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Climate policy and solutions for green supply chains: Europe's predicament

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Abstract
Purpose – This paper aims to measure carbon footprints (CFs) of products at the sectoral levels. The paper also aims to provide potential solutions to adopt greener supply chains to minimise CFs.
Design/methodology/approach – The assessment of CFs uses a data set for nine sectors and environmental extended input output tables, as well as other six models. The analysis uses modules for regional economy, freight, logistics and mode choice, among other modules. The output of these modules includes increases or cuts in carbon dioxide (CO_2) emissions following a shift in supply chains.
Findings – The authors identify five supply chains that are closely connected to the growth of CFs. The highest CF is found for the electronics and textiles products. Offshoring manufacturing capacity produces an increase of emissions (production and freight transport sectors) of 42 million tonnes of CO_2 emissions, or 12 per cent of the Kyoto target of 341 million tonnes of CO_2. Using a different metric to measure emissions, offshoring the same volume of production appears as a reduction in European Union (EU)-wide CO_2 emissions. To reduce CO_2 emissions, the authors propose a carbon tax on imports, increasing R&D subsidies to industry and freight sectors and on-shoring a greater volume of production into the EU economies, among other measures.
Research limitations/implications – This paper only measures CFs at the sectoral level. Further work should include survey data on CFs, longer historical data series and larger set of products for assessment. Another limitation is the lack of analysis of freight transport flows of non-EU regions, (i.e. China and Latin America).
Practical implications – The authors propose the following measures: at least five policies to offset offshoring of production, several measures to reduce carbon emissions, propose introducing mandatory audits for CFs and mandatory labelling. This work has implications for carbon taxation of exports and imports in an effort to decarbonise European and global supply chains.
Social implications – Social implications include the need to lower personal goods consumption in the EU to minimise the impact of supply chains on carbon emissions; the need to tax exports/imports may have an impact on jobs in the EU, among other effects.
Originality/value – This paper is the only study that uses the TRANS-TOOLS model and the only study to measure CFs of products within the context of freight transport flows within the EU. The analysis relies on inputs from several modules that apply data on 24 EU economies.

Keywords Logistics, Green supply chains, Environmental management strategy, Globalisation, Carbon footprint, Offshore arrangements

Paper type Research paper

1. Introduction

The aims of this paper are twofold: to identify potential supply chains that minimise carbon footprints (CFs) of products and of freight transport activities; and to provide a set of policy recommendations to reduce CF of products and related activities. Porter and van der Linde (1995) provide the arguments for low-pollution supply chains (lower CFs), but Vachon and Klassen (2006) develop the concept further. Both modern supply chains and freight transport enable the growth of CF globally. Both the freight transport (the movement of goods by road, rail and inland waterways means) and the manufacturing sectors are large contributors to carbon dioxide (CO_2) emissions in the European Union (EU); the two sectors account for about 34 per cent of total emissions in the EU 27

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Members States (Eurostat, 2013); freight transport produced about 113.5 Mt-CO_2 (Eurostat, 2013) and manufacturing industry around 968 Mt-CO_2 emissions in 2010 (Eurostat, 2013)[1]. These two sectors broadly make up supply chains and depend symbiotically on each other's inputs. A supply chain is defined as the system of organisations, technologies and activities which is involved in the product life cycle (WEF, 2009).

Modern industry relies on supply chains that have emerged in the past 40 years on a global scale; however, the emphasis in the paper is on Europe's CF (carbon footprints) of manufactured (cement, chemicals and steel, etc.) and finished products, i.e. autos. Under the Kyoto Agreement, targets for CO_2 eq. emissions have been set at minus 8 per cent with 1990 as the base year by 2008-2012 for the EU 15 States; these targets are not applicable for specific sectors. This means that greener supply chains that can be measured by CFs of products have to be encouraged. The CO_2 targets of the (Kyoto Agreement) and the base year are based on the production (territorial) emissions criteria which exclude CO_2 emissions from imported products.

Urban supply chains mirror the changes in freight transport and in the manufacturing sectors These supply chains will need to decarbonise in the future to operate in the next decades, as a global climate agreement will cap CO_2 emissions. Measuring CFs allows the analysis of the full impact of EU consumers and of supply chains on CO_2 emissions.

A WEF (2009) study on the global supply chain lists 11 measures to reduce CFs of products, chief among these are modal shift, the adoption of clean technologies in manufacturing and optimising the manufacturing location. Rizet *et al.* (2012) measure the CF of jeans, apples and furniture from the perspective of global and local supply chains; those authors examine two steps in the supply chain:

1 the urban distribution systems of Paris and London; and
2 cargo movements from New Zealand to Europe.

The Rizet study does not consider the energy use for the manufacturing process. In contrast to the Rizet study, we consider nine industry sectors' CFs and cover the freight transport flows, its emissions and the manufacturing-related CO_2 emissions within the EU 27 Member States. Other studies (Reinhardt, 2000; Sinclair-Desgagné and Gabel, 1997; Johnstone, 2007; OECD, 2013) also examine greener supply chains, which is essentially equivalent to lower CFs of products supply chains. These studies propose auditing of environmental effects of firms to reduce CFs of products.

The OECD highlights incentive provision to better monitor the levels of CFs of firms, i.e. performance rewards, monitoring of non-financial objectives, task design and allocation, decision-making processes, employee selection (including its training) and changing corporate culture.

A CF is defined as *the amount of carbon emitted indirectly (or directly) during production or consumption of commodities (this includes freight movements); or the amount of carbon that accumulates during the life stages of the product or service*. The CF term is based on the ecological footprint concept of Wackernagel and Rees (1995). An important step in isolating the key points in the supply chain, where reductions of CO_2 are possible, is to map out the supply chain (Rizet *et al.*, 2012).

In this paper, we map out the various supply chains that contribute to the CF at the industry level. A CF is akin to the emissions estimated on the basis of the consumer-based accounting or "CBA" method.

Supply chain-related CO_2 emissions are usually higher if the CBA system is used because emissions from the imported supply chain need to be added up. Imported supply chains are assumed to be sited in non-EU nations or regions where energy efficient technology is less widely diffused in the manufacturing and building sectors (Jochem, 2000), and where the fuel economy of truck fleets (litre/KM-driven) do not match EU-based truck fuel economy. The industrial and freight transport energy efficiency patterns of the non-EU regions do not match those of the EU-based industry, as a result CFs of imported products are higher than those produced within the EU[2].

