

Background & theory

“Production” and “consumption” views of global GHG emissions offer very different perspectives on CO₂ releases, and highlight the interconnected nature of emissions abatement activities. This section explains the fundamentals of production and consumption accounting, and provides greater detail on the theory behind consumption views of global emissions.

Key concepts

- **The production view of GHG emissions**

The emissions produced by human activity are usually considered from a production perspective: that is, the country (or factory, etc.) from which the emissions are released is seen as the “owner” of the emissions. This is the traditional approach taken in global, sectoral and company-level assessments of greenhouse gas emissions.

The production view is the basis of current GHG policy approaches such as the Kyoto Protocol or the EU Emissions Trading Scheme. By measuring or estimating the emissions released within a country or company, overall emissions production can be assessed. From this assessment, policy options (e.g. sector caps on emissions, country targets) can be considered where carbon abatement is a public policy objective.

- **The consumption view of emissions**

The production of virtually all greenhouse gas emissions from human activity can ultimately be traced to satisfying consumption (purchase and/or use of final goods or services) in some form. This can take many routes and includes not only the emissions associated with making of a new good such as clothes or cars, but also in the creation of infrastructure to support manufacturing.

A consumption view of greenhouse gas emissions reflects the impact of a country’s consumption on global greenhouse gas emissions (rather than accounting for the emissions produced within a country), accounting for the emissions arising internationally to support consumption within a country. By directly linking the original driver of emissions (consumption of goods and services) with the release of GHG emissions, a different global picture of emissions emerges. This linkage between consumption and greenhouse gas emissions lends new perspectives, and potentially

solutions, that are not readily visible from a traditional emissions production perspective.

The consumption view of emissions can be presented in two ways: the environmentally extended bilateral trade (EEBT) approach, which assesses the flow of emissions between two countries; and the multi-regional input-output (MRIO) approach, which allows the assessment of full upstream or downstream flows of emissions including those passing through intermediary countries. While this analysis has made extensive use of the MRIO approach, EEBT data has also been used where relevant.

Background and theory

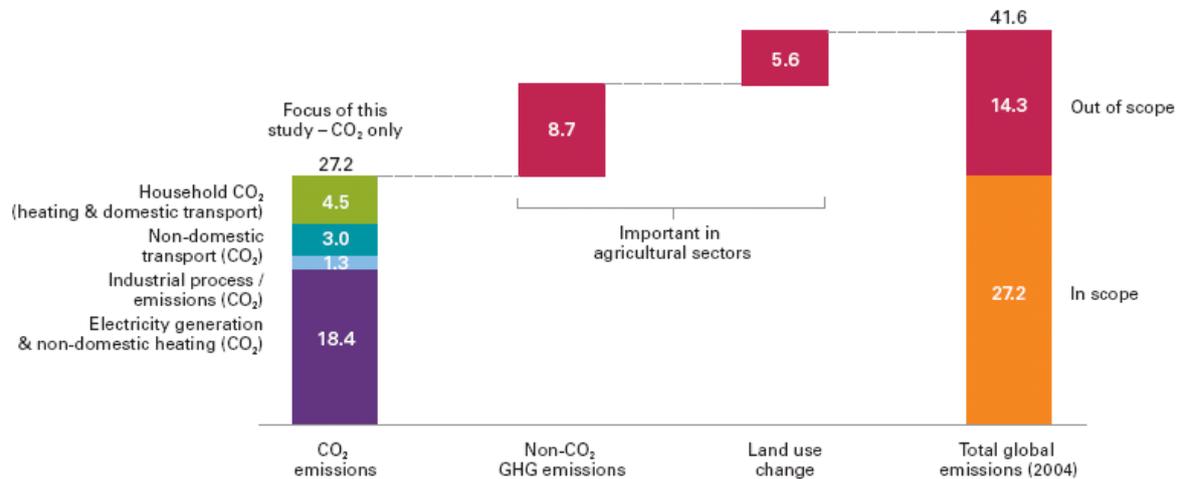
- **Datasets**

The consumption emissions analysis presented here is based on models built on the Global Trade Analysis Project (GTAP 7) dataset, using modelling carried out by Dr Glen Peters (CICERO, Norway), Dr Chris Weber (Carnegie Mellon University, USA), and Dr Jan Minx (Technische Universität Berlin, Germany). For specific sectors, this global data was supplemented by trade and industry data, industry interviews and targeted research in specific sectors.

