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Belgium's Carbon Footprint

Calculations based on a national accounts consistent global multi-regional input-output table

September 2017

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Abstract - The traditional attribution of responsibility for greenhouse gas (GHG) emissions to producing countries may be distorted by international trade flows as importing emission-intensive commodities contributes to reducing a country's production-based emissions. This has motivated the calculation of carbon footprints that measure the amount of domestic and foreign GHG emissions (directly and indirectly) embodied in commodities intended for final consumption by a country's residents. In this working paper, we present carbon footprint estimations for Belgium based on global multi-regional input-output (MRIO) tables that have been made consistent with detailed Belgian national accounts. According to our calculations, Belgium's carbon footprint is substantially higher than its production-based emissions, which means that Belgium is a net importer of GHG emissions. Moreover, our results show that consistency with detailed national accounts does matter for MRIO-based carbon footprint calculations, in particular for a small open economy like Belgium.

Abstract - L'attribution traditionnelle de la responsabilité pour les émissions de gaz à effet de serre (GES) au pays producteur est susceptible d'être biaisée par les flux de commerce international. En effet, les importations de produits intensifs en émissions contribuent à réduire les émissions d'un pays liées à la production. Ce constat a motivé le calcul de l'empreinte carbone, qui mesure le volume d'émissions domestiques et étrangères de GES contenus (directement et indirectement) dans les produits destinés à la consommation finale des habitants d'un pays. Ce working paper présente des estimations de l'empreinte carbone de la Belgique basées sur des tableaux entrées-sorties multi-pays mondiaux rendus cohérents avec les comptes nationaux détaillés de la Belgique. D'après nos calculs, l'empreinte carbone de la Belgique dépasse nettement ses émissions liées à la production, ce qui signifie que la Belgique est un importateur net d'émissions de GES. De plus, nos résultats montrent que la cohérence avec les comptes nationaux détaillés revêt une grande importance pour le calcul de l'empreinte carbone sur la base de tableaux multi-pays, surtout pour une petite économie ouverte comme la Belgique.

Abstract – De traditionele toewijzing van de verantwoordelijkheid voor de uitstoot van broeikasgassen (BKG) aan het producerende land kan een vertekend beeld opleveren als gevolg van internationale handelsstromen. De invoer van emissie-intensieve producten draagt immers bij aan het verkleinen van de op productie gebaseerde uitstoot van een land. Die vaststelling heeft geleid tot de berekening van koolstofvoetafdrukken, die alle broeikasgassen omvatten die (rechtstreeks en onrechtstreeks) vervat zitten in de producten bestemd voor de finale consumptie van de ingezetenen van een land. Deze Working Paper presenteert ramingen voor de Belgische koolstofvoetafdruk berekend aan de hand van globale multiregionale input-outputtabellen die in overeenstemming zijn gebracht met gedetailleerde Belgische nationale rekeningen. Uit onze berekeningen blijkt dat de Belgische koolstofvoetafdruk aanzienlijk groter is dan de emissies op basis van productie, wat betekent dat België een netto-invoerder is van BKG-emissies. Onze resultaten tonen bovendien aan dat overeenstemming met gedetailleerde nationale rekeningen wel degelijk van belang is voor de raming van de koolstofvoetafdruk gebaseerd op MRIO, in het bijzonder voor een kleine open economie zoals België.

Jel Classification - Q54, Q56, F18, C67

Keywords - Carbon footprint, Consumption-based Emission Accounting, Global Multi-Regional Input-Output Tables.

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Executive summary

So far, international climate negotiations have been based on inventories of greenhouse gas (GHG) emissions. Thereby responsibility for emissions is attributed to the producing country. However, this may be distorted by international trade. Indeed, even with identical consumption levels and profiles, a country importing emission-intensive commodities will have lower production-related emissions than a country exporting such commodities. This has motivated the calculation of carbon footprints, which measure all greenhouse gases (directly and indirectly) embodied in commodities intended for final consumption by a country's residents. It is however crucial that the method and data for the calculation of carbon footprints is sufficiently robust if they are to be used as a tool for climate policy.

This working paper presents carbon footprint estimations for Belgium based on global multi-regional input-output (MRIO) tables that have been made consistent with detailed Belgian national accounts. MRIO tables contain information about production technology abroad and hence allow for a more realistic estimation of foreign emissions for Belgian final consumption compared to calculations based on purely national input-output tables. Hence, for our footprint calculations, we have reproduced the construction process of MRIO tables in the World Input-Output Database (WIOD) project and injected detailed supply-and-use tables for Belgium from national sources into the process. We refer to the resulting MRIO tables as WIODBEL tables. They improve carbon footprint calculations for Belgium (1) in terms of methodology compared to national IO tables, and (2) in terms of data compared to MRIO tables that are not consistent with Belgium's detailed national accounts.

