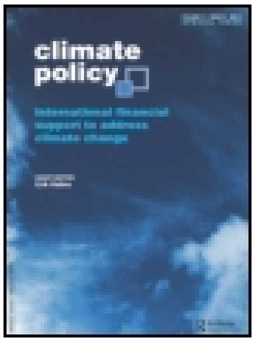

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Beyond peak emission transfers: historical impacts of globalization and future impacts of climate policies on international emission transfers

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ABSTRACT

Globalization of supply chains has resulted in rapid increases in emission transfers from the developing to the developed world. As outsourcing has risen, developed countries have been able to decarbonize domestically, at the expense of increased emissions in developing countries. However, the rapid improvement of carbon efficiency in developing regions together with the post-2008 deceleration in international trade raises the question of whether such embodied emission transfers have peaked. Here we update historical analysis, finding that emission transfers between OECD and non-OECD countries peaked in 2006, and have been declining since. The reversal is principally due to the reduction in the emissions intensity of traded goods, rather than the volume of trade. A more recent decline in embodied emissions transfers is also observed in trade between developing countries. We analyse whether these trends are likely to continue, by exploring a baseline and a Nationally Determined Contribution (NDC) scenario with the Macro-econometric Energy-Environment-Economy Model (E3ME) model. The results suggest that absolute embodied emissions will plateau at current levels or slowly return to pre-2008- crisis levels, and differences between the NDC and baseline scenarios imply that NDC policies will not result in significant carbon leakage. However, the share of national footprint embodied in imports, at least for countries with ambitious decarbonization policies, will likely increase. This suggests that, despite the world-wide stabilization of emissions transfers, addressing emissions embodied in imports will become increasingly important for reducing carbon footprints.

Key policy insights

- Emissions embodied in imports have plateaued since 2006, and are unlikely to return to the peak of the mid-2000s.
- For developed countries, as domestic decarbonization occurs, the share of emissions embodied in imports as a percentage of the total national carbon footprint will increase.
- The Paris NDCs in themselves are unlikely to cause significant carbon leakage.
- Climate policy will ideally focus on reducing both production and consumption emissions, through a variety of mechanisms, especially centred around international assistance.

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Introduction

Since the mid-1980s, developing countries have seen rapid rises in territorial CO_2 emissions, in part due to production for foreign consumption and domestic investment in productive capacity. In contrast, many developed countries saw their territorial emissions decline (at least in per capita terms), whilst emissions embodied in imports grew rapidly. This was due in part to the increased off-shoring of production to developing countries with often more carbon intensive means of production (Malik & Lan, 2016; Raupach et al., 2007). For almost all developed countries, reductions in territorial emissions up to the mid-2000s were accompanied by rising emissions embodied in imports, leading to stable or even increasing emissions when measured on a consumption basis (Peters, Minx, Weber, & Edenhofer, 2011). There has been further concern that such embodied emission transfers will increase under globally heterogeneous climate policy (Kuik & Hofkes, 2010). This concern has been so great that it has been suggested that the displacement of embodied emissions may undermine efforts to achieve climate policy targets (Blanco et al., 2014; Kanemoto, Moran, Lenzen, & Geschke, 2014).

International emission transfers measure the occurrence of emissions embodied in trade, that is, emissions which arise in the supply chain of products that are internationally traded. They show the difference in emission accounts between the region where greenhouse gases (GHGs) are emitted, and the region of destination of related final goods. Most studies focus on CO_2, one of several GHGs. Such transfers grew significantly faster than global trade and gross domestic product (Peters et al., 2011) in the 1990s and early 2000s, with the inter-country trade of embodied emissions as a percentage of total global GHG emissions rising from 19% in 1995 to 24% in 2011 (Wood, Stadler, et al., 2018). The growth in CO_2 emission transfers was thought to have been interrupted by the global financial crisis in 2007–8, but rebounded by 2011 (Peters, Marland, et al., 2012). Emission transfers have been thought to broadly follow the volume of trade up until 2011. However, since the financial crisis, there has been a marked slowdown in the growth of global trade (Constantinescu, Mattoo, & Ruta, 2015; Evenett & Fritz, 2016), a trend that looks set to continue.

China has been the main engine of growth in global international emission transfers (Peters, Davis, et al., 2012), and since the analysis in this paper was completed, other work by Pan et al. (2017) and Mi et al. (2017) have shown China's effect on the stagnation of emission transfers. They attribute changes in emission transfers directly to the change in export volumes in the 1997–2007 period, before declines in Chinese emissions intensity and changes to production structure overtook growth in exports post-2007. A growth in exports to other developing countries between 2007 and 2011 was also identified (Mi et al., 2017). More recently, we have seen an even more marked emissions decoupling in China, where emission levels remained stable for three years before a slight rise due to increased fossil fuel use in 2017 (Le Quéré et al., 2018).

The slowdown in trade volumes, and the continued focus on enhancing demand-side climate policies (Creutzig et al., 2018), trigger some important questions: How closely linked are emission transfers and globalization? Will the combination of the change in global emissions (Jackson et al., 2016) and peak globalization (Curtis, 2009) mean that the fast growth in international emission transfers is over?

