	Canada, Mexico, S. Arabia
	◆ Mineral or chemical fertilizers, nitrogenous	Canada, Russia, Kuwait	◆ Motor vehicles for the transport of persons, n.e.s.	Canada, Germany , Mexico
	◆ Semi-finished products of iron or non-alloy steel, <0.25% of carbon	Russia, Mexico, Ukraine	◆ Cyclic hydrocarbons	Mexico, Canada, Netherlands

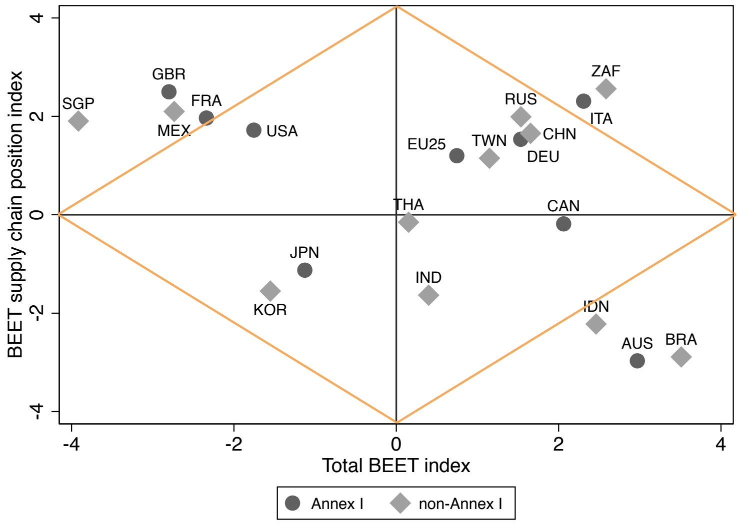
Source: Author's own calculations.

The vertical axis plots an index of a country's balance of EET in terms of their position on a supply chain. It indicates the relative importance of each supply chain stage for any one country. Countries with low values of the vertical axis exhibits a greater imbalance in upstream segments of the supply chain such as fuel and ore production (primary products) whereas those with higher values have an EET imbalance in downstream, light industrial products such as apparel and machinery. The middle values indicate imbalances at mid-stream, heavy industrial products such as semi-finished steels, basic chemical products, cement and pulp. This is measured by a simple summation, taking the absolute value of the BEET for the heavy industrial products, subtracting that of the primary products, then adding that of the light industrial products.

Combining these two indices and plotting several major economies, three broad groups of countries emerge from Figure 4. Countries closer to the bottom right corner (e.g. Indonesia, Australia and Brazil) represent resource rich countries which export large volumes of EEE via industrial feed-stock products including mined, energy and basic industrial products as inputs to industrial production globally. This group can be termed as "production centres". On the opposite side, the countries closer to the top left corner of the chart (e.g. Singapore and UK) represent service industry oriented countries with significant energy and merchandise imports, and can be characterised as "consumption centres" as net importers of EET and significant imbalance in the upstream sectors. Countries that lie closer to the origin can be grouped as "production & consumption centres" which can be further distinguished into subgroups. Very close to the origin are four countries (Thailand, Japan, EU, Taiwan and India) which appear to exhibit very similar EET characteristics – small negative balance of overall EET and greatest EET activity in 'mid-stream production stages'. These represent countries with high levels of processing trade (manufacturing of export goods using imported inputs). The USA and France are similar to this group, except that the negative balance of total EET is mainly due to the importing of 'down-stream' or light industrial products. Mirroring this, Germany, China, Russia and Italy form a cluster of net exporters of total EET, which is likely due to the export of 'down-stream' goods.

Some observations can be drawn from this perspective. First, it emphasises how the convention of grouping countries into Annex I vs non-Annex I and viewing embodied emissions in trade as a North-South issue is too simplistic. This analysis instead suggests that a more relevant grouping of countries in this context may be according to patterns of production and consumption: Production centres; Consumption centres and; Production & consumption centres. Second, according to the calculations in this paper, the majority of large emitters fall into the category of "production & consumption centres".

Figure 4: Position of countries in the global supply chain according to their BEET



Source: Author's own calculations. On the x-axis, the negative values indicate the size of net import and positive values indicate the size of net exports. On the y-axis, negative values indicate 'upstream' and positive values indicate 'downstream'.