In this paper, a set of policy recommendations are made. The recommendations cover European freight transport policy and supply chains following an empirical assessment of global CF in production, transport and environmental sustainability from a supply chain perspective. The key supply chain that has contributed to higher CF is the offshoring practices of logistics and manufacturing firms (L&M).

Van Mieghem (2008) defines offshoring neatly as:

> Offshoring denotes the (re) location of operations, esp. production processes, abroad in a country where operational costs such as labour costs are lower. For the sake of reducing operational costs, negative side effects such as increasing transport costs, longer lead times, etc. are accepted. Offshoring has to be distinguished from the terms outsourcing which means that an external party supplies an activity. Outsourcing is therefore related to a change in the organisation structure of a company, whereby offshoring is related to the geographical dispersion of a company. Typically offshore regions are located in Asia (Van Mieghem, 2008, p. 223).

The results of this study are partly based on analysis done elsewhere (Logman, 2011).

2. Background

As a general rule, CFs respond to production activity, consumption of goods and regional trade or cross-country trade of goods, as described above. Producing goods requires fossil fuels, which increases CO_2 emissions, and some supply chains rely on more energy-efficient technology than others do. Globalisation of supply chains is associated to greater distance between nodes in the distribution network (Elhedli and Merrick, 2012) and greater distances translate into higher CO_2 emissions of lorries, which raises the level of CFs.

In the past three decades, four developments have increased the consumption of goods, and thereby of CFs; these are:

- the establishment of the single European market in 1992;
- the fall of the Berlin Wall, which opened up trade-enhancing opportunities for many West European manufacturers;
- the establishment of free trade agreements with many regional trade blocs; and
- the adoption of the single European currency (euro), among others.

In the external front, there was also an increase in global trade, which raised European trade volumes and thereby freight transport.

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Production-related CFs are closely linked to five factors:

1 the volume of goods moved around the world;
2 the adoption of the container;
3 new management techniques such as "Just in Time";
4 the growth in number and geographical dispersal of warehousing and distribution around the world; and
5 low energy prices.

For example, "Just-in-Time" delivery have saved 80-90 billion USD on a world scale (Levinson, 2006, p. 287), but this leads to CO_2 emissions from greater trade gains. In contrast to production CFs, consumption-based CFs are generated by imports of CO_2-intensive products which need to be moved by long distances or through many links (uploading, storing, moving cargo) in the supply chain. These factors have resulted in both additional freight transport performance (t-km) and an increase in hauling distance at the region, European and global scales in recent decades.

The expansion of global trade in the post-war years, in the 90s before the financial crises, the entry of China to the WTO in 2001 and the rise of the BRICS (Brazil, China, India, Russia, South Africa), and the new architecture of global supply chains has also raised the global CF of goods. Freight transport has been instrumental in allowing the growth of products' CFs. As said above, the CBA approach to CO_2 emissions involves including extra-territorial freight transport flows, in contrast to the other approach. The PBA (production-based accounting) system only gives a partial account of the real CO_2 emissions flows of freight transport and of manufacturing activities.

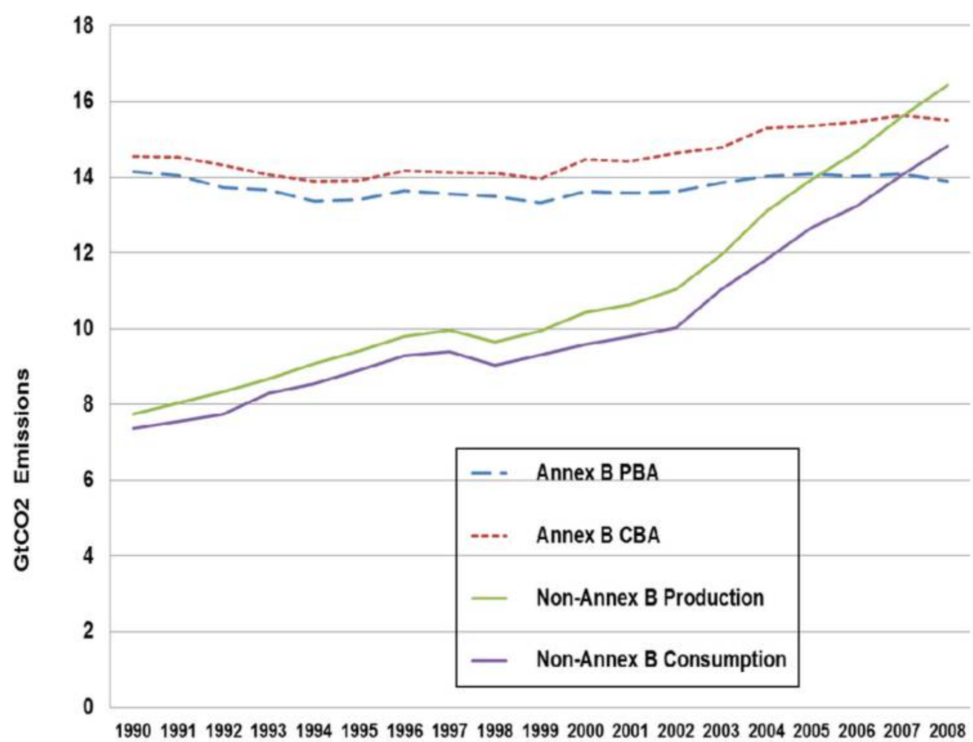
Figure 1 depicts the time series of world CO_2 emissions estimates for 1990-2010 using two distinct approaches. One approach uses the CBA system to calculate emissions; the second approach uses the PBA system to estimate these emissions. PBA emissions of less developed countries outweigh those of developed countries, mainly OECD ones, in 2010[3].

PBA emissions in 2000 of less developed countries (non-Annex B) were significantly below those of Annex B countries (developed economies). CO_2 emissions of Annex B countries are constant in 1990 until early 2000s under both measures (CBA and PBA). CO_2 emissions of less developed countries grow exponentially, under both measures (Figure 1).

By 2005, CO_2 emissions of Annex B countries match the level of developed countries. In short, PBA emissions of less developed countries have grown consistently as a result of two changes: offshoring of manufacturing capacity from developed countries to less developed countries and as a result of the growth of their manufacturing base needed to supply their internal market and world market.