To address these questions, we investigate long-term trends in CO_2 emission transfers, covering the period 1970–2050. Data to 2015 are verified with all available global multi-regional input-output (MRIO) models; post-2016 analysis is informed by the E3ME global macroeconomic model aligned to the World Energy Outlook Current Policies Scenario.This study uses a combination of up-to-date nowcasts and novel scenarios of consumption-based accounts to obtain insight into potential future developments in the levels of emissions transfers, and to understand the changing relevance of emission transfers over the coming decades.

Methods and data

Consumption-based accounts and emissions embodied in trade

Territorial accounts report the emissions physically emitted within a region. Production-based carbon accounts (PBCA) differ slightly from territorial accounts by also including emissions of residents outside the territory: including emissions from international transport (emissions from bunker fuels), fishing vessels, and emissions by residents abroad. Consumption-based carbon accounts (CBCA) report the emissions due to final demand in a region, and capture the 'embodied' emissions in global supply chains for products finally consumed by households, government and for capital purposes. Net emission transfers calculated here consist of production minus consumption. Here, we study only CO_2 emissions, the principal greenhouse gas contributing to global warming, from fuel combustion, hence excluding, for example, significant methane emissions agriculture and mining and industrial process emissions.

Historical observations of net emission transfers are not necessarily (and quite unlikely) to be the result of differentiated carbon policy. In contrast, in the scenario work (as described below), where differentiated carbon policies are modelled under the Paris Agreement's Nationally Determined Contributions (NDCs), changes in net emission transfers are purely due to the difference in carbon policy between the scenarios, and hence may indicate a form of carbon leakage.

We use MRIO analysis for the calculation of CBCA and thus emission transfers. The application of input-output tables for the calculation of consumption-based accounts is well described elsewhere (Minx et al., 2009), where the standard calculation is based upon the Leontief demand model (Miller & Blair, 2009). As a result, the reader is referred to standard descriptions, as found for example in (Peters, Davis, et al., 2012; Wood, 2017). For trade-related results, the emissions embodied in imports are calculated for each region. Bilateral transfers are calculated showing the origin to destination of emissions.

Historic data sources

In order to explore the critical question of the historical developments in net emission transfers, and whether these have peaked, we rely on a range of model outputs. Previous literature (Moran & Wood, 2014; Owen, 2017; Rodrigues, Moran, Wood, & Behrens, 2018; Tukker et al., 2018) has pointed to sometimes significant differences between models, hence the main results of this paper are based on an assessment of the mean and variation of CBCA from multiple models with respect to their change over time, and are fully described in (Wood, Moran, et al., 2018). In this work the various model results were benchmarked to an average 2007 value for each country (the main base year of most databases) (Wood, Moran, et al., 2018), such that the time-series of estimates show the relative change in production or consumption emissions from 2007. Such normalization eliminates almost all variation between the various models, such that variance of major regions reduces to circa 5% or less using relative standard deviation as a measure of precision.

For the investigation of the structural changes underlying the net emission transfers, further analysis was undertaken based upon the EXIOBASE dataset, which provides a full MRIO model and associated GHG emission accounts for the years 1995–2016. A single model was used in order to isolate structural changes, allowing for consistent regional/sectoral disaggregation, and the ability to reference constant price data. The principal development of EXIOBASE is described in Stadler et al. (2018), with subsequent data updates to extend the main economic database to 2016 described in Stadler et al. (2016). The principal dataset for CO_2 emissions in EXIOBASE is based on International Energy Agency (IEA) energy balances, but reallocated to industrial sectors (Stadler et al., 2018) and adjusted for the residential principle (Usubiaga & Acosta-Fernández, 2015). The data is updated for CO_2 emissions for the years 2012–16 based on sectoral projections (Stadler et al., 2016) and constrained to aggregate level data from the EDGAR dataset (Janssens-Maenhout et al., 2017). We focus on fuel combustion emissions of CO_2 only, in order to keep consistency with other work (Le Quéré et al., 2018) and to allow use of the most recent emission datasets at the time of this work (BP, 2016). Constant price (ie. deflated) trade data used in the calculation of emissions intensity of trade was taken directly from EXIOBASE3, which is based on the UN Main Aggregates data (United Nations Statistics Division, 2017). GDP data is taken from the World Bank using 2011 international PPP (World Bank, 2015).