- **Theory and background**

Consumption based views of GHG emissions are based on theoretical work pioneered by Wassily Leontief, who was awarded the Nobel Prize for Economic Sciences in 1973 for the “development of the input/output method”, tables for which are now published by a wide range of governments. These tables are presented in economic units, and part of the modelling carried out for this analysis was to convert these tables into environmental (CO₂) datasets. This information is then combined with other sources of data, including international trade statistics and energy efficiency data, to finally arrive at the data underpinning this analysis.

The production view of greenhouse gas emissions

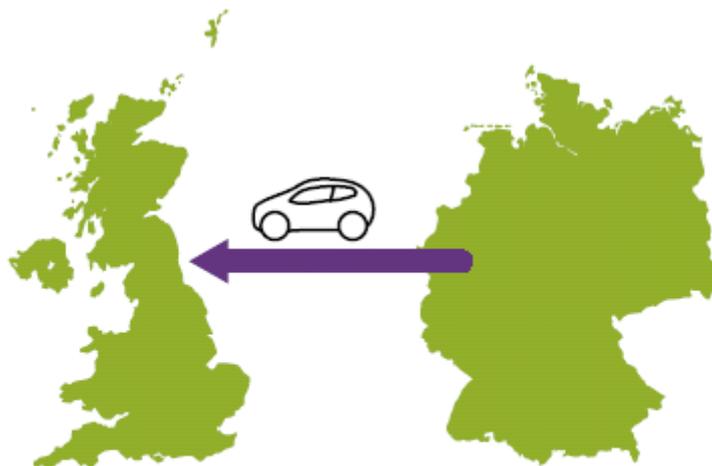


The emissions produced by human activity arise from a variety of sources. Those included in this analysis are based on the GTAP 7 database, and include emissions from electricity generation and non-domestic heating, industrial processes and non-domestic transport, and household emissions (including heating, private transport, and other fuels used directly in the home such as for cooking and hot water).

There are two significant sources of emissions that were not included in the GTAP 7 database at the time this analysis was carried out: non-CO₂ GHG emissions from industrial processes, and GHG emissions arising from land use change. Non-CO₂ emissions include gases such as methane (from livestock farming, rice cultivation, etc.), refrigerants and other industrial gases. Land use change emissions include CO₂ and other greenhouse gases released due to human-induced changes to land use, such as the clearing of native forest for agriculture or other purposes. The estimate of emissions from land use change shown above include CO₂ from the loss of above-ground and below-ground biomass, together with losses of carbon in the soil (such as the conversion of carbon in peat soils to CO₂). Taken together, non-CO₂ and land use change emissions account for around one-third of total GHG emissions arising from human activity.

The consumption view of greenhouse gas emissions

Environmentally extended bilateral trade (EEBT) assessment



Emissions from a car produced in Germany and bought in the UK would be tracked, but emissions embedded in imports into Germany for car making would not be included

Environmentally extended bilateral trade (EEBT) assessment

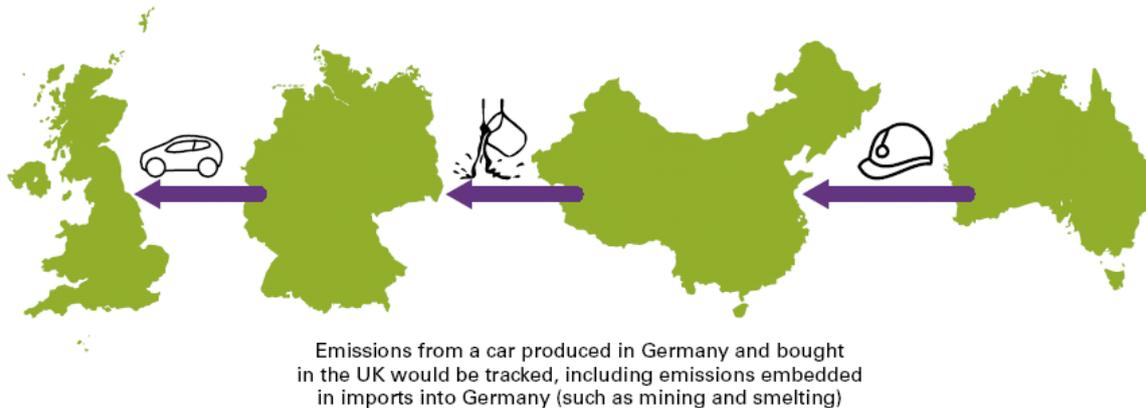
An environmentally extended bilateral trade (EEBT) model adjusts the traditional production-based view of emissions by accounting for the import and export of emissions embodied in trade with direct trade partners. By establishing the carbon intensity of trade, based on the activities taking place in the trade partner country and the volume of trade between the countries, the net import or export of emissions embodied in this trade can be determined and applied to the original production view of country emissions. EEBT models adjust existing production-based assessments of GHG emissions by country, by correcting for the emissions embodied in trade (imports and exports) with direct trade partners. An example of such an approach would be the assembly of a car in one country, and the consumption (sale) of that car in another country: in this case, the country exporting the car would see its emissions reduced, while the country importing the car would see its emissions increase by the same amount.