In contrast to less developed countries, PBA emissions of developed countries have shown no growth and in recent years, their emissions decline; this reflects the decline in manufacturing capacity in developed countries. Figure 1 also reveals that the CO_2 trade deficit (imports of CO_2-intensive products outweigh exports of CO_2-intensive products) is increasing. The gap between production (territory) and consumption (CBA) emissions widens in 1990-2008 in both regions. CBA emissions respond to greater imports of products, as Figure 1 demonstrates. Figure 2 shows CO_2 emissions of both approaches for the EU 28 States.

Figure 1 CO_2 emissions of global production (PBA) and global consumption (CBA)



Source: Based on data in Peters *et al.*, 2011

Supply Chain Management: An International Journal
Volume 20 · Number 3 · 2015 · 249–263

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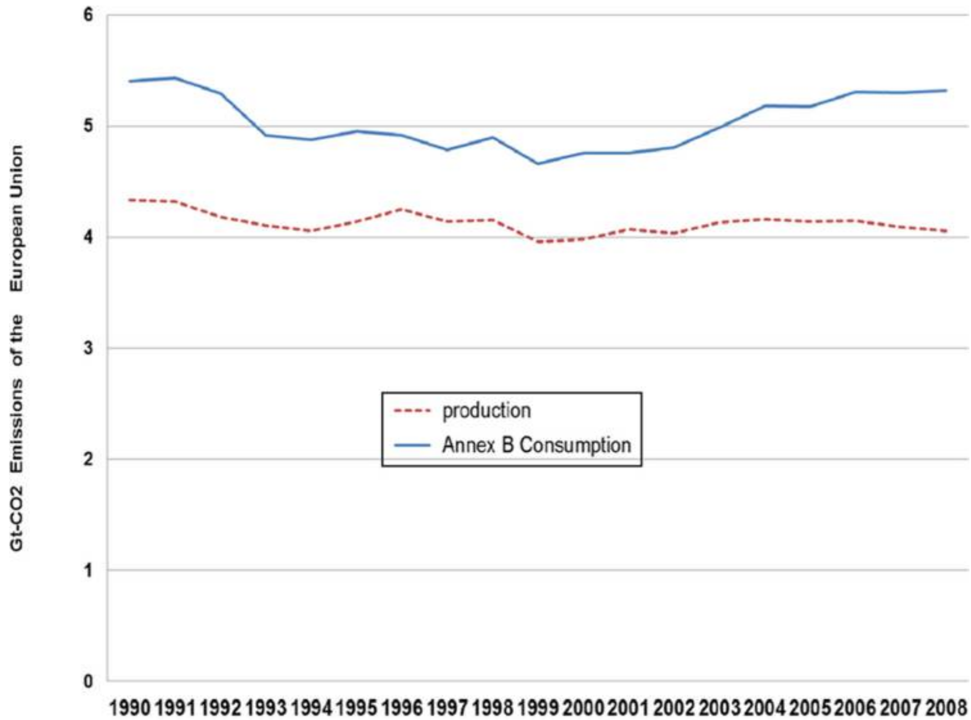
Figure 2 Economy-wide CO_2 emissions of the European Union 28 countries' production (PBA) and consumption (CBA)



Source: Elaborated by the authors based on data in Peters *et al.*, 2011

Trends in consumption mirror increases in the volume of imports in both Annex B and non-Annex B nations. In developed countries, CBA emissions outweigh those estimates that are based on PBA; for less developed countries, the opposite is found: PBA emissions outweigh those of CBA throughout the entire 1990-2008 period.

Production-based (PBA) emissions do not include the connection between developed countries (mainly OECD nations) and less developed countries via international trade, which in turn depends on international freight transport, i.e. shipping, road freight and air freight. The advantage of the CBA is that it does include CO_2 emissions produced by international freight transport. PBA emissions are increasingly diverging from those of CBA; the latter outweigh the former by a large margin. This is found in both less developed countries and in developed countries.

Figure 2 reveals that as imports of goods rise so does the level of CO_2 emissions, along with the size of the gap between PBA emissions and those of CBA in recent years, which is highly correlated to the volume and type of trade.

The growth of CO_2 emissions, of developed countries, based on the CBA method outpaces those of production CO_2 emissions (territorial or national ones) (Figure 1). Higher economic growth rates (and a recovery in global trade) of emerging powers (BRICS: Brazil, India, China, South Africa; in addition, Turkey and Mexico) will change the emissions profiles of consumption and production activity; these countries will "import" emissions from developed countries. This has implications for global supply chains and for the demand for freight transport in the coming decades in the context of CO_2 targets for the transport sector and in the context of carbon budgets to 2044. In the future, three factors will affect freight transport: international trade flows, climate policy regimes and "imports" or "exports" of CO_2 emissions.

The present article starts by giving an overview of the CFs and this is followed by a synthesis of the sensitivity analysis highlighting the key messages for policy action. The second part of the article discusses the policy recommendations with particular reference to the EU Transport White Paper (2011).

3. Literature review on CFs and supply chains

3.1 Urban logistics and green growth

There are two key studies that attempt to measure CFs for products and sectors and for entire economies; estimating CFs allow policymakers to allocate emissions cuts in certain sectors. One set of literature uses survey evidence on supply chains of specific sectors or products for a specific period. The other set of works focuses on methods of input–output and principles of environmental economics; these methods are best represented by the work of Peters *et al.* (2011) and of the Exiopol project (2011). Global CFs for products have been measured using an input – output methodology (Exiopol project, 2011).

The literature on the CO_2 emissions responsibility of supply chains is new and incomplete; geographical regions or countries are responsible for emissions. However, a few authors (Peters *et al.*, 2011; Peters and Hertwich, 2006) examine CO_2 emissions responsibility and suggest avoiding estimates based on national territory CO_2 emissions. They have, however, neglected the key enabler for CF: the role played by the international transport sector and related emissions of CO_2 which are integral parts of global supply

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chains. One issue with the above literature is the absence of detailed treatment of freight transport movements.

In contrast to the environmental economics literature that often relies on input output and applied econometric methods, the urban supply chain literature has only recently assessed CFs. For example, a World Bank study (Interamerican Development Bank and World Bank, 2009) on urban freight transport and the UN habitat (UN habitat, 2013) fail to link urban freight and supply chains to CFs or to structural changes in trade elsewhere in the world. Ambrosini and Routhier (2004) emphasise that the definition of urban supply chains differs from country to country, which, in our view, brings methodological difficulties for measuring CFs and freight movements.