Scenario projections of 2015–2050 emissions

Scenarios of future consumption and production-based emissions are investigated here using the E3ME[1] model, a sectoral dynamic macroeconomic model of the global economy, which has been designed to assess options for climate and energy policies and to allow for energy-environment-economy (E3) interactions. The E3ME model is widely used by research into low-carbon futures (e.g. Barker, Alexandri, Mercure, Ogawa, & Pollitt, 2016; Barker, Anger, Chewpreecha, & Pollitt, 2012 ; Mercure et al., 2018) and for wider European and global policy advice (e.g. Eurofound, 2019). The model allows for annual dynamic (short-, medium- and long-term effects) scenario analyses of future emission pathways, stemming from combinations of forecasted economic activity and policy impacts, and their macroeconomic effects. E3ME also allows for calculations of consumption-based emissions, being built on a similar input-output basis as the MRIO models used for the historical analysis. For more detailed theoretical assumptions see the model manual (Cambridge Econometrics, 2014). The model is disaggregated into 59 world regions and 43–69 industrial sectors in each region. Trade is modelled as bilateral trade between the model regions. Trade volumes are determined primarily by domestic activity rates and relative prices. The model is based on cross-section and time-series data analysis of the global economic system 1973–2010 (in the version used for this paper) using formal econometric techniques. The complete model equation set is provided in Mercure et al. (2018).

Scenario specification

The projections used in this paper are drawn from the E3ME baseline and a scenario in which the NDCs agreed as part of the Paris Agreement are implemented. These should be viewed as possible scenarios, rather than forecasts. The baseline projections incorporate projections of future energy demand (set to match the IEA's World Energy Outlook (WEO) current policies scenario) and extrapolations of recent trends in economic indicators (constrained to match OECD projections of GDP growth, consistent with the IEA's work).

The baseline rates of trade growth account for the recent slowing in growth in trade volumes and do not anticipate a return to previous rates that substantially exceeded growth in GDP (Livesey, 2017). Over the period 2017–2030, world trade increases by around 3.7% in real terms in the projections (and 3.2% over 2017–2050). We also test a sensitivity in which global trade increases annually by 4.7% up to 2030 (in addition to sensitivities on energy consumption patterns).

The modelling undertaken in this study required the specification of a scenario to reflect the set of policies for GHG mitigation. The reference or 'current policies' scenario is intended to represent the outcome for the global economy for 2015–2030 of adopting current policies as of mid-2014, but without the extra efforts promised in existing policy proposals. This scenario is mainly based on the IEA's current policies scenario using our model to provide a fully dynamic solution over the period (IEA, 2014). The population forecasts by region are the same as those used in the IEA WEO (IEA, 2014) namely the ones projected in the UNPD medium fertility scenario (UNPD, 2013). The energy and economic projections are also set to be consistent with the WEO assumptions. The economic projections are typically only provided at an aggregate rate and so must be disaggregated across sectors and economic indicators (e.g. the components of GDP). Again, figures are interpolated across years. The model projections are scaled, 'calibrated' to match WEO projections and provide a fully endogenous solution.

Changes in patterns in trade and energy growth in the NDC scenario follow those in the baseline, with the model determining endogenously the additional impacts of the NDCs. The NDC scenario adopts countries' climate change mitigation pledges as they have been submitted under the Paris Agreement. Where policy detail was available (e.g. on renewables promotion or land use change) this was entered into the model directly; otherwise a basic carbon pricing mechanism was used. This approach reflected the lack of information that was available at the time and does not account for specific policies. It will have some impact on results but is unlikely to change the underlying trends. Through both competitiveness and absolute volume effects, implementation of the NDCs will result in changes in trading patterns. For further information on how non-energy sources of emissions were handled, the reader is referred to the Supplementary Information.

The final result from the exercise is an estimate of CO_2 emissions that can be used as a target in E3ME for the year 2030. Where the NDCs set targets for earlier years, extrapolations were made to provide a consistent endpoint for the analysis.

Linking the historic assessment and scenario work

E3ME links sectors by input-output tables and the regions via bilateral trade matrices, as per the above MRIO models, thus using a broader dynamic macroeconomic framework to estimate annual PBCA and CBCA up to

2050. As mentioned above, E3ME is based on econometrically-derived equations using data from 1973 to 2010, but has a 2005 base year for most of the data. In order to keep consistency with the historical work, we apply the relative change in PBCA and CBCA from the scenario model to the 2007 historical data. This allows the presentation of both differences between scenarios, whilst also capturing the absolute level of emissions relative to the historical dataset.

Results

Peaking emission transfers: south-north

Net emission CO_2 transfers to OECD from non-OECD members (which for simplicity we term 'south-north' transfers) grew from close to zero in the 1970s to over 2 $GtCO_2$/yr in 2006 with a global emissions total of 29$GtCO_2$/yr (+/−12% variation in raw data across models; +/−5% based on growth rates; see Wood, Moran, et al. (2018) and Supplementary Information). However, over the nine years since 2006, such emission transfers have consistently decreased, apart from the short recovery identified by Peters, Davis, et al. (2012).