That is to say, on a country level, emission levels are comparable when using the production-based vis-à-vis the consumption-based accounting methods, because they tend to import as much as they export or vice versa. Of course the same cannot be said for the balance of EET at the sector or product level. This suggests that the role of consumption-based accounting methods may be limited at the country level, for example in the context of multilateral burden sharing agreements. On the other hand, the role of consumption-based accounting methods may be important at the sector level, particularly for key energy-intensive and trade-intensive sectors. Efforts to improve the estimations of EET flows for such sectors are likely to add more value than repeating country-level estimations (as has been the trend in the literature to date), more for the discussions about carbon leakage than about fairness and responsibility. Finally, focusing efforts to improve production technologies and carbon efficiency in production centres may be an effective strategy for decarbonising global supply chains. It also suggests that advancing consumption-based accounting principles for climate policy design is particularly relevant for the consumption centres.

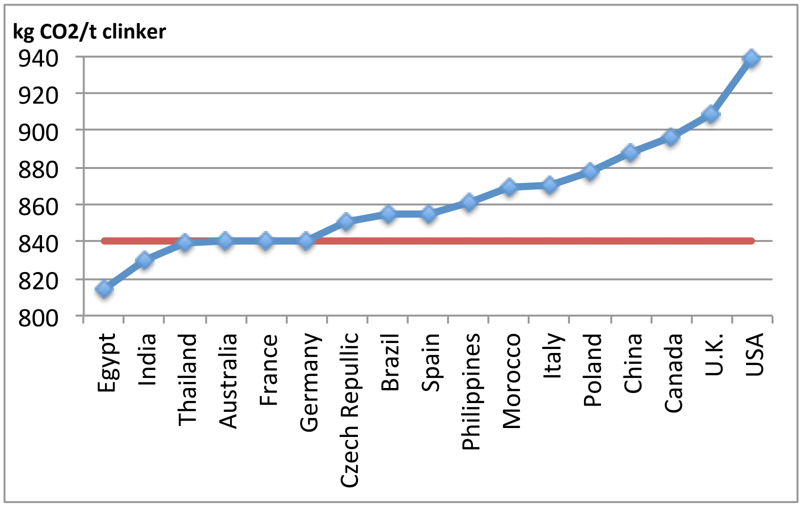
4 Sensitivity analysis - A comparison of the WAEF and CSEF assumptions in the case of cement clinker trade

This subsection explores the sensitivity of the results to the use of world average emission factors instead of the country specific emission factor (CSEF), using a case study of the cement clinker trade. Currently, the extent to which using WAEF affects the accuracy of results is poorly understood. MRIO analysis has shown that the assumptions about carbon intensity matter, usually by comparing EET estimates when using country-specific emission factors vis-à-vi the domestic technology assumption (DTA) i.e. assuming imports are produced using the same technology as domestic production. In the case of Norway, applying the DTA can underestimate emissions by up to a factor of 2.5 (Peters & Hertwich, 2006a). Andrew et al. (2009c) compare the WAEF assumption relative to DTA when estimating EET within a single-region IO framework and argue that the use of WAEFs can perform well for the estimation of EET for and reduce data requirements in certain cases. To the author's knowledge, the relevant comparison between using WAEF and country-specific emission factors has yet to be made. Previous comparisons have also been based on estimation using data expressed in monetary terms (kg CO_2/USD) rather than in physical quantity terms.

Cement manufacturing accounts for around 5-7% of global emission (Benhelal et al., 2013), and clinker production is the most energy-intensive step, accounting for around 80% of the energy used. International differences in carbon intensity of clinker production are driven mainly by the thermal efficiency of plants (which strongly relates to kiln technology type and age of installations) and the carbon intensity of the fuel mix (fossil fuels, waste and biomass). Relative to the most efficient plant type (preheater kilns with precalciner or PH-PC), long dry kilns consume around 33% more thermal energy and the old wet kilns consume up to 85% more (Cement Sustainability Initiative, 2009). In addition, capacity utilisation rate and asset rationalisation can strongly influence the regional average thermal consumption. Operating an installation at just a small fraction of its design capacity increases the energy consumption per ton clinker produced.

Using 2006 bilateral trade data in cement clinker (sector 66121 using SITC Revision 3 classification) between the 17 countries in the sample, EET volumes for each country pair and both directions of trade are estimated. This gives a sample of 176 flows for which the EET estimates can be compared. Using the WAEF, the embodied emissions in bilateral trade between these countries totalled 11.9Mt CO_2, whereas using CSEF, it totalled 12.3 Mt CO_2. The latter is higher because in this sample there are more countries with CSEF greater than WAEF as shown in Figure 5. For each EET flow, we take the difference between the two estimated EET volumes, and divided it by the estimate using CSEF, in order to calculate the impact of the WAEF assumption in percentage terms. The results are described in Figure 6. The histogram shows the distribution of the inconsistency across the 176 flows, and the box-plot above shows the quartile ranges. Using WAEF on average underestimates embodied emissions in clinker by 2%. On the more affected end, EEE from the US, UK and Canada are systematically underestimated by 6-10%. This is a relatively small sensitivity in the context of EET measurement, where assumptions can swing estimate results by orders of magnitude (Sato, 2013).