CFs of products can also be assessed partially through estimating seven key ratios (Mckinnon, 2007) of supply chains; however, this is difficult, as collecting data on a specific product requires survey exercises that are expensive and time-consuming to carry out[4]. Helm *et al.* (2007) have taken the literature further by incorporating case studies of UK CFs of supply chains of key products. However, accurate statistics on the entire volume of CFs do not exist, neither do accurate statistics on CO_2 emissions at the urban supply chain level, nor on how the latter interact with global supply chains.

3.2 The offshoring of manufacturing capacity and trade expansion

As said above, offshoring of manufacturing plants in developed countries reduces the reported CO_2 emissions of them. There are competing explanations for the emergence of offshoring of manufacturing activity from developed countries' economies to emerging ones. In general, production costs, including labour costs, are lower in the receiving country. The labour cost factor in the decision (and the global division of labour) to offshore is a valuable explanation for the current and past levels of offshoring of manufacturing plants from Europe to the rest of the world.

Offshoring of manufacturing capacity has been underpinned by trade liberalisation. The mainstream economics literature (World Bank, 1993) asserts that trade liberalisation is key for economic growth, job creation and obtaining best practice technology; however, the dominant economic paradigm ignores the possibility that there are limits to growth and this applies to trade expansion and to personal goods consumption. The dominant paradigm ignores the interaction in the world economy of CO_2 emission flows and CFs of products and of established transport patterns of global supply chains. These established patterns have enabled the CFs to continue to grow for many of our everyday products.

Broadly speaking, there are two approaches that explain the rise of global supply chains through offshoring: the world systems and the globalisation approaches. The latter approach is best represented by the Washington Consensus. That consensus argues for greater trade liberalisation, tariff reduction and privatisation of state infrastructure, as it is argued that by doing this, there will be greater economic growth. For example, countries like Singapore, Thailand, Malaysia and other similarly sized nations have seen greater growth than other regions (World bank, 1993). The rapid growth of trade translates into larger supply chains at the national and urban levels. As a consequence of this growth, freight transport demand also grows. In general, freight transport demand is governed by the type of commodities moved, the size of the service sector, road freight rates and inefficient utilisation of road vehicles, besides economic growth (Agnolucci and Bonilla, 2009).

The world system approach (Wallerstein, 2011) provides a theoretical explanation of the rise of offshoring of industrial firms. Offshoring manufacturing activity to a less developed countries region provides access to cheaper labour markets. The core regions of the world economy, among these the EU, have offshored (or relocated) their manufacturing activities to developing economies in the border of the EU and in Asia, in the outer Mediterranean, as these regions are part of the world division of labour. It must internalise many of its costs and bring new markets and workers into production. Contemporary analysis of CO_2 trends from supply chains tends to neglect the connection made by the world system approach and the increase in global CF.

3.3 The literature on green supply chains

The literature on green supply chains has exploded in the past 40 years (Mckinnon, 2010), but Porter's competitive advantage concept, that is the "five forces" concept, has played an initial role in the area (Porter, 2008). The area has also been influenced by that author's concept of "value chain", which is defined as a set of activities that a firm operating in a given industry performs to deliver a product for the market. How value chains are managed determines costs and profits and identifying green activities can add value. Vachon and Klassen, 2006) have found that many authors use the term "supply chains" in different ways. One common feature in the literature is the collaborative role of firms to reduce environmental impacts and how firms can monitor these impacts along the supply chain (Vachon and Klassen, 2006).

A special issue of the SCM-IJ produced nine articles on the theme of measuring green supply chains for various countries: China, the UK and Sweden. Bai *et al.* (2012) suggest a seven-step methodology that relies on grey system theory, in the context of uncertainty, to measure green, business and management factors of supply chains. However, that mathematical analysis fails to use real-world data on supply chains. Bjorklund *et al.* (2012) reviews 1,137 articles on green supply chains and finds that the literature is divided into "different measures and actions to take" rather than on how to measure green supply chains. Bjorklund *et al.* (2012) only finds 17 articles on green supply chains and relies on one case study to assess performance factors of green supply chains. It is difficult, however, to arrive to generalised conclusions about an entire industry regarding its green performance by using evidence from a single case study as in Bjorklund *et al.* (2012). Song *et al.*'s (2012) study is closest to our approach, as it measures the energy consumption of entire supply chains; lower energy use should indicate greener supply chains. The cited author claims that three factors affect the energy efficiency of the logistics service industry:

1 industrial restructuring affecting low productivity sectors by high-productivity sectors;
2 technological improvement of energy efficiency of industry; and
3 industrial restructuring and technological progress.

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In sum, the literature has not addressed in sufficient detail the role of international trade, within international supply chains, and of freight flows in improving or worsening environmental performance (lower CO_2 emissions) of entire supply chains as we do in our study.

The paper contributes to green supply chain theory by identifying the external forces on CFs of products such as changes in trade structure via offshoring of manufacturing, on-shoring or near-shoring of supply chains within key industries. The literature on green supply chains has assessed CFs of supply chains often using case studies or analytical approaches that lack real-world evidence. However, we have yet to identify a top-down approach to assess performance of green supply chains as we do in our study.

4. Analysis and methodology

The methodology is based on four steps:

1 identification of the trade factors that affect supply chains;
2 sectoral sensitivity analysis of CO_2 emissions of these supply chains;
3 a case-study approach to examine the logistics practices that are utilised in these key industries; and
4 a sensitivity analysis to analyse changes in the logistics or in supply chains practices.

This research is part of a larger project that investigated how the logistics and the manufacturing sectors affect freight transport activity. Further implications for the recently published EU Transport White Paper (2011) are also discussed.

To assess the impact of the current global economic trends on freight transport and to suggest possible transport policy measures, a microeconomic approach is used.

For the purpose of examining global supply chains, a sensitivity analysis is applied. The sensitivity analysis is done by two models (TRANS-TOOLS, Environmentally Extended Input Output model; for further details, see Logman, 2010). The TRANS-TOOLS model is made of different modules. The main modules are: a regional economic module (SCGE-model), a freight module, a logistics one and mode choice module, among other ones. The output of these models includes positive or negative impacts on CO_2 emissions after a future shift in a specific supply chain.

5. Results

In this section, we discuss the sensitivity analysis of CFs (per manufacturing industry) following the adoption of different supply chains: offshoring, near-shoring, on-shoring, etc. The section also discusses the changes in CO_2 emissions following the adoption of each of these various supply chains practices for the nine sectors that we assess.