Figure 1 documents a significant reversal in a trend that many had assumed to be unstoppable, and provides a significantly different view to earlier findings (Peters et al., 2011; Peters, Davis, et al., 2012). The result is visible in all available models, and not just for the OECD, but also for all Annex I countries[2], and for the EU27 (see methods and Supplementary Information). The growth in net transfers up to 2006 reflects the growth of globalization, with the trade liberalization of the early 1980s reflected in the growth of emission transfers at an almost exponential rate. The fast development of developing countries as manufacturing centres, and hence net carbon exporters, based on direct savings and direct foreign investment, together with low labour costs, displaced manufacturing investment in the OECD over this period. Symbolically, 2006 was the year in which Chinese emissions exceeded those of the US, and the following year non-OECD consumption-based emissions finally outstripped the OECD's, just as emission transfers peaked. However, it is notable that south-north emission transfers peaked at about 7.3% of total global CO_2 emissions (15% of OECD CBCA) two years *before* the financial crisis of 2008. The post-crisis recession hit OECD imports in particular – indeed, the reduction in consumption emissions exceeded that in production emissions in the US and Europe. Non-OECD consumption emissions growth was largely unaffected.

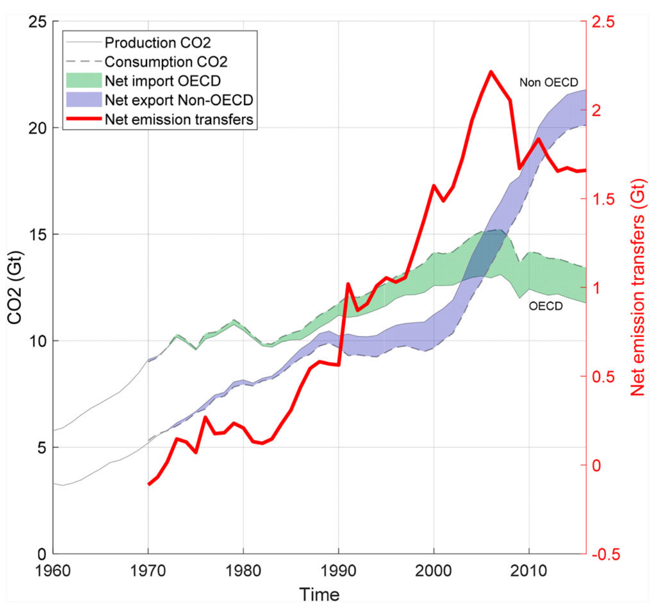

Figure 1. Production and consumption based CO_2 emissions and net 'south-north' emission transfers, OECD (green) and non-OECD (blue), 1960–2016 (background format inspired by Peters et al (2011)).

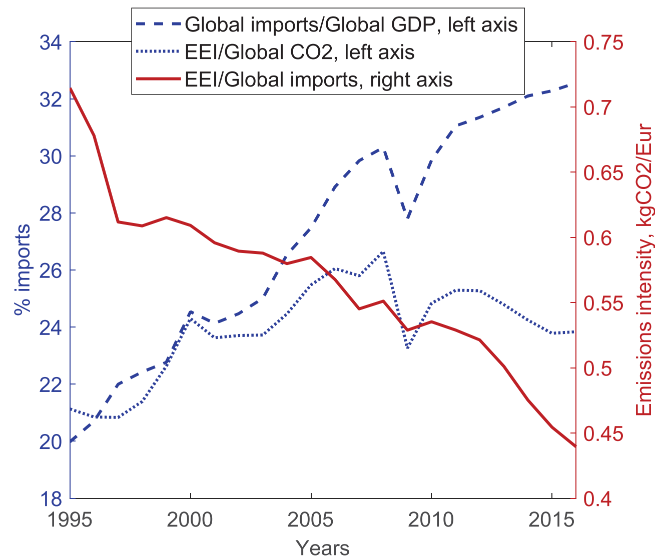

Figure 2. Recent developments of trade and embodied CO_2 emissions in trade, 1995–2016. Blue line (dashed): Ratio of the value of global imports to global GDP, constant 2005 prices (left axis); Blue line (dotted): Ratio of emissions embodied in trade (EEI, global trade = imports) to global carbon dioxide emissions (left axis); Red line: Emissions intensity of trade (right axis).

Peaking emission transfers

The development of south-north emissions transfers is mirrored in the broader development of all emissions embodied in trade, including bilateral trade within the regions. Along with the general rise in global traded value (Figure 2, blue dashed line, referenced to GDP), global emissions embodied in all international trade flows (not just south-north) peaked in 2008 at just over a quarter of global CO_2 emissions (blue dotted line). The percentage of embodied emissions per unit of trade stabilized before the onset of the financial crisis in 2007–8. This points to the fact that improvements in emissions intensity (measured as CO_2 emissions per unit of traded value in constant prices) outpaced the growth in trade volumes from around 2005–6. The rate of decline in emissions intensity of traded goods has increased since 2005 (red line in Figure 2), and reflects the compound of trade composition (e.g. a shift to higher-value-added products), and energy intensity of production processes. When trade volumes (in monetary terms) fell after the crisis, the intensity effect started to dominate, leading to declining emission transfers.

After a rapid decline in 2009, both trade and emissions transfers rebounded in 2010 and 2011 as identified by Peters, Davis, et al. (2012). However, the percentage of emissions embodied in trade has declined since 2012, while the ratio of global trade to GDP has continued to grow, albeit slower than before. The reason for this decline is the accelerated decrease in emissions intensity of trade (Figure 2, right axis), which has dropped by almost 15% between 2012 and 2015. Hence, the decline in south-north emission transfers since 2005–6 (see Figure 1) has been reflected to a lesser degree by declining overall embodied emissions in trade.