It is important to note that under this approach, it is only the emissions occurring in the trade partner country that are re-allocated, not any emissions occurring further upstream: in this case, emissions from the assembly of the car would be re-allocated; however, if the smelting of the steel in the car had occurred in a different country, this would not be included. As a result, EEBT approaches offer a partial correction of current production-based country emissions data which addresses many of the limitations of production-based emissions assessments. However, the degree of correction is dependent on the significance of activity undertaken in the trade partner trade country. In highly extended supply chains, the final country of export may be a minor contributor to overall upstream emissions in the supply chain, limiting the value of this correction. (For the UK, embodied emissions in bilateral trade result in a net import of CO₂ equal to around 25% of the emissions produced in the UK, compared to a total estimated increase of 34% if all upstream imported carbon is included, as in the multi-regional input-output (MRIO) assessment).

An EEBT view of consumption emissions is appropriate in some circumstances, particularly where there is limited data or where a simplified view of emissions flows is needed. However, the EEBT approach does have some limitations and a more complete consumption perspective from a multi-regional input-output modelling approach can be used as an alternative.

The consumption view of greenhouse gas emissions

Multi-regional input-output (MRIO) assessment



MRIO models go beyond the approach described for EEBT, by providing a fully re-allocated view of global emissions. MRIO models alter the traditional production-based view of emissions by country by factoring in the effect of imports and exports of embodied emissions in trade with direct trade partners and also factoring in the full upstream life cycle emissions occurring in any sector or country that supports final consumption. Under this approach, emissions arising from the production of goods and services are allocated solely to the country of consumption of those goods and services, irrespective of the country of production of the emissions. MRIO models use environmental data (in this case, GHG intensity of production) to convert monetary data in national input/output models into national CO₂ production information. These national tables are then linked via trade data, and matrix mathematics approaches are used to calculate the re-allocation of global emissions on the basis of consumption.

Consider the car example given above: while the EEBT approach was able to correct for embodied emissions flowing between direct trade partners, it was not able to correct for embodied flows of emissions occurring further upstream in the supply chain. An MRIO approach would result in all emissions associated with the production of the car being allocated to the country where final consumption of the car occurred. This would include not just the assembly of the car, but (for example) manufacture of the engine, smelting of the steel for the engine, mining of iron ore for the steel, manufacture of mining equipment etc., across all countries in which these (and/or other) activities took place.

Under this approach, emissions allocation is based solely on the country of consumption of goods and services, rather than the country of production of the goods and services. Even where two countries have bilateral trade links, emissions exchanges between the two countries can occur through both direct bilateral trade between the two countries (EEBT) and through indirect trade via intermediate countries (included in the MRIO approach). For the UK, an MRIO analysis reveals that consumption results in total emissions around 34% higher than those produced domestically: the difference between this figure and EEBT estimate (25% increase in emissions) demonstrates the importance of emissions arising in the supply chain, in activities carried out in countries upstream of the UK's bilateral trade partners.

The International Carbon Flows analysis presented here adopts an MRIO approach to describing consumption emissions wherever possible, as it provides the most complete view of the allocation of emissions from a consumption perspective. However, in some circumstances an MRIO approach is not appropriate, or the data to support an MRIO approach is not available: in these circumstances an EEBT approach has been adopted.

The modelling behind this analysis:

People, datasets and further reading

The models used for the International Carbon Flows analysis were developed by Dr Glen Peters from the Centre for International Climate and Environmental Research Oslo (CICERO), Dr Christopher Weber from Carnegie Mellon University (CMU) Pittsburgh and Dr Jan Minx¹ from the Technische Universität Berlin. For the construction of the EEBT and MRIO models the GTAP database 7.0 for the year 2004 was used (Narayanan and Walmsley 2008). The Global Trade Analysis Project (GTAP) is a collaboration of various institutions with the goal to construct and maintain a global database for economic modelling. The database contains input-output, bilateral trade, trade protection, energy and other economic data for 113 world regions and 57 sectors.