5.1 The baseline, offshoring and on-shoring of supply chains

Table I shows the European market shares, by industry sector, for the baseline and for off-shoring, on-shoring and near-shoring cases. These European market shares for industry are given for four regions: EU-27 Member States, China, Turkey and the rest of the world. China and Turkey are singled out for two reasons: first, for the geographical proximity of the latter and for the participation of the former in the world trade and therefore in global freight flows. The shares are calculated using monetary data of sales per region. The shadowed column shows the assumed changes for offshoring, on-shoring and near-shoring when compared to the baseline.

Figure 3 shows today's market shares for sectors. The textiles and apparel and the electronics sectors show the lowest levels of EU market share. These sectors have seen the largest decline in EU-based industrial activity in recent decades.

Table I tabulates the shifts in the market share of EU products. Using the values in Table I, two assumptions apply for the offshore case: a 20 per cent of increase in production in textiles and electronics in China; and a 15 per cent increase production in the sectors of food and beverages, of paper and of transport equipment.

The transport equipment sector is taken to provide an estimate on the effects of offshoring on CFs. The latter are linked to product supply chains in this sector. The following is found after comparing offshoring to on-shoring changes in supply chains (Table I, transport equipment row). It is assumed that an increase in offshoring of L&M systems raises China's market share today (2011, in € in absolute terms) by 15 per cent. This absolute increase (in absolute terms in Euros) is subtracted from the European market share, to ensure that the size of the market remains identical and thus comparable. As a result, China's market share (transport equipment column only) increases from 1.4 per cent to 1.6 per cent, while the European market share decreases (Table I, "Imports from China" row). The two other regions shares are held constant. The same methodology applies to all other sectors and to variations.

Two things emerge from the Table I. First, imports of energy intensive products are large in terms of CO_2 emissions, although in percentage units they do not appear to be so. Second, energy-intensive products, i.e. chemicals, cement (non-metallic minerals), iron-steel and aluminium (basic fabricated metals), are less exposed to trade than finished products are, i.e. the textile and the electronics sectors. However, for the UK steel sector, it is known that the sector is trade-sensitive (Carbon Trust, 2004).

Table II tabulates the changes in emissions of freight transport.

Table III reveals the estimated CO_2 emissions of supply chains (production process and freight transport activities included); the data show how much each sector contributes to higher emissions under the CBA and PBA methods. It is clear that offshoring contributes to lower emissions under the PBA method but does not do so under the CBA method. On-shoring produces lower emissions under PBA and higher emissions under CBA. Near-shoring production reduces emissions (CBA only) significantly for textiles and electronic products.

Two things emerge from Table II and III. First, freight transport does not contribute a large fraction to total emissions of supply chains. Second, energy-intensive products that are less exposed to trade (i.e. chemicals, paper, iron-steel, aluminium) show smaller changes in CO_2 emissions than highly traded products such as the textile and electronic ones.

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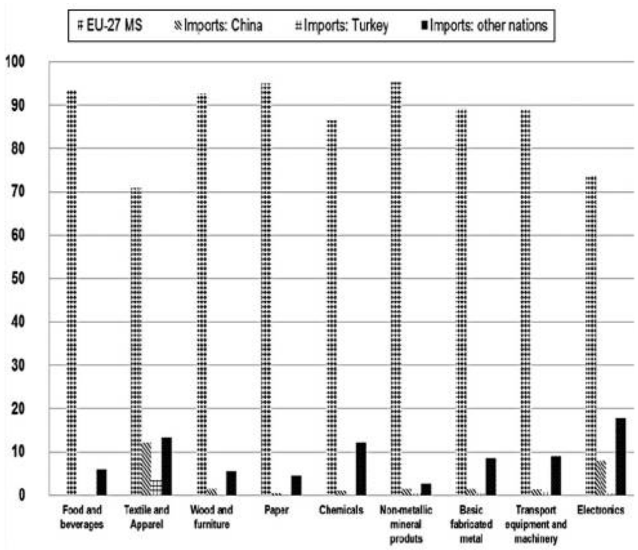
Table I Sensitivity analysis per industry and changes in China's market share (%)

Market shares	Food and beverages	Textile and apparel	Wood and furniture	Paper	Chemicals	Non-metallic mineral products	Basic fabricate metal	Transport equipment and machinery	Electronics
Offshoring sensitivity analysis									
Increase in % market share in China (%)	1.5	20	15	15	15	5	2.5	15	20
EU 27 MS	93.5	68.5	92.5	95	86.4	95.3	89.3	88.8	72.2
Imports from China	0.3	14.8	1.9	0.4	1.2	1.7	1.7	1.6	9.6
Imports from Turkey	0.3	3.5	0.1	0.1	0.2	0.4	0.4	0.7	0.4
Imports from other countries	5.9	13.4	5.6	4.6	12.3	2.6	8.6	8.9	17.9
On-shoring sensitivity analysis									
Increase in market share in China's market	−15	−15	−2.5	0	−2.5	−2.5	−2.5	2.5	2.5
EU27	93.6	72.8	92.7	95	86.6	95.5	89.3	89.1	73.9
Imports from china	0.3	10.4	1.6	0.4	1.0	1.5	1.6	1.4	7.80
Imports from Turkey	0.3	3.5	0.1	0.1	0.2	0.4	0.4	0.7	0.4
Imports from other countries	5.9	13.3	5.6	4.6	12.3	2.6	8.6	8.9	17.9
Near-shoring sensitivity analysis									
Increase in market share (%) in China's market	−2.5	−15	−2.5	0	−2.5	−2.5	−2.5	−2.5	−2.5
EU27	93.5	70.9	92.7	95	86.6	95.4	89.3	89.1	73.7
Imports from China	0.3	10.4	1.6	0.4	1.0	1.5	1.6	1.4	7.8
Imports from Turkey	0.3	5.3	0.1	0.1	0.2	0.5	0.5	0.7	0.6
Imports from other countries	5.9	13.3	5.6	4.6	12.3	2.6	8.6	8.9	17.9

Source: The authors

Figure 3 Baseline case of market shares (per cent) of energy-intensive and finished products in the EU 27 Member States



Source: The authors

Table IV shows the percentage contribution to emissions under the PBA (Kyoto targets of the EU) and CBA methods. The emissions of textiles, transport equipment and electronics increase EU emissions under the CBA method; these products do show greater import vulnerability than other products do. But offshoring, under PBA, shows that emissions apparently decline for all sectors. In reality, emissions grow after offshoring from a CBA viewpoint.