Regional contributions

The major decline in CO_2 emission transfers since 2006 has occurred in both trade from the non-OECD to the OECD and in intra-OECD trade (Figure 3). In contrast, trade among non-OECD countries has grown strongly until 2012. Our results suggest the trend picked up by Meng of growing south-south trade (Meng et al., 2018) has ended, with a stabilization also occurring. Splitting off these changes into volume (volume of trade in constant Euros) and intensity effects (emissions per unit of imports), we see the dichotomy between north-south and

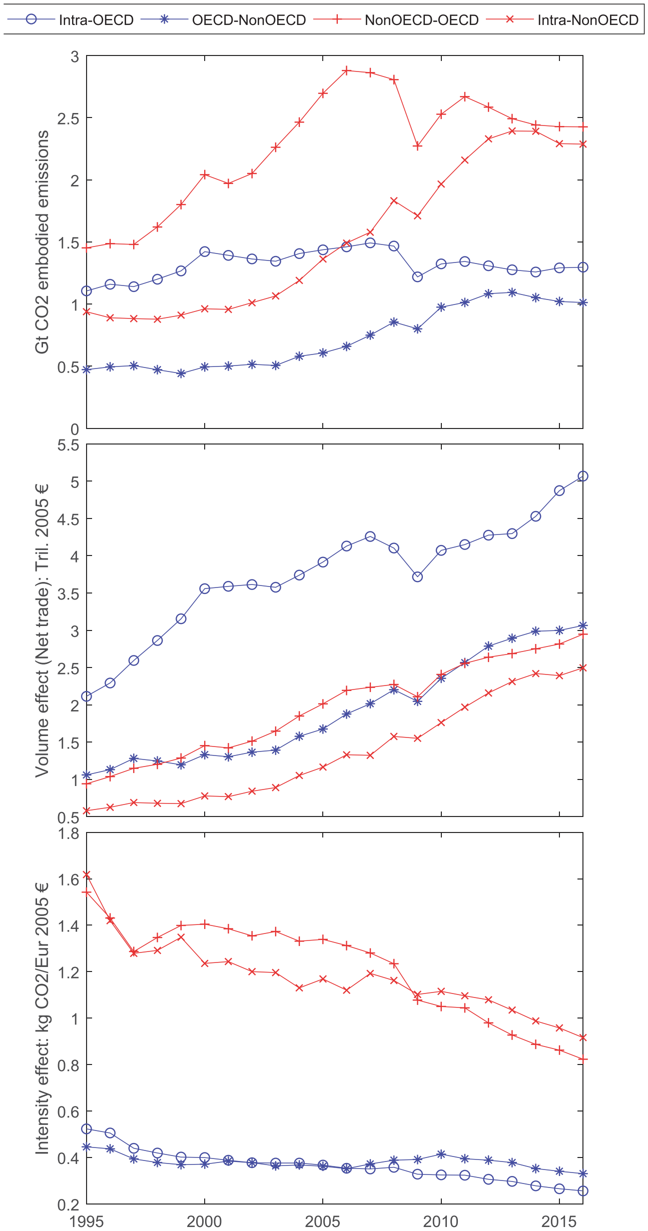

Figure 3. Changes in inter and intra regional embodied CO_2 emissions. Top: Emissions embodied in inter and intra -regional trade, Gt CO_2; Middle – the volume of inter and intra-regional trade; Lower: The intensity of trade, showing the embodied emissions per unit of net inter/intra regional trade.

south-north trade: the OECD has continued to dominate trade, but with a relatively low and slowly decreasing domestic carbon intensity, whereas non-OECD intensities were much higher but decreased at a fast rate. Of note is that the emissions intensity of products exported from the OECD to non-OECD grew between 2005 and 2010, reflecting a shift in exports from the OECD to more carbon intensive products. In contrast, the intensity effect has had a more significant impact in non-OECD trade, with the recent stabilization of intra-non-OECD embodied emissions due to the intensity effect catching up to the growth in volume. This suggests a mirroring of the event that happened in the mid-2000s for non-OECD to OECD trade.