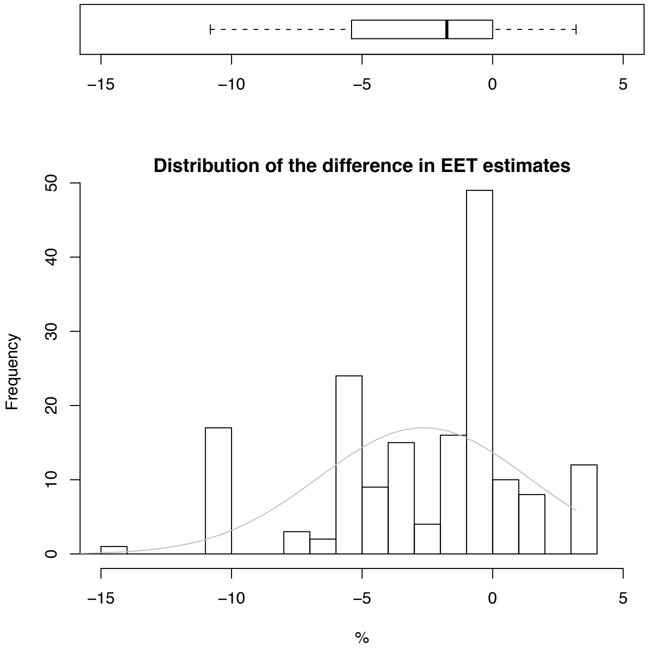
Figure 5: Weighted average CO_2 (excluding CO_2 from electric power) emission per tonne clinker by country in 2006



Source and Notes: The red line shows the WAEF used in this analysis and the blue line shows the CSEF obtained from Cement Sustainability Initiative (2013).

Figure 5 shows how the country-averages diverged from the world average emission factor in 2006 – WAEF was 840kg CO_2 /tonne of clinker as shown by the red line and the CSEFs ranged between 814-939kg CO_2/t clinker across 17 countries. The data is obtained from the “Getting the Numbers Right” (GNR) database, which is high quality environmental and production data collected by the WBCSD’s Cement Sustainability Initiative. The coverage of plants in this database is more comprehensive (>70%) for Europe, North America, Central America and Brazil but varies for the rest of the world (Cement Sustainability Initiative, 2013). The high average carbon intensity in the USA is due to the relatively large number of wet, semi-wet and long dry kilns. This is in turn due to the slow asset renewal driven by low energy prices and lengthy procedures for new kiln permits. Preheater kilns with or without precalciner are more dominant in China, India and rest of Asia and Australia reflecting the growing cement market and relatively young assets. The average thermal efficiency is about 10% better in the non-Annex 1 region than in the Annex 1 region, reflecting the generally newer, more efficient equipment in non-Annex 1 countries.

Figure 6: Sensitivity analysis - inconsistency in EET estimates using WAEF and CSEF for the case of bilateral trade in clinker, 2006



Of course, the sensitivity of the EET estimates to the WAEF assumption varies across products. Greater sensitivity may be found for products such as aluminium and steel which exhibit large heterogeneity in carbon intensities across production plants. In the case of aluminium, this is a function of the source of electricity (from zero carbon hydro or nuclear to high-carbon coal plants), as well as the share of recycled aluminium. For steel, the electric arc furnace plants typically use 30-40% of the energy required for the blast oxygen furnace plants (Hourcade et al., 2007). The available data was insufficient to conduct sensitivity analysis for these sectors.[15]

This case study also provides some insights into the use and adjustments of carbon intensities in general. One way to address the lack of country specific carbon intensity data is to systematically adjust world average coefficients, according to weights that reflect an average technology level of a country, typically measured by the average carbon intensity of GDP. This approach has been applied by the GTAP to fill

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[15] For the case of aluminium, data on the production share of primary and secondary aluminium was available for many countries, but not the carbon intensities of primary and secondary production by country. For steel, the carbon intensities for BOF and EAF were available at the regional level, but not the share of production.