From an entrepreneurial perspective, the increasing practice of offshoring supply chains is expected, as it a cost-minimising measure; however, in most cases, such practice does increase supply chain's emissions and CFs. Should restrictions on offshoring industrial capacity (beyond the EU) be imposed, meeting future CO_2 targets for these sectors will be harder despite energy-saving practices of these firms[5].

Finally, there are interactions (not shown in the table) among the five supply chains strategies: off (on) shoring; intermodal transport interacts with transport consolidation, with recycling and with decentralisation.

Intermodal transport has a knock on effect on-shoring practices. Transport consolidation is directly related to decentralisation/centralisation of transport services. The impacts of recycling on other supply chains depend on whether the recycling networks are set up at a local or global level: Global recycling networks in particular for metals tend to encourage offshoring, while local ones are expected to induce on-shoring with effects on urban supply chains. Possible triggers of these strategies are discussed in Section 5.3.

Figure 4 shows the breakdown by region (EU-27 MS; China, Turkey and rest of the world), and by sector, of transport supply chain emissions.

The contribution of regions to overall freight transport CO_2 emissions (logistics and manufacturing sectors) varies strongly. The share of the EU region is about 65 per cent on average for all sectors. Figure 4 reveals that the region distribution data (EU, China, Turkey and rest of the world) are skewed for the EU region.

Domestic EU freight CO_2 emissions are highest for the food beverages and the non-metallic minerals sectors, i.e. cement and paper. The lowest EU transport shares are recorded for the textiles and the electronics sectors; these sectors show high impact on extra EU transport, i.e. transport activity of China and Turkey. Two comments can be made. First from a CBA perspective, the effect of transport should add additional externalities, i.e. traffic and CO_2 emissions; second, offshoring manufacturing capacity to those regions increases freight transport demand in those same regions, as Figure 4 shows, as well as CO_2 emissions.

5.2 Policy implications of CF growth

Given the findings reported in Section 5.1 regarding changes in supply chains, transport-related measures are now discussed below. Because of the externalities produced by offshoring practices, freight transport policy (and supply chain) measures are needed. Emphasis is given to the Transport White Paper 2011 – Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system (The White Paper henceforth). Our results indicate several areas that need to be addressed for an improved freight transport policy:

- The overall aims of the EU White Paper on the future of freight transport.
- The implications of our sensitivity analysis on the future of freight transport policy and on the goals of the EU White paper.

In contrast to previous EU announcements on transport policy, the White Paper (2011) emphasises freight transport. This shows that EC is ready to intensify its efforts on reducing bottlenecks for an efficient supply chain, L&M and freight transport systems. The rest of the section discusses *infrastructure* and *sustainable transport* policy implications of on supply chains.

5.3 Sustainable transport and 2011 Transport White Paper

The present study also addresses some policy areas that have not been tackled in the White Paper.

The White Paper states:

> [. . .] a lot needs to be done to complete the *internal market for transport*, where considerable bottlenecks and other barriers remain. We need to readdress these issues – how to better respond to the desire of our citizens to travel, and the needs of our economy to transport goods while anticipating resource and environmental constraints. The transport systems of the Eastern and Western parts of Europe must be united to fully reflect the transport needs of almost the whole continent and our 500 million citizens [. . .] (European Commission, 2011, p. 3).

Moreover, the cited White Paper states:

> [. . .] at the same time, the EU has called for, and the international community agreed, on the need to drastically reduce world *greenhouse gas emissions*, with the goal of limiting climate change below 2°C. Overall, the EU needs to reduce emissions by 80-95 per cent below 1990 levels by 2050, in the context of the necessary reductions of the developed countries as a group, in order to reach this goal. Commission analysis shows that while deeper cuts can be achieved in other sectors of the economy, a reduction of at least 60 per cent of GHGs by 2050 with respect to 1990 is required from the transport sector, which is a significant and still growing source of GHGs. By 2030, the goal for transport will be to reduce GHG emissions to around 20 per cent below their 2008 level. Given the substantial increase in transport emissions [. . .] (European Commission, 2011, p. 3).

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Table II Absolute change in CO_2 emissions of freight transport in kt-CO_2 for various supply chains

Supply chain	Accounting method	All (kt-CO_2)	Food and beverages	Textile	Wood and furniture	Paper	Chemicals	Non-metallic products	Basic fabricated metals	Transport equipment and machinery	Electronics
Offshoring	P	−1,519	−35	−506	−23	−15	−62	−13	−21	−181	−665
	B										
	A										
Offshoring	C	160	−245	−307	616	−7	−217	43	−109	1,734	−1,348
	B										
	A										
On-shoring	P	576	35	382	4	2	10	7	21	30	84
	B										
	A										
On-shoring	C	415	−103	−492	431	6	−182	53	−110	1,296	−1,314
	B										
	A										
Near-shoring	P	149	2	99	1	1	3	1	7	9	26
	B										
	A										
Near-shoring	C	443	−143	−467	430	2	−188	51	−111	1,286	−1,302
	B										
	A										

Source: The authors

Table III Supply chains (kt-CO_2); production and freight transport sectors included

Supply chain	Accounting method	All (Mt-CO_2)	Food and beverages	Textile	Wood and furniture	Paper	Chemicals	Non-metallic products	Basic fabricated metals	Transport equipment and machinery	Electronics
Offshoring	P	19.5	−788	6,349	−308	−183	1,080	−380	−385	−2,144	−7,946
	B										
	A										
Offshoring	C	41.6	−1,341	16,244	809	162	1,507	254	287	9,764	13,921
	B										
	A										
On-shoring	P	7.7	789	4791	51	31	180	190	386	358	1,001
	B										
	A										
On-shoring	C	17.5	−354	−13,241	401	+8	391	71	488	180	3,240
	B										
	A										
Near-shoring	P	1.5	14	971	10	7	36	14	71	100	290
	B										
	A										
Near-shoring	C	17.7	−379	−13,338	391	−56	−527	−108	−473	−198	−3,039
	B										
	A										

Source: The authors

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Table IV Per cent changes in total CO_2 emissions of supply chains; Kyoto targets for offshoring, on-shoring and near-shoring

Supply chain	Accounting method	All industries	Food and beverages	Textile	Wood and furniture	Paper	Chemicals	Non-metallic products	Basic fabricated metals	Transport equipment and machinery	Electronics
Offshoring	PBA	−0.46	−0.02	0.15	−0.01	0.0	−0.03	−0.01	−0.01	−0.05	−0.19
Offshoring	CBA	0.98	−0.03	0.38	+0.02	0.0	0.04	0.01	0.01	0.23	0.33
On-shoring	PBA	0.18	0.02	0.11	0.0	0.0	0.0	0.0	0.01	0.01	0.02
On-shoring	CBA	−0.41	−0.01	−0.31	0.01	0.0	−0.01	0.0	−0.01	0.0	−0.08
Near-shoring	PBA	0.04	0.0	0.02	0.0	0.0	0.0	0.0	0.0	0.0	−0.01
Near-shoring	CBA	−0.42	−0.001	−0.31	0.01	0.0	−0.01	0.0	0.01	0.0	0.07

Source: The authors

Reducing CF should be one option to meeting the EU objective stated above. This can be done by singling out the various supply chain practices that can be CO_2-saving, as we explained in the previous section.