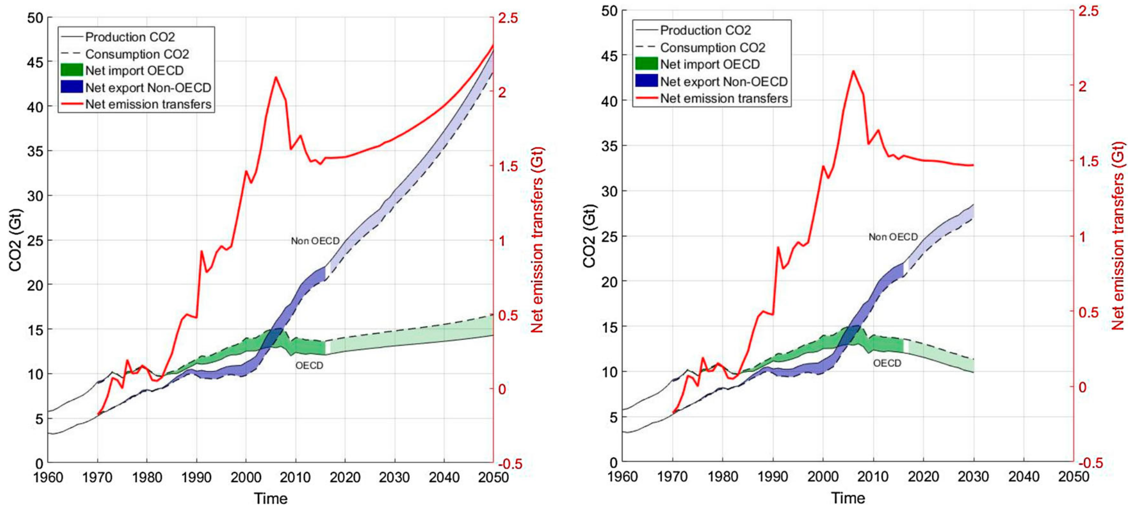

Figure 4. Projections of production-based and consumption-based CO_2 emissions, Left – baseline scenario to 2050; Right – NDC scenario to 2030, when commitments end.

Scenarios of future emission transfers

With the latest developments around declining global coal use, slowdown of growth in global trade and, more importantly, the adoption of the Paris Agreement, the question arises as to whether or not (all else being equal) the decline in emission transfers will continue.

The fear that production and emissions will move to countries with less stringent environmental conditions has impeded the scope and ambition of unilateral climate policies. Our results suggest, however, that this fear is largely unfounded at the macro level, with both baseline and NDC scenarios not showing a return to the rapid growth in emission transfers seen from 1970 to 2005 (Figure 4). Whilst the baseline scenario predicts a return to the absolute level of emission transfers near to 2007 levels, this does not occur until after 2040. In the NDC scenario, we observe an almost complete levelling out of emission transfers, partly due to the global impact of NDCs on production, but also to the decarbonization of global trade.

Whilst our results point to a lower absolute level of CO_2 emission transfers under the NDC scenario, this is in line with lower overall emissions. Whereas stronger climate action in OECD countries has traditionally been assumed to be at risk of being offset by increased 'carbon leakage', our results suggest the opposite. The most striking observation is that by 2030, net embodied imports to OECD countries decline by about 15% in the NDC scenario (Figure 5(a)). This is because any impacts on trade are much more than offset by the declining emissions intensity of production including in the rest of the world (Figure 5(b)). Baseline intensities for both regions decrease by roughly 20%, whilst under the NDC scenario, they decrease by over almost 40% for the OECD and slightly lower than 30% for the non-OECD. The gap between the production-based and consumption-based emissions intensities, however, points to how important emission transfers will be in the future (Figure 5(c)). Especially under the NDC scenario, the relative contribution of imported emissions to the total CBCA of the OECD will rise as the OECD decarbonizes domestically. Emission transfers as a percentage of total production or consumption accounts increase from roughly 11% to 13% by 2030 (compared to around 10–11% for the baseline) for the OECD. For the non-OECD, the percentage of emission transfers (relative to production accounting, as net-exporter) decreases to between 5.5% and 6% under the two scenarios.

Discussion

CO_2 emissions embodied in trade peaked in 2006 at around 26% of total global CO_2 emissions. Such emissions are determined by a combination of the total level of trade and the carbon intensity of the production of that