Based on these WIODBEL tables, Belgium's carbon footprint amounts to 138 Mt CO_2-eq. in 1995 and 145 in 2007 (total GHG emissions excluding direct emissions of households). These consumption-based emissions are substantially higher than production-based emissions, which stand at 121 Mt CO_2-eq. in 1995 and 110 in 2007. Hence Belgium is a net importer of GHG emissions over the entire period. This allows to revise the earlier – counterintuitive – finding based on national IO tables that Belgium is a net exporter of emissions. Moreover, Belgium's carbon footprint calculated with the original WIOD MRIO tables is higher (14% on average) than the WIODBEL-based footprint from 2002 onwards. The difference between the two is growing: the original WIOD footprint increased by 15% between 1995 and 2007, whereas the WIODBEL footprint only grew by 5% over the same period.

All in all, our findings show that consistency with detailed national accounts does matter for MRIO-based carbon footprint calculations, in particular for a small open economy like Belgium. Calculations with standard MRIO tables that are not consistent with detailed Belgian data tend to overestimate the country's carbon footprint. The growing discrepancy in the estimation of re-exports widens the gap with respect to the footprint based on MRIO tables that are consistent with detailed national accounts.

Synthèse

Jusqu'à présent, les négociations internationales sur le climat ont toujours été basées sur des inventaires d'émissions de gaz à effet de serre (GES), et, de ce fait, la responsabilité pour les émissions a été attribuée au pays producteur. Le commerce international est toutefois susceptible de biaiser cette attribution. En effet, pour des niveaux et profils de consommation identiques, un pays qui importe des produits à forte intensité en émissions aura des émissions liées à la production moins élevées qu'un pays qui exporte de tels biens. Ce constat a motivé le calcul de l'empreinte carbone, qui mesure le volume d'émissions domestiques et étrangères de GES contenus (directement et indirectement) dans les produits destinés à la consommation finale des habitants d'un pays. Pour une utilisation comme outil de politique climatique, il est cependant essentiel que la méthode et les données utilisées pour le calcul de l'empreinte carbone soient suffisamment robustes.

Ce working paper présente des estimations de l'empreinte carbone de la Belgique basées sur des tableaux entrées-sorties (IO) multi-pays mondiaux rendus cohérents avec les comptes nationaux détaillés de la Belgique. Par rapport aux tableaux IO purement nationaux, les tableaux multi-pays contiennent des données sur les technologies de production à l'étranger. Cela permet d'estimer de façon plus réaliste les émissions générées à l'étranger pour satisfaire la consommation finale belge. Dès lors, pour le calcul de l'empreinte carbone, les tableaux multi-pays du projet World Input-Output Database (WIOD) ont été reconstruits en injectant les tableaux des ressources et des emplois détaillés pour la Belgique provenant de sources nationales. Les tableaux multi-pays qui en résultent sont appelés tableaux WIODBEL. Ils permettent d'améliorer le calcul de l'empreinte carbone belge (1) du point de vue méthodologique comparé aux tableaux IO nationaux et (2) du point de vue des données comparé aux tableaux multi-pays qui ne sont pas cohérents avec les comptes nationaux détaillés de la Belgique.

Sur la base des tableaux WIODBEL, l'empreinte carbone de la Belgique s'élève à 138 Mt d'équivalent CO_2 en 1995 et 145 en 2007 (total des émissions de GES hors émissions directes des ménages). Ces émissions liées à la consommation sont nettement plus élevées que les émissions liées à la production qui s'élèvent à 121 Mt d'équivalent CO_2 en 1995 et 110 en 2007. La Belgique est donc un importateur net d'émissions de GES sur l'ensemble de la période étudiée. Ce résultat permet de revoir la conclusion contre-intuitive, obtenue précédemment sur la base de tableaux IO nationaux, selon laquelle la Belgique est un exportateur net d'émissions. Par ailleurs, à partir de 2002, l'empreinte carbone de la Belgique calculée à l'aide des tableaux WIOD originaux est plus élevée (de 14 % en moyenne) que celle obtenue en utilisant les tableaux WIODBEL ; et l'écart entre les deux grandit : l'empreinte WIOD originale augmente de 15 % entre 1995 et 2007 contre 5 % pour l'empreinte WIODBEL.