In addition to the above, the EU White Paper has proposed the achievement of ten goals for transport. This study can contribute towards achieving those goals. The major goals, described in the White Paper, are listed in Table VI. The affected supply chain is also identified in relation to the EU policy goal, i.e. on-shoring is positively encouraged if new and sustainable fuels are developed in the EU.

5.4 Summary of policy packages for low carbon freight transport

To reduce the CFs of products of the nine sectors considered in our study, measures will have to be implemented for each of the supply chains at the public policy, corporate and at the global levels. Table V lists the key measures.

Public policy measures include adopting a CO_2 price or tax, and a border tax adjustment: taxes on imports to offset CO_2 taxes on domestic production; and providing rebates on exports of low CF products. Pricing CO_2, however, raises the cost of exports of trade-intensive products, which reduces the competitiveness of the EU industry (Carbon Trust, 2004). These adjustments allow foreign and domestic producers to operate on equal footing in world and EU markets. However, these measures are difficult to implement for the following reasons: it is very difficult to know the exact CF on a product basis, and there is a wide diversity of the CO_2 tax regime as the Scandinavian experience reveals, the legal validity of these measures is not yet clear. A third key measure is the provision of subsidies for energy-efficient equipment for manufacturing plants and for transport technologies, i.e. hybrid trucks in non-EU countries.

Further measures that we considered belong to the following areas: fiscal, funding by public authorities, environment and research and development, industry and infrastructure, pricing or taxing CO_2 emissions. Supply chain practitioners can use the table to understand how these dimensions affect or will affect them in the future.

Broadly speaking, intermodal transport, transport consolidation and recycling are found to be beneficial for the reduction of emissions from transport, while the impacts of centralisation and on/near-shoring practices vary among industries.

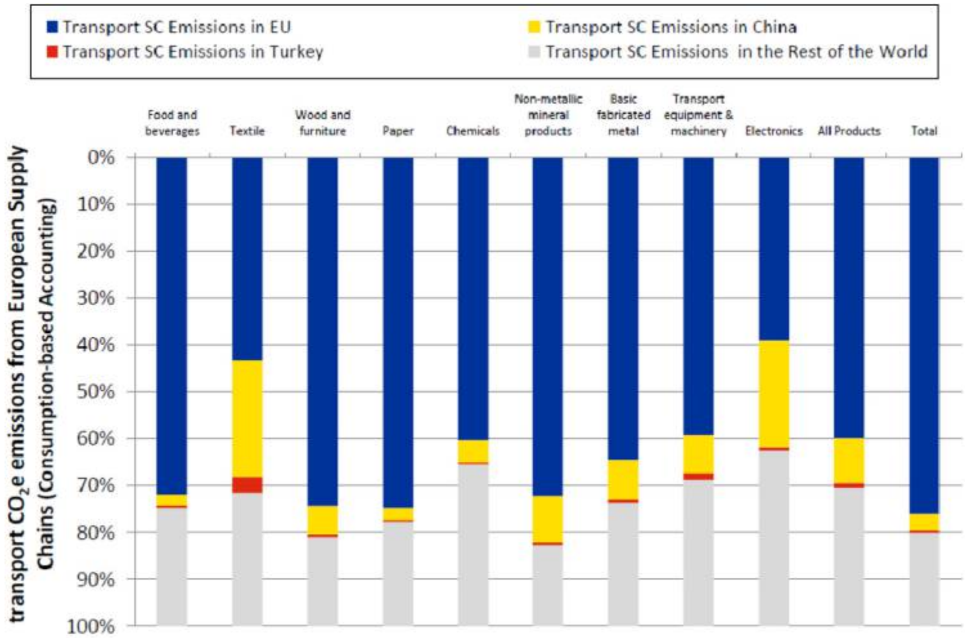
Table VI summarises the measures for each supply chain and policy area.

6. Conclusions

This paper has identified potential supply chains strategies that minimise or increase the CF of these with a particular focus on the contributing role of freight transport activities, and we have provided a set of economic and policy factors that will improve the green performance of supply chains. Our recommendations aim to reduce CF of products. Future cuts in CO_2 emissions will need solutions for green supply chains.

The growth of freight activity has been linked to the globalisation of supply chains, as it has lengthened the distance per good or component moved. These supply chains support the EU economy and thus the burden of cutting CO_2

Figure 4 Freight transportation CO_2 emissions of EU-27 Member States by region and sector under the CBA method



Source: CBA = carbon footprint of products

emissions is economically large and even more so in the coming decades. It is imperative that firms identify value in their supply chain by considering greener practices.

We have identified five supply chains that contribute to the rise of the CF of products and we offer potential solutions for minimising the CF of products today and in the future. Practitioners can use these framework to understand how various supply chains affect their CFs. Europe can achieve these CO_2 targets in the future so long as country responsibility of these emissions is correctly assigned. We have found that offshoring of supply chains increases emissions outside the EU by a large amount, which is about 41 Mt-CO_2, or 12 per cent, of the total EU economy-wide commitment to 2012. The cut commitment amounts to a decline of 341 Mt-CO_2 emissions. The CBA trends, for supply chains, reveal the true CO_2 emissions of EU supply chains. The true CO_2 burden of the EU supply chains is much larger than the PBA levels indicate; the latter are currently used in international