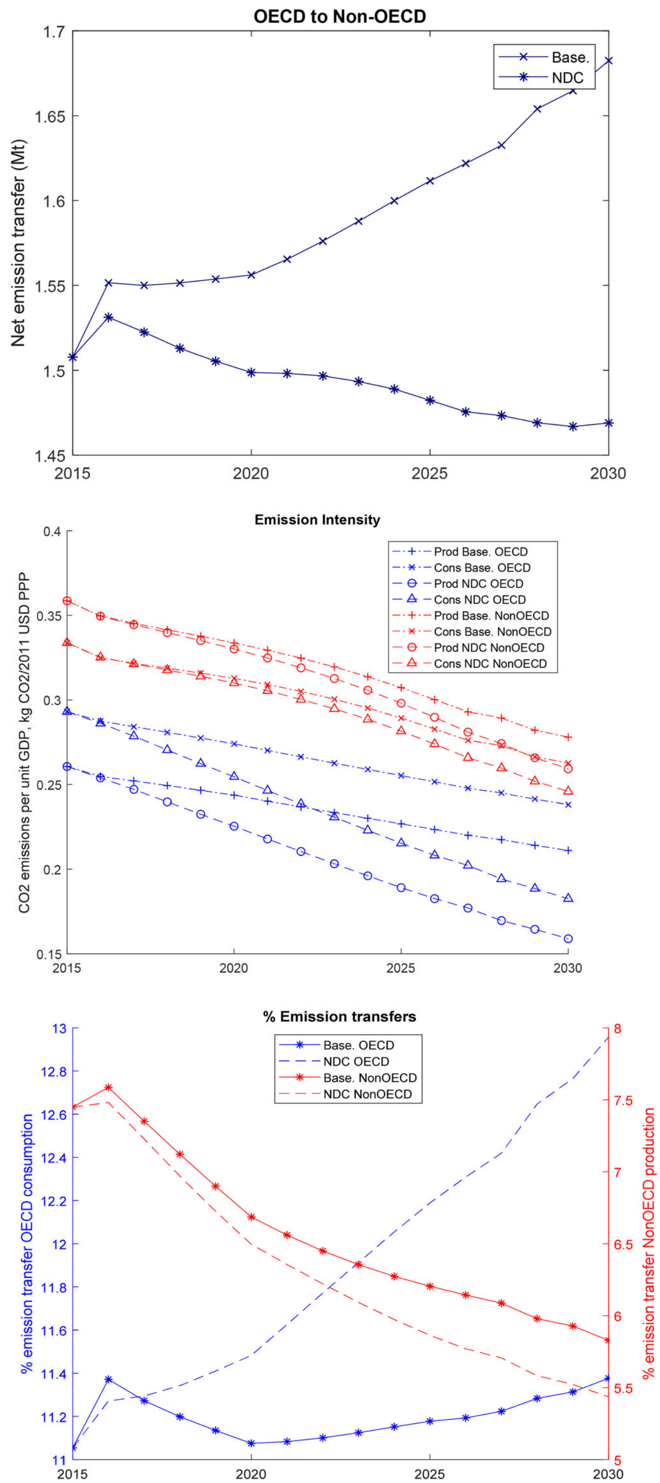

Figure 5. Relative importance of net CO_2 emission transfers 2010–2030. (A) Scenarios of absolute emission transfers between OECD and non-OECD; (B) Evolution of scenario emission intensities for OECD and non-OECD, production and consumption account; (C) % Emission transfer of consumption account (OECD) and production account (non-OECD).

trade. We observe both a decline in the emissions intensity of trade since 2005 and a marked slowdown in global trade growth since 2008, with trade now appearing to stabilize as a percentage of global GDP. We hypothesize that this is in part due to hitherto cheap exports from some non-OECD countries becoming more expensive, and partly due to a stoppage in the erosion of the manufacturing industry in the US and Europe, reinforced by policy initiatives for a reindustrialisation of these regions (Krawczyński, Czyżewski, & Bocian, 2016). Another aspect of the results supports this hypothesis: overall south-north transfers have declined while the global total transfers have remained only just below peak levels, thus indicating a gradual shift away from south-north transfers to a broadening south-south trade of carbon intensive goods (see also Meng et al. (2018)).

Our results show that the rate of decarbonization of global trade now exceeds the rate of growth in trade value. This is a reversal of the trend from the period from 1990 to 2006, and 2009–11. During those periods, the exceptional rise of China as an exporter of low cost products, produced with a carbon intensive, coal-based energy system, led to a significant rise in the carbon intensity of global trade reported earlier (Davis & Caldeira, 2010; Peters et al., 2011).

Future emission transfers will reflect the tensions both within trade (resumed globalization based on comparative advantage *vs* opposition to trade and efforts to reindustrialize); and in energy and climate policy (focus on domestic emissions *vs* globalization of effort and shift to low carbon energy). Our projections suggest that in a business-as-usual scenario, south-north emission transfers may slowly increase towards former levels, while with the NDCs in place, they will remain at roughly current levels.

There is a risk of some reversal to higher levels of emissions embodied in trade if efforts to reduce emissions intensities fail, particularly in non-OECD countries, and in the event of a renewal in the trend of strongly rising global trade levels, particularly among countries of the non-OECD. This is not predicted by our modelling, but it is not inconceivable: in the absence of globalized action on climate change, the world could easily be facing the prospect of 'two more Chinas', most obviously in the development of the Indian subcontinent, and Africa. Whether the emissions embodied in trade will rise accordingly will largely depend on the carbon intensity of the energy system backing up their growth in manufacturing, as was the case for China. The more ambitious NDCs of these regions are expressly conditional on continued international support. They face the imperative of development, but their need for international assistance also reflects their greater difficulty in accessing advanced technologies, or low cost finance, both of which are necessary to many aspects of low carbon development.

Our findings help to put the scale of emission transfers in perspective, but their prominence in the policy debate is still likely to rise, not lessen. In all the scenarios, if and as mitigation efforts advance with a focus on domestic emissions, traded goods will again make up an increasing proportion of emissions, not just south-north, but more globally. Our modelling results do not show evidence that the NDC scenario leads to higher emission transfers, which suggests there is a low risk of carbon leakage. Yet the fear of carbon leakage may still hinder strong emission reduction policies with regard to industrial emissions. Industry is often perceived as relatively mobile, while at the same time industrial emissions will become relatively more important, as decarbonization proceeds on buildings, transport and power generation.