Ces résultats montrent donc que la cohérence avec les comptes nationaux détaillés est importante pour le calcul de l'empreinte carbone avec des tableaux multi-pays, surtout pour une petite économie ouverte comme la Belgique. Les calculs basés sur des tableaux non-cohérents avec les données détaillées de la Belgique tendent à surestimer l'empreinte carbone de notre pays. La divergence croissante dans l'estimation des réexportations creuse l'écart par rapport à l'empreinte carbone calculée avec des tableaux MRIO cohérents avec les comptes nationaux détaillés.

Synthese

Internationale klimaatonderhandelingen zijn tot dusver gebaseerd op emissie-inventarissen, wat betekent dat de verantwoordelijkheid voor broeikasgasemissies (BKG) bij het producerende land wordt gelegd. Een en ander kan echter worden vertekend door emissies die vervat zitten in internationale handel. Zelfs met identieke consumptieniveaus en -profielen zullen landen die emissie-intensieve producten invoeren immers lagere productiegerelateerde BKG-emissies hebben dan landen die dergelijke producten uitvoeren. Die vaststelling heeft geleid tot de berekening van koolstofvoetafdrukken, die alle broeikasgassen omvatten die (direct en indirect) vervat zitten in de producten bestemd voor de finale consumptie van de ingezetenen van een land. Opdat dergelijke maatstaf in aanmerking zou komen als richtsnoer voor het klimaatbeleid moeten de methode en de gegevens gebruikt voor de berekening van de koolstofvoetafdruk evenwel voldoende robuust zijn.

Deze Working Paper presenteert ramingen voor de Belgische koolstofvoetafdruk berekend aan de hand van globale multiregionale input-outputtabellen (MRIO) die in overeenstemming zijn gebracht met gedetailleerde Belgische nationale rekeningen. De MRIO-tabellen bevatten gegevens over buitenlandse productietechnologieën, waardoor (in vergelijking met ramingen die alleen op nationale input-outputtabellen zijn gebaseerd) een meer realistische raming kan worden verkregen van buitenlandse emissies voor de Belgische finale consumptie. Voor de berekening van de koolstofvoetafdruk werd het constructieproces van de MRIO-tabellen uit het project World Input-Output Database (WIOD) nagebootst en werden daarin gedetailleerde aanbod- en gebruikstabellen voor België afkomstig van nationale bronnen opgenomen. De MRIO-tabellen die daaruit voortvloeien worden hieronder 'WIODBEL-tabellen' genoemd. Die laatste laten toe de raming van de Belgische koolstofvoetafdruk te verbeteren (1) qua methodologie, in vergelijking met methodes enkel gebaseerd op nationale IO-tabellen en (2) qua gegevens, in vergelijking met de MRIO-tabellen die niet in overeenstemming zijn met de gedetailleerde Belgische nationale rekeningen.

Op basis van de WIODBEL-tabellen bedraagt de Belgische koolstofvoetafdruk 138 Mt CO_2-eq. in 1995 en 145 in 2007 (totale BKG-emissies, exclusief directe emissies door gezinnen). Die op consumptie gebaseerde emissies zijn aanzienlijk hoger dan de op productie gebaseerde emissies, die 121 Mt CO_2-eq. bedragen in 1995 en 110 in 2007. Volgens onze ramingen is België over de volledige onderzochte periode dus een netto-invoerder van BKG-emissies. Hiermee kunnen eerdere – contra-intuïtieve – op nationale IO-tabellen gebaseerde bevindingen worden herzien die stelden dat België een netto-uitvoerder van emissies is. Daarnaast blijkt de Belgische koolstofvoetafdruk berekend op basis van de oorspronkelijke WIOD MRIO-tabellen vanaf 2002 (gemiddeld 14%) hoger te zijn dan de afdruk op basis van de WIODBEL MRIO-tabellen. Het verschil tussen beide neemt toe met de tijd: de oorspronkelijke WIOD-koolstofvoetafdruk steeg immers met 15 % tussen 1995 en 2007, terwijl de WIODBEL-koolstofvoetafdruk slechts met 5 % steeg over dezelfde periode.

Onze vaststellingen tonen dus aan dat overeenstemming met gedetailleerde nationale rekeningen van belang is voor de berekening van de koolstofvoetafdruk op basis van MRIO-tabellen, in het bijzonder voor een kleine open economie zoals België. MRIO-tabellen die niet in overeenstemming zijn met gedetailleerde Belgische gegevens hebben de neiging de koolstofvoetafdruk van ons land te overschatten.

Het is meer bepaald de groeiende discrepantie in de raming van de wederuitvoer die aan de basis ligt van het toenemend verschil met de koolstofvoetafdruk gebaseerd op MRIO-tabellen die in overeenstemming zijn gebracht met de gedetailleerde Belgische nationale rekeningen.

1. Introduction

International climate negotiations have up to now been based on emission inventories for greenhouse gases (GHG), thereby attributing responsibility to the producing country. However, this attribution may be distorted by emissions embodied in international trade: even with identical consumption levels and profiles, countries exporting emission-intensive commodities will have higher production-related GHG emissions than countries importing such commodities. This has motivated the development of consumption-based GHG emission accounting to calculate carbon footprints (e.g. Peters and Hertwich, 2008). But although the carbon footprint is advocated as a key indicator by international institutions (e.g. UNECE, 2017) and considered as an official statistic in some countries (e.g. the UK, see Defra, 2017), the method and data for its calculation must be sufficiently robust if it is to be used as a tool for climate policy (Kanemoto et al., 2011).

Even before the term 'consumer responsibility' was introduced by Munksgaard and Pedersen (2001), there have been contributions establishing consumption-based GHG emission accounts using (environmental) input-output (IO) techniques. Wiedmann et al. (2007) provides an overview up to 2006 of IO-based analyses of environmental impacts in general. This comprises a large share of contributions on carbon footprints and GHG emissions embodied in trade. It clearly illustrates that data availability has been the main issue faced by researchers when trying to establish robust consumption-based emission accounts (see also Hoekstra, 2010), conditioning the type of IO models that have been used. Early contributions to the literature were almost all restricted to national IO tables and therefore had to rely on a single country input-output (SRIO) model and the domestic technology assumption (DTA) for import flows (e.g. Kondo et al., 1998; Munksgaard and Pedersen, 2001; Mäenpää and Siikavirta, 2007). This gives an unrealistic picture of foreign emission intensities and technology and excludes any trade links between other countries. A partial solution was offered by including emission and IO data for major trading partners (the so-called unidirectional trade models, see e.g. Lenzen et al., 2004; Weber and Matthews, 2007). In this case, "technologies of trading partners are represented in the model, but bilateral trade links between other countries are either excluded or approximated using DTA" (Andrew et al., 2009, p.312). In view of this shortcoming, a fully-fledged global multi-regional input-output (MRIO) model is to be preferred for calculating footprints (Turner et al., 2007) as emissions embodied in trade between other countries are adequately measured and feedback loops accounted for. Although methodologically desirable, the main hindrance to developing global MRIO tables were the huge data requirements and the considerable workload for their construction. Several global MRIO databases (Eora, EXIOBASE, WIOD, GTAP-MRIOT, GRAM, IDE-JETRO's AIIOT) have been developed since the mid-2000s through the efforts of different consortia of academic researchers (see Tukker and Dietzenbacher, 2013, for an overview). They have been used to calculate carbon footprints for large panels of countries (e.g. Peters et al, 2012; Arto et al., 2012; Tukker et al., 2014).

Even though the development of global MRIO databases constitutes a major step towards greater robustness of consumption-based GHG emission accounts, it has not settled all issues. The mere fact that several global MRIO databases have been created in parallel reflects differences in many aspects of the construction process, e.g. the degree of harmonisation of underlying data or the approach to reconciling conflicting data sources. As emphasized by Tukker and Dietzenbacher (2013), "[d]epending on choices, assumptions and perceptions of which data seem most reliable, one will arrive – with certain limits – at different but equally plausible 'mappings of the world economy'" (p.14). As a consequence, carbon footprint estimations for individual countries vary between MRIO databases. Moreover, the databases differ with respect to country and industry detail.

From the perspective of individual countries, it is not only differences in data between MRIO databases that matter but also divergence with respect to published national data (Edens et al., 2015). Some MRIO databases ensure consistency with national accounts aggregates, e.g. industry-level output and value added. However, in MRIO construction, the reconciliation of conflicting data sources entails the "need for significant transformation of data originally validated in national statistical systems" that "makes it difficult for the National Statistical Institutes to build [G]MRIO tables themselves or even participate in their building" (Tukker and Dietzenbacher, 2013, p.7). As shown by Edens et al. (2015) for the Netherlands, these transformations affect import and export data in particular. Moreover, other data considered as particularly reliable from a national perspective may be altered by these transformations. Therefore, the use of MRIO-based carbon footprints may prove difficult to accept at the national level. Edens et al. (2015) show that, for an individual country, it is possible to get the best of both worlds, i.e. to reconcile the use of an MRIO framework with the demand for consistency with national data. They have reproduced World Input Output Database (WIOD) MRIO tables that fully respect the national accounts and trade data for the Netherlands, and used them to calculate a carbon footprint.

Evidence on the carbon footprint and emissions embodied in trade is scarce for Belgium. Sissoko and Vandille (2008) have computed a balance of CO_2-emissions embodied in trade for Belgium based on national IO data and a single-region model. They find that Belgium is a net exporter of emissions. This counterintuitive finding is contradicted by MRIO-based evidence of Belgium's carbon footprint exceeding the country's production-based emissions (Peter and Hertwich, 2008; Arto et al., 2012; Tukker et al., 2014). Given these priors, the work presented here pursues the aim of determining Belgium's carbon footprint in a MRIO-setting with data that are consistent with detailed Belgian national accounts. First, we reproduce WIOD MRIO tables for all years from 1995 to 2007 injecting data for Belgium in a way that is similar to what Edens et al. (2015) have done for the Netherlands for 2003 and 2009. We refer to these tables as WIODBEL MRIO tables. A comparison of temporally consistent supply-and-use tables for Belgium (Avonds et al., 2012) with WIOD data for Belgium does indeed reveal large differences in exports and imports. Second, we calculate Belgium's carbon footprint based on the original WIOD MRIO tables and the WIODBEL MRIO tables for the years 1995-2007. Hence, we observe not only differences in carbon footprint levels but also differences in the trend over time. Finally, we analyse the difference between WIOD and WIODBEL carbon footprints for Belgium by means of structural decomposition analysis (SDA), identifying on a year-by-year basis to what extent differences in emission intensities, the input structure and imports and exports contribute to the difference in footprint results.

This article is organised as follows. We start off by comparing national data with WIOD data for Belgium in section 2, and then describe in section 3 how the WIODBEL MRIO tables are built with data for Belgium from national sources. Section 4 presents the carbon footprint calculations and results according to single-region and multi-region models. The structural decomposition analysis comparing WIOD and WIODBEL carbon footprints for Belgium is developed in section 5. Finally, section 6 provides a discussion of results and conclusions.

2. Comparing national data with WIOD data for Belgium

The main advantage of using an MRIO database rather than only national data for calculating a country's carbon footprint and emissions embodied in trade is the more realistic description of foreign technology. However, data for individual countries in MRIO databases differ from (official) national data. Wilting (2012) was the first to point out this issue in the context of footprint calculations, and it was then analysed in detail in Edens et al. (2015). Discrepancies with respect to national data are due to differences in source data and adjustments made in the construction process of the multiregional tables.

Here, we compare Belgian SUT from national sources with SUT for Belgium used in the construction of the World Input Output Database (WIOD). On the one hand, we take data from the UpdateSUT project of the Belgian Federal Planning Bureau (FPB) as the national reference data (see Avonds et al., 2012, for the methodology). The project consisted in revising and updating Belgian SUT for the years 1995-2007 so as to produce a time series of SUT consistent with the then most recent national accounts (NA) vintage (November 2010). On the other hand, we have chosen WIOD among the available MRIO databases for the same reasons as Edens et al. (2015): because it largely respects countries' national accounts, because the WIOD MRIO tables are derived from supply-and-use tables (SUT), and, in particular, because of its open source character whereby the SUT and final result MRIO tables are freely available on the website of the project. Dietzenbacher et al. (2013) provides a detailed description of the construction process of the first vintage of the WIOD MRIO tables released in 2012. They are industry-by-industry tables consistent with SNA93 for the years 1995-2009 covering 40 countries (among which Belgium) and a 'rest of the world' (RoW) region, and 35 industries in a classification derived from Nace Rev.1.1.[1] The underlying product-by-industry SUT contain 59 product categories that correspond to the 2-digit CPA.[2]

The MRIO construction process in WIOD is summarised in flowchart form on the left hand side of Figure 1. Source data for Belgium comprise national SUT taken from Eurostat for the years 1995, 1997 and 1999-2007 as well as NA data (output and expenditure) from the OECD's STAN database (see Erumban et al., 2012, p.6). While the NA data are available in a consistent time series, i.e. data for all years respecting the same and then most recent NA vintage, the SUT have not been revised. Dietzenbacher et al. (2013) describe the process of harmonising and subsequently benchmarking country's SUT to their revised NA, and of extrapolation and interpolation to complete the SUT time series for missing years. Moreover, to obtain use tables in basic prices, valuation tables for margins (trade and transport) and taxes minus subsidies on products were estimated by the WIOD consortium. The distribution over use categories of margins and net taxes is largely proportional. As a further step, bilateral trade was derived from detailed product-level trade data from COMTRADE for all countries including Belgium, and it was used to construct the import part of the use tables with a split up by country of origin.[3] Thereby, the so called 'international supply-and-use tables' (IntSUT) were obtained. In parallel, the bilateral trade data also served to estimate international trade margins (ITM) based on the difference between 'cost-

1 The time coverage of the first vintage of WIOD MRIO tables was subsequently extended to more recent years. Here, we restrict the WIOD data to the period 1995-2007 to match the period covered by UpdateSUT.

2 CPA stands for Statistical Classification of Products by Activity in the European Economic Community. Here, the CPA version of 2002 is used.

3 In this procedure, different use categories (intermediate inputs, final consumption and investment) were considered separately along the lines of the Broad Economic Categories (BEC) classification of trade.

insurance-freight' (cif) and 'free-on-board' (fob) valuation of mirror import and export flows. In the next stage, the IntSUT were then combined for all countries in the database in a world SUT that was completed by the estimation of (trade and internal) flows for the RoW. The industry-by-industry MRIO table was then derived from this world SUT based on the fixed product sales structure assumption.[4]

The UpdateSUT project started from the original non-revised Belgian SUT published by the Belgian National Accounts Institute (NAI). Valuation tables for margins, taxes and subsidies as well as import use tables were available for the IO benchmark years, all estimated in the process of deriving IO tables. Avonds et al. (2007) provide further detail on methods used for constructing tables for missing years (1996 and 1998), for revising tables so that they respect the common NA vintage and the estimation of the valuation and import use tables for non-benchmark years.

Regarding the source data, the Belgian SUT available from Eurostat are the same as those published by the Belgian NAI. The NA data underlying the first release of the WIOD MRIO tables (taken from the OECD's STAN database) are identical to the corresponding vintage of the NA published by the NAI. This facilitates the comparison between the Belgian SUT from UpdateSUT and the IntSUT from WIOD. However, for IO benchmark years, the construction of valuation tables for trade and transport margins, taxes and subsidies is based on firm-level data and detailed fiscal data in UpdateSUT (BFP, 2010), i.e. the methodology for estimating those tables differs from what is done by the WIOD consortium.

For trade, there is also a difference in source data between what is used for UpdateSUT and what is used for WIOD. Merchandise trade statistics for Belgium are established according to two different concepts: the community concept and the national concept (see NAI, 2010, for the full detail on the two concepts). Data in the community concept are internationally comparable and are reported for international trade databases like COMTRADE, which is used for constructing WIOD MRIO tables. They comprise all cross-border transactions with a change of ownership as well as transactions for processing. Merchandise trade data in the national concept are derived from those in the community concept and are used in building the NA and balance of payments statistics. Compared to the data in the community concept, they do not comprise cross-border transactions of non-residents. In UpdateSUT, use tables are split into uses of domestic production and imports based on trade data in national concept at the level of the firm for IO benchmark years (Van den Cruyce, 2004).[5] First, firm-level imports and exports are compared at the most detailed product-level (8-digit Combined Nomenclature) to identify re-exports. Then, remaining imports are matched to firm-level input use by product. Thus, methodological differences compared to WIOD are clearly driven by differences in the available data (firm-level data by product in national concept vs product-level data in community concept). In particular, the identification of re-exports is different in WIOD: there are re-exports for a specific product when exports exceed domestic production. For services, the use table of imports is determined based on detailed service trade data by EBOPS[6] category according to the specific methodology described in Hambÿe (2001).

Finally, WIOD also modifies data for Belgium in the process of constructing the IntSUT due to adjustments in the trade flows to align mirror export and import statistics and, further down the line, in the

4 Dietzenbacher et al. (2013) provide a WIOD-specific explanation of this last step, while Eurostat (2008) is the standard methodological reference for this transformation.
5 IO-benchmark years are 1995, 2000 and 2005. The use tables for imports are interpolated for all other years in UpdateSUT.
6 EBOPS stands for Extended Balance Of Payments Services classification.

process of constructing the MRIO tables when it comes to balancing world-wide flows and estimating flows to the RoW region.

Table 1 WIOD Supply Table (2x2), Belgium, 2005, basic prices, million USD

	Manufacturing	Services	Imports	Total
Manufacturing	295368	11381	230025	536773
Services	15785	460959	37034	513778
Total	311153	472340	267059	1050552

Table 2 UpdateSUT Supply Table (2x2), Belgium, 2005, basic prices, million USD

	Manufacturing	Services	Imports	Total
Manufacturing	295561	11520	236162	543243
Services	15592	460821	41006	517418
Total	311153	472340	277168	1060661

Table 3 WIOD Use Table (2x2), Belgium, 2005, basic prices, million USD

	Manufacturing	Services	Final demand	Exports	Re-exports	ITM	Total
Manufacturing	135462	41216	114505	199686	37228	8678	536773
Services	77225	166946	222228	47379	0	0	513778
Total	212686	208162	336733	247066	37228	8678	1050552
ITM	4091	1006	3581	-			
TXSP	10764	11077	19222	-			
Value Added	83612	252095	-	-			
Total	311153	472340	359536	247066			

ITM: International trade and transport margins; TXSP: Other taxes minus subsidies on production

Table 4 UpdateSUT Use Table (2x2), Belgium, 2005, basic prices, million USD

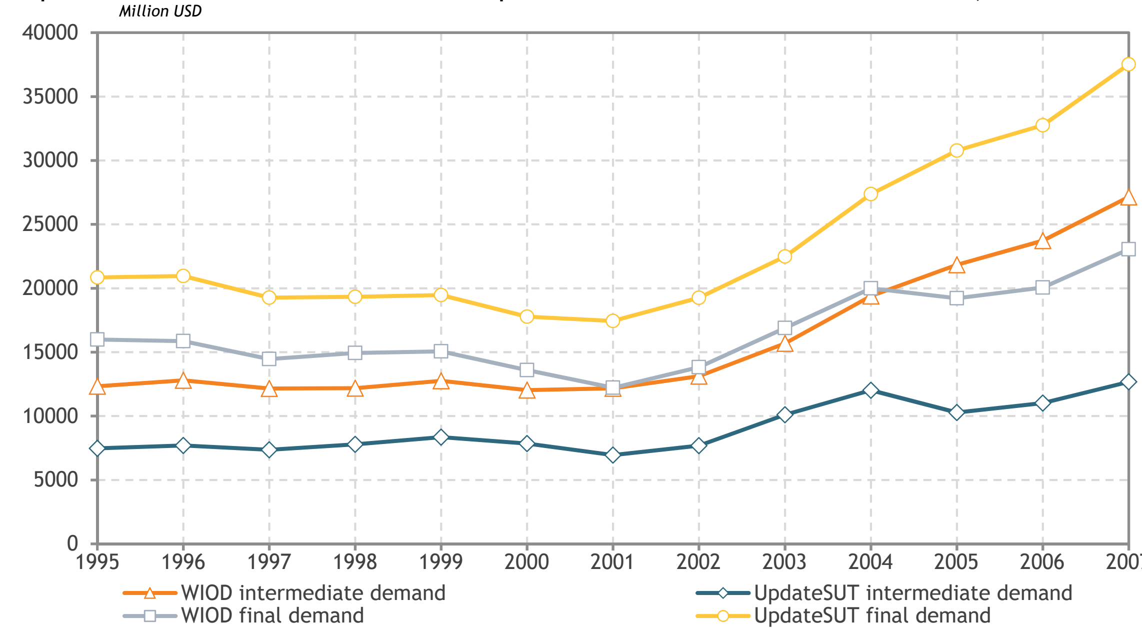
	Manufacturing	Services	Final demand	Exports	Re-exports	ITM	Total
Manufacturing	159647	45096	106037	144039	80812	7611	543242
Services	62160	165600	220548	68759	351	0	517419
Total	221807	210696	326582	212798	81163	7611	1060661
ITM	4100	897	2614	-			
TXSP	1634	8652	30336	441			
Value Added	83612	252095	-	-			
Total	311153	472340	359532	213239			

ITM: International trade and transport margins; TXSP: Other taxes minus subsidies on production

These differences in source data and methodology should not be considered a shortcoming of the construction process of the WIOD MRIO tables. On the one hand, using detailed firm-level data in a multi-country project would be a very complicated undertaking: access to national firm-level data is mostly restricted, and national firm-level data used for constructing SUT and IO tables are not harmonised across countries. Moreover, trade flows would nonetheless need to be adjusted to align mirror export and import statistics for different countries, and the sheer workload of an MRIO table construction process relying on firm-level data for every country would likely not be warranted by the improvement in the quality of the tables. On the other hand, the WIOD consortium pledges to use publicly available data and manages to stick to that principle all along the construction process of its global MRIO tables (Dietzenbacher et al., 2013). Given the aforementioned issues, this pledge makes sense. Nonetheless, it is useful from a national perspective to examine differences between national statistics and MRIO data for Belgium to get a grasp of where discrepancies in the results of analytical applications, e.g. footprint calculations, come from.