Sectoral CO₂ emission data was estimated from the energy data using the IPCC Tier 1 approach (Narayanan and Walmsley 2008). Process emissions from cement production and flaring were added from the CDIAC database (<http://cdiac.ornl.gov>). The resulting CO₂ emission estimates can differ considerably from national environmental accounts due to differences in system boundaries, specific manipulations of the energy data undertaken by GTAP and the application of global rather than region specific emission factors. As a response emission estimates were updated with national environmental account data where possible. This update covered all EU countries, Australia, New Zealand, China, U.S., Canada and Japan and therefore more than 70% of global CO₂ emissions.

Regardless of these efforts to improve the quality of the data as much as possible, the challenge of undertaking a global analysis with considerable region and sector detail leaves considerable sources of uncertainties. Some of the most important are outlined below:

1. Input-output data is submitted by database contributors on a voluntary basis. The data can therefore be rather old. For instance, the table for New Zealand are from 1996 and tables can be even more out-dated. The GTAP scales the data to match 2004 GDP in international dollars, which means the data has the *structure* of its base-year, but the *volume* of 2004.
2. The input-output data is harmonized. The data needs to be converted to the GTAP format. This requires various aggregations and disaggregations. Disaggregation is the main issue, with data provided by some countries aggregated to as low as 20 sectors (Russia). Further disaggregations are performed in the food and agriculture sectors.
3. GTAP includes various additional data, such as trade and energy volumes, to update the input-output data. Once all the data has been linked it has to be “balanced” to obtain a global equilibrium.

The magnitude of the arising uncertainties is unknown, but must be expected to be of considerable size. However, putting a measure on the uncertainty in GTAP is difficult, because without knowing the uncertainty associated with the original data it is not easily possible to assign uncertainties to the final estimate of GHG emissions. Often input/output tables are created by central statistical agencies within governments, and the underlying survey data are either unavailable or only partially public. To circumvent the lack of data, analysts often assume uncertainty distributions by assuming that small values have larger uncertainties compared to large values. Consistent with this is that studies have found that small values have a minor effect on the results (Jensen and West 1980). Some studies have employed Monte-Carlo analysis to estimate uncertainties (Bullard and Sebald 1977; Lenzen 2001; Lenzen et al. 2010). These studies generally find that errors tend to cancel due to the summation and multiplication of many numbers. The implication for this analysis is that for larger regional groupings we can expect uncertainties to be small across the whole economy, but this uncertainty increases as regional and sectoral detail is added. Hence, the more specific the input-output results presented the more cautious the reader needs to be in terms of interpretation and policy implications.

¹ Dr Jan Minx carried out some of the work for this project whilst being affiliated with Stockholm Environment Institute at the University of York, UK

The GTAP database is designed to support policy analysis based on computable general equilibrium modelling and not specifically for emission attribution exercises as presented here. This is one of the reasons why not so much emphasis in the development of the database is given to issues such as a regular updating of production structures, increases in the level of sector detail for environmental key sectors or improvements in energy and emission statistics. Currently, there are European efforts to construct better and more timely global input-output databases including environmental extensions (see, www.feem-project.net/exiopoli/ and www.wiod.org/). However, these efforts are one-off projects and lack a continuous support structure so far. This analysis demonstrates the importance of compiling consumption-based emission inventories and quantifying the emissions associated with international trade on a regular basis. As for territorial emission inventories, data collection could be mandated and overseen by an (international) institution such as the Intergovernmental Panel on Climate Change. These reporting duties could be limited in temporal and regional scope and be extended over time.

More recent results could be generated in a two-tiered strategy. For the first tier, simplified methods can be used for estimating sufficiently robust, timely consumer emission accounts. Peters et al. (2010) have recently proposed such a method and presented time-series results for the 113 GTAP world regions from 1990 to 2008. In general, simplified methods can give consumer emission estimates with a delay of 1-2 years. For the second tier, more time and resource intensive detailed sector and supply chain studies require continuous development of a global high-quality input-output and environmental account database. The more robust second tier estimate would come out with a time delay (3-5 years), but provide more detail and quality. One option to develop high-quality databases at the global level would be to build on existing initiatives such as GTAP, which already have a support structure in place. Alternatively, the ongoing European efforts mentioned above (EXIOPOL, WIOD) could be extended globally and continuously supported.

Further Reading

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Narayanan, B. and T. Walmsley (2008). Global Trade, Assistance and Production: THE GTAP7 Database. C. f. G. T. Analysis, Purdue University.

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Making business sense of climate change