data gaps, but it requires the assumption that the technology level does not vary across sectors within a country, which is in contrary to recent studies' findings for large countries like China (e.g. Su & Ang, 2010). Having 'country specific' carbon intensities has obvious advantages for the analysis of carbon leakage. Yet the cement sector shows that this may be a rather arbitrary way to adjust emission factors. At 1080 tCO_2/ Million \$GDP, China has a much higher carbon intensity of GDP relative to others such as Australia (760 tCO_2/ Million \$GDP), Egypt (504 tCO_2/ Million \$GDP), USA (451 tCO_2/ Million \$GDP), UK(271 tCO_2/ Million \$GDP) and France (204 tCO_2/ Million \$GDP). Yet as shown in Figure 5, China's carbon intensity in the cement clinker sector is lower than the UK or the US. This analysis shows that such simple adjustment does not lead to improvements in emission factors. Indeed, this method has been shown to produce country level annual emission volumes that are inconsistent with the UNFCCC and IPCC data (Reinvang & Peters, 2008). The majority of multi-regional analysis of embodied carbon, carbon leakage and related studies on impacts from border adjustments (e.g. Mattoo et al. (2009)) rely to varying degrees on such artificially adjusted emission factors, and this should be an important caveat to their results. Overall, obtaining reliable country specific emission factors for the key products identified in Section 3.1 will go a long way to improve the reliability of such analyses.

5 Discussion and conclusions

High resolution product level bilateral trade data from the COMTRADE were combined with carbon intensity coefficients, to obtain a detailed mapping of global embodied carbon trade. Like previous studies, this analysis finds that significant volumes of carbon emissions are traded between countries. However, thanks to the level of disaggregation that was not available in previous studies, this paper has revealed new insights into the nature of these flows.

For example, whereas the EET literature thus far has primarily highlighted the large Chinese surplus and the USA's deficit in EET, this study highlights the embodied carbon trade flows with neighbouring countries are also important, such as the large EU internal trade. It suggests that regional harmonisation of climate mitigation policy should be a priority. Focusing only on the Annex I and non-Annex I imbalance of embodied carbon in trade invite simplistic and problematic interpretations of EET estimates. It is often combined, for example, with a literal interpretation of classical trade theory based on the notion of comparative advantage, giving rise to interpretations such as "rich countries are outsourcing carbon-dioxide emissions" (The Economist, 2011).

In terms of the distribution of global EET across products, of the 1080 products examined, around 10% of the products account for around 70% of global EET. This suggests that focusing mitigation efforts and trade-measures on the products in this group would be an effective approach to address potential trade related distortions, and will also help in decarbonising international supply chains. Such product-specific measures could be better justified on environmental grounds, and less vulnerable to criticism of applying trade protectionist measures. As a first step in this direction, it narrows down the products for which rectifying data constraints about their carbon footprints should be a priority.

Examining product level bilateral trade in EET revealed striking differences in terms of the product composition of a country's EEE and EEI. China's carbon imports are typically embodied in primary inputs to industrial production: mined products such as iron and aluminium ores, raw cotton, basic chemicals and plastics. In contrast, significant volumes of embodied carbon are exported via manufactured products such as furniture and apparel products, and also upstream industrial products such as basic steel products, chemicals, cement and cement clinker. The origin and destination of countries' EEI and EEE are also very different. This shows that product and country coverage are therefore key to the impact and effectiveness of measures designed to address carbon leakage.

Looking at the origins of EEI for China, Europe and US revealed the important role played by resource rich countries such as Russia, Australia, Brazil, and Canada, in contributions to carbon flows through global supply chains. Indeed, from a global supply chain perspective, the results found that at the top of the chain, a non-trivial volume of EET flows can be attributed to energy products and metal ores, particularly as imports by large industrial centres such as China, Japan, and Korea. Indeed, concerns about the consistency between long-term GHG concentration stabilisation goals and the signing of long-term contracts and trade deals between Australian mining companies and Chinese companies have been raised (The New York Times, 2010). Further down-stream in the supply chain, embodied carbon is traded in various upstream industrial products, such as in the iron and steel sector, primary plastics and non ferrous metals.

Examining cross-country differences EET composition in terms of three supply-chain stages showed that the majority of large emitters import and export similar amounts of embodied carbon via 'midstream' industrial goods such as iron & steel, chemicals, paper & pulp and glass. Some countries have a notable EET surplus through large export volumes of 'upstream' production such as ores and fuel (e.g. Brazil and Australia), whereas others have a notable EET deficit through imports of 'downstream', or consumer goods (e.g. UK and Singapore). It is argued that grouping countries according to patterns of production and consumption may be more relevant in discussions surrounding climate policy and trade, rather than discussing in terms of industrialised vs developing countries, as is often done.