In Tables 1-4, we compare the Belgian IntSUT for 2005 from WIOD with the same year's SUT from UpdateSUT. The values of the latter have been converted to USD at the rate used in WIOD. For ease of presentation, the tables are aggregated to a two-industry-two-product (manufacturing and services[7]) format. Use tables are in basic prices. The tables confirm that WIOD does indeed largely respect the NA totals. The values of total output and value-added are identical in the WIOD IntSUT for Belgium and the UpdateSUT tables, and the difference in total domestic final demand is negligible. The NA consistency of WIOD also holds at a more detailed industry level (WIOD classification) and for all domestic final demand categories. The distribution of output over product categories is also very similar in the supply tables (Tables 1 and 2). There are larger discrepancies in the product distribution of intermediate and domestic final demand in the use tables in basic prices (Tables 3 and 4). They are partly due to differences in the valuation tables for taxes and subsidies.[8] Although the totals are identical, there are large and from 2003 onwards growing differences in the distribution of other taxes and subsidies on production (TXSP) over industries and domestic final demand in the use tables (see Graph 1). As they are subtracted from uses in purchaser prices for conversion to basic prices, they make for a large part of the differences in the product distribution of intermediate and domestic final demand.

Graph 1 Distribution of taxes and subsidies on production over intermediate and final demand, 1995-2007
Million USD



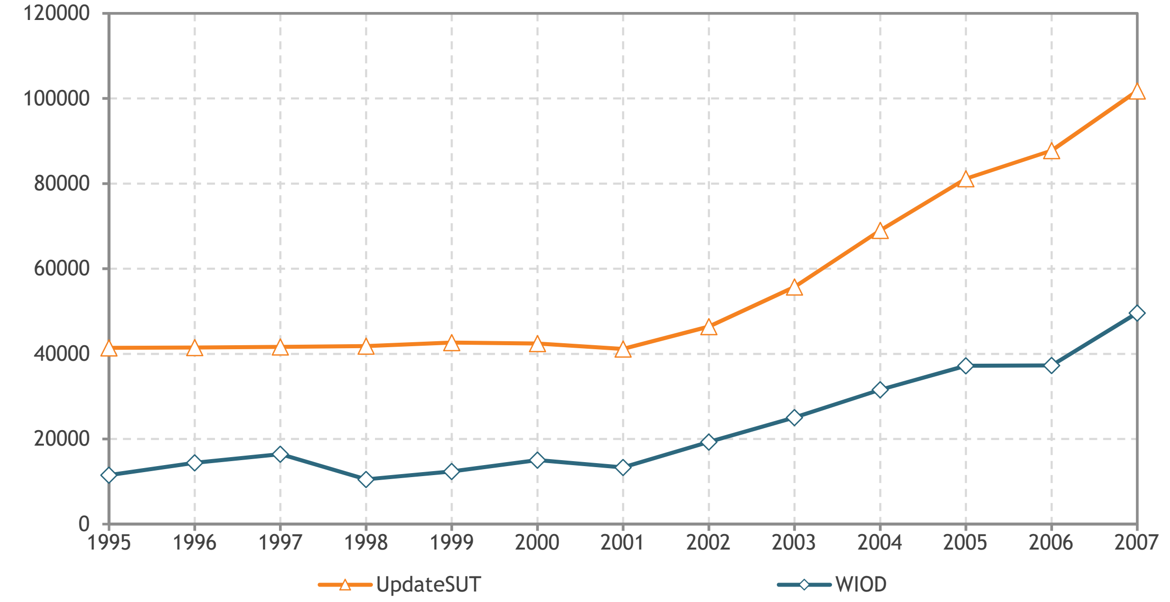
Another major difference between WIOD and UpdateSUT concerns re-exports. This difference matters because re-exports are excluded when deriving MRIO tables, i.e. only exports of domestic origin and

7 In 2-digit NACE Rev.1.1, 'manufacturing' as reported in Tables 1-4 corresponds to industries 01-45 and services to 50-95, i.e. construction is part of 'manufacturing'. The equivalent split-up in terms of the WIOD classification is AtB-F and 50-P.

8 Valuation tables for trade and transport margins are also likely to differ in the two databases, but as data on trade and transport margins other than international trade and transport margins (ITM) is not explicitly reported by WIOD, a comparison of valuation tables with UpdateSUT was not possible.

imports that are not re-exported are taken into account. While values for total exports and imports (including re-exports) are relatively similar in the two datasets, the estimation of re-exports yields substantially different results due to differences in source data and methodology as explained above. For 2005, re-exports amount to 37 billion USD in WIOD whereas in UpdateSUT they amount to 81 billion USD.[9] Graph 2 shows that there is indeed a