Trade policy and globalization

The scenarios we model are, of course, under pressure from far more than climate policy; we write at a time of apparently high uncertainty for the future of international trade. Most notably, the US Presidency of Donald Trump is challenging the ascendency of globalization, whilst 'Brexit' and the election of nationalist Jair Bolsanaro in Brazil also underline the challenges to the existing economic order.

What bearing might this have on our analysis? Clearly, declines in aggregate trade value volumes would tend to reduce emission transfers, particularly if focused on a narrative of reindustrialisation in OECD countries (Livesey, 2017). However, there is little evidence or rationale to suggest that this would be good for GHG emissions; even in the age of Chinese coal-dominated growth, the analysis by Wood et al ((2019) for the European Union (EU) indicates that the *increased volume* of trade has dominated by far any impact of the higher carbon intensity in China. Hence, the impact on global emissions of importing foreign-produced goods, compared with producing the equivalent goods domestically, has been modest. With China itself rapidly reducing its carbon intensity, the net emissions benefit of relocating industry *per se* back to OECD countries is debateable, unless in doing so it involves a radical shift towards low carbon manufacturing. Indeed, even for the EU's trade footprint, Wood, et al.'s (2019) analysis suggests that the impact of radical reindustrialisation would be modest, since a sizeable portion of that footprint arises from mining and agriculture, for which the EU would still be dependent on foreign resources and land.

Thus, any impact of 'anti-trade' policies on emissions would probably be dominated by blunter routes: adverse impacts on economic growth itself, or impeding the international flow of cleaner technologies.

Policy Implications

A key question for climate policy is how consumption-based and trade-related policies can help reduce the emissions embodied in imports. Supplementing territorial-based NDCs with consumption-based NDCs may be the most effective solution (Springmann, 2014). The Paris Agreement goals are global but approaches to implementing and strengthening the NDCs vary from country to country. We suggest four policy approaches to ensure that the last decade's stabilization of emission transfers is not reversed, but rather moves from 'peak transfers' into future decline:

- *International assistance*. International support from developed to developing countries could be used to help the next wave of emerging economies, in particular, to decarbonize their development, especially in the manufacturing and agricultural sectors, thereby further lowering the carbon intensity of traded goods as well as contributing to the broader Paris Agreement goal of peaking global emissions as soon as possible.
- *Tackling domestic materials consumption*. The great bulk of emission transfers are associated with materials (and food). Consumption and associated emissions, including transfers, could be reduced, for example by extending to materials those approaches already demonstrated for improving energy efficiency (Scott, Roelich, Owen, & Barrett, 2018), and/or introducing a carbon charge for materials consumption (analogous to excise duties on petroleum) (Neuhoff et al., 2016, Pollitt, Neuhoff, & Lin, 2019). To maintain balance across the supply chain, a levy could be applied to the content of key materials in major goods (e.g. mass of steel in vehicles), an approach that is administratively more feasible than tracking embodied emissions of specific products through their supply chains (Ismer, Haussner, Neuhoff, & Acworth, 2016).
- *Trade rebalancing / low carbon reindustrialisation.* The loss of manufacturing industries from developed economies is already driving opposition to further trade liberalization. To the extent that calls for reindustrialisation have policy impact, it will be important to focus these efforts on high efficiency manufacturing processes and, even more, innovative low carbon materials and technologies.
- *Targeting lower intensity of imports, exports and supply chains.* A variety of approaches (including several of those reviewed in Grubb et al ((2019) can also help lower the carbon intensity of trade itself whether directly through mandatory policy, or often, through collaborative efforts between government, business and consumer groups to tackle emissions from supply chains.

Conclusion

This study has explored past trends in international emission transfers, and their future prospects with and without the Paris Agreement NDCs.

The historical results were based on a combination of models to provide a long time-series of historical and scenarios of emission transfers. We conclude that international emission transfers have peaked and subsequently plateaued, a finding supported by multiple models. Our baseline scenario suggests that south-north emissions transfers might slowly increase but would be unlikely to return to the peak of the mid-2000s before 2040.

Our scenario results imply that the delivery of NDCs under the Paris Agreement, far from driving 'carbon leakage', would tend to reduce net south-north emission transfers. However, for developed countries, as domestic decarbonization occurs, the share of emissions embodied in imports as a percentage of the total carbon footprint is likely to increase.

Ideally, climate policy should focus on reducing both production and consumption accounts through a variety of mechanisms, including through international assistance. To be feasible and effective, such measures would have to be set in a wider context that informs and legitimizes attention to tackling emission transfers. Finally, we suggest that, whereas the current Paris Agreement NDCs concern almost exclusively territorial emissions, the next round of NDCs, due in 2020, could expand the horizons by also setting out what countries offer to do with respect to their overall carbon footprint, both through varied domestic consumption-oriented policies, and through international assistance.

Notes

1. www.e3me.com.
2. Annex I Parties include the industrialized countries that were members of the OECD (Organisation for Economic Co-operation and Development) in 1992, plus countries with economies in transition (the EIT Parties), including the Russian Federation, the Baltic States, and several Central and Eastern European States.

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