For example, the fact that most large emitting countries has a small net balance of EET at a country level suggests that the role of consumption-based accounting methods may be limited at the country level, for example in the context of multilateral burden sharing agreements. Given the large uncertainties surrounding EET measurement as highlighted in the literature, it is likely that the costs of reaching international agreement on a reasonable range of estimates may far outweigh the gains from incorporating consumption-based metrics into such already politically sensitive decisions. On the other hand, the role of consumption-based accounting methods may be important at the sector level, particularly for key energy-intensive and trade-intensive sectors. This suggests efforts to improve the estimations of EET flows for such sectors are likely to add more value than repeating country-level estimations and add to discussions about carbon leakage.

Relevant constraints to the material balance approach have been highlighted in this paper. A sensitivity test was conducted using a case study of cement clinker to examine how results vary when using world average emission factors and country specific ones. It showed differences up to around 10%, but typically much smaller. The uncertainty due to this assumption is relatively small, compared to the many other sources of uncertainty in EET estimation. It also shed light on problems with simple methods commonly used in the literature to artificially create country-specific sector level emission factors, as well as analysis (such as carbon leakage assessments) using such data. Overall, the increasing availability of embodied carbon estimates for more products and regions will improve the robustness of estimates under the approach used in this study.

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6 Appendix

Table 4: Carbon intensity factors, summary statistics

	Carbon intensity (kg CO_2/kg)
Mean	3.069838
Standard deviation	4.763699
Median	2.580637
Minimum	0
Max	69.74235
Variance	22.69283
Skewness	7.962029
Kurtosis	91.21711
N	1026

Table 5: Regional aggregation used in Section

	Country by ISO code
Australia- Asia	NZE AIA ATG AUS CXR KIR MHL NCL NZL WSM SLB TKL TON TUV VUT
Africa	DZA AGO BEN BWA BFA BDI CMR CPV CAF TCD COM COG CIV COD DJI EGY GNQ ERI ETH ETH GAB GMB GHA GIN GNB KEN LSO LBR LBY MDG MWI MLI MRT MUS MYT MAR MOZ NAM NER NGA RWA STP SEN SYC SLE ZAF SOM ZAF SDN SWZ TGO TUN UGA TZA ESH ZMB ZWE
Central Asia and Russia	AFG SUN KAZ KGZ MNG RUS TJK TMP TKM UZB
China	CHN HKG MAC
EU	ALB AND ARM AUT BLR BEL BEL BIH BGR HRV CYP CZE CSK DNK EST FRO FIN DDR DEU YUG FRA DEU GIB GRC GRL VAT HUN ISL IRL ITA LVA LTU LUX MLT MNE NLD NOR POL PRT MDA ROM SMR SRB SCG SVK SVN ESP SWE CHE MKD UKR GBR
Japan, Korea and Taiwan	TWN PRK JPN KOR
North America	CAN MEX SPM UMI VIR USA
Latin America	ABW ATA PCN ARG ARB BHS BRB BLZ BMU BOL BRA CYM CHL CCK COL COK CRI CUB DMA DOM ECU SLV FLK PAN PCZ GUF GRD GLP GTM GUY HTI HND JAM MTQ MSR NIC PRY PER SHN KNA KNA LCA VCT SUR TTO URY VEN
South Asia	IOT BGD BTN PAK IND MDV NPL PAK LKA
South-East Asia	PLW ASM BRN KHM FJI VDR PCI VNM PYF FSM GUM HMD IDN LAO MYS MMR MNP PNG PHL SGP THA VNM
West Asia (Middle-East)	AZE BHR YEM YMD GEO IRN IRQ ISR JOR KWT LBN OMN QAT SAU SYR TUR ARE YEM

Table 6: Supply chain stage groupings by sector

Supply chain stage	Sectors
Primary products	meat; dairy; fish; cereals; veg and fruit; sugars; coffee tea cocoa; animal feed; other food; beverages; tobacco; metal ore; coal coke; petroleum; gas ; electricity; hides skins; oil seeds; crude rubber;cork wood; pulp; textile; crude fertiliser; crude animal material; animal fats; veg. fats; processed fats; leather
Heavy industrial products	organic_chemicals; inorganic chemicals; colour dye; fertilisers; plastics primary; cement lime non-metallics; iron steel; nonferrous metals; essential oils; plastic non primary; insecticides; rubber manufactures; cork manufactures; textile articles
Light industrial products	power generating machines; industrial machinery; metalworking machinery; general industrial equipment; office machinery; telecom machinery; electrical machinery; road vehicles; non-road transport; power generating machines; industrial machinery; metal working machinery; general industrial equipment; office machinery; telecom machinery; electrical machinery; road vehicles; scientific instruments; pharmaceutical; paper; metal manufactures; prefab buildings; furniture; travel goods; apparel; foot ware; photo equipment; optical wear; other manufactured goods