Table V Objectives of the EU-White paper for transport

EU policy goals	Affected supply chain
Developing and deploying new and sustainable fuels and propulsion systems	On-shoring (positive)
Optimising the performance of multimodal logistic chains, including by making greater use of more energy-efficient modes	On-shoring (positive)
This includes	
30% of road freight over 300 km should shift to other modes such as rail or waterborne transport by 2030, and more than 50 per cent by 2050, facilitated by efficient and green freight corridors. To meet this goal will also require appropriate infrastructure to be developed	Offshoring (negative)
By 2050, complete a European high-speed rail network	
Triple the length of the existing high-speed rail network by 2030 and maintain a dense railway network in all Member States	
By 2050, the majority of medium-distance passenger transport should go by rail	
Set up a fully functional and EU-wide multimodal TEN-T "core network" by 2030, with a high-quality and capacity network by 2050 and a corresponding set of information services	
Ensure that all core seaports are sufficiently connected to the rail freight and, where possible, inland waterway system	
By 2050, connect all core network airports to the rail network, preferably high-speed	On-shoring(positive)
Increasing the efficiency of transport and of infrastructure use with information systems and market-based incentives	On-shoring (positive)
EU-ETS (European Union Emissions Trading)	Offshoring (positive)

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Table VI Measures for supply chain strategy according to policy area

Scenarios policy areas	Off-/on-/near-shoring	(De)centralisation	Transport consolidation	Intermodal transport	Recycling	
Fiscal	Provide tax discounts for green truck fleets Border tax adjustment Tax on CO_2-intensive (imports) products Consider fuel taxation, pricing CO_2 emissions and road user charges alongside green taxes Provide export subsidies for low CO_2 products Tax CO_2-intensive products coming into the EU markets			Road pricing at national level	Less-than-truckload transport: mileage taxes on collection in densely populated areas to stimulate geographical efficiency (from e.g. collaboration or load-swapping)	
Funding	Take steps to devise an effective infrastructure funding mechanisms Provide subsidies to non-EU countries for energy-efficient equipment for industry			Provision of funding to support port links with the hinterlands of the EU Increase in the share of infrastructure funds in the EU Cohesion Funds		
Environment	Adopt consumption-based accounting (CBA) of CO_2					
Research	Learn from other international schemes for CO_2 accounting: Japan, Korea and China	Launch a survey of CO_2 footprints of products (industry, national and EU wide) Identify cost-effective ways to cluster production sites closer to consumption sites and provide subsidies		Improve freight statistics	Benchmarking of the logistics trend Research for identification of bottlenecks Research initiatives for network modelling	Develop improved statistics on usage of recycled materials Development of logistics trend guidelines of usage of recycled material – global guidelines for materials with a high maximum economic haulage radius, local guidelines for materials with a small maximum economic haulage radius
Other	Introduce CO_2 audits for fast-growing sectors industry					City council contracting of the collection of all waste and end-of-life products from businesses (less-than-truckload efficiency)
Industry	Adopt voluntary initiatives for CO_2 reporting of products (industry in EU) Adopt a "Name and Shame" strategy for those who fail to adopt a decentralisation			Introduce industrial benchmarks Raise awareness for supply chains	Improving handling times	Encourage usage of sustainable vehicles or transport options in container and bulk transport of to be recycled products and materials
Infrastructure		Invest in the rail network to ensure the achievement of logistics trends Establish a single "European rail freight" network		Facilitate higher vehicle utilisation	Relaxing train sizes Provision of a multi-level network Spatial planning Provision of coordinated information systems	Stimulating the development of industrial parks based on concepts of multi-modal connectivity and industrial symbiosis Encourage city hub concepts with mixed deliveries and collections
Harmonisation				Standardisation of packaging Harmonise truckloads and lengths of trucks	Full liberalisation of railways Securing "European maritime transport space without barriers" Overcoming issues at the borders including language barriers and working hours	Harmonisation in the application of collection targets of end-of-life products with hazardous components across nations

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policy discussions. Although the PBA metric is useful, EU climate policy targets on emissions should be complemented with the CBA metric. However, in the future, more energy-intensive products and finished ones could be imported into the OECD, which would raise the level of CFs of the EU economy and of its product supply chains.

Similarly, a high level of trade exposure of certain product supply chains will be associated to offshoring production capacity and thus to higher CFs of products. In the future two factors can change: the trade exposure of these products and the structure of exports and imports; both of these changes determine the CFs of product supply chains.

The volume of exports is dominated by finished products: chemicals, iron and steel, cement, transport equipment and food beverages. However, two finished products stand out: textiles and electronics. These two products have a larger than average contribution to the entire emissions levels of supply chains. Therefore, green supply chain solutions will need to focus on these two sectors; other sectors are less vulnerable to offshoring, as they are not as exposed to international trade.

To offset the rise of the CFs, seven measures were identified. First, higher taxes on CO_2-intensive products and practices; second, technology standards on logistics and on trucks, and third, imposing financial penalties. A fourth measure includes introducing energy-efficiency programmes in the manufacturing sector. A fifth action suggests adopting a border tax adjustment at the product level that can also be used to reduce CO_2-intensive imports. A sixth one calls for greater incentives at the firm level, i.e. energy-efficiency subsidies. A seventh action to offset the rise of CF of products includes efforts to raise awareness on CFs of urban freight transport, of logistics systems, of manufacturing patterns of CO_2 emissions. Corporations, consumers, private actors and the policy community should be better informed on CFs of products. Corporations' reports on CFs should be mandatory rather than voluntary.

The paper contributes to green supply chain theory by identifying the external forces on CFs of products such as changes in trade structure via offshoring of supply chains, on-shoring or near-shoring of these within key industries. Additional forces include the role of freight transport in enabling urban and international supply chains.

Future research should assess CF at a higher level of detail than this study has done and consider a larger number of case studies and survey information on CF of specific firms at specific European cities. Future work should assess how CFs can be reduced by further technological progress and new global consumer trends.

Notes

1 We assume the two sectors should capture at least the largest part of the supply chain-related CO_2 emissions, but official statistics do not classify CO_2 emissions for specific supply chains. For emissions estimates, we assume the freight transport share of emissions of previous years holds in 2010.

2 Jochem (2000) reports that the final energy use to produce one tonne of steel requires between 27.5 and 35 GJ in China and 17.5 GJ in Japan. This means that Chinese-made steel bears a higher CF than that made in Japan.

3 Cumulative CFs dating from the age of industrialisation (early 1800s) to today would show that developed countries show much higher CFs than less developed ones do.

4 The seven key ratios are value density of goods, weight of goods, average handling factor of goods, average length of haul and modal split.

5 The UK has undergone substantial loss of its manufacturing capacity since the 70s enabling the achievement of lower CO_2 emissions targets in recent years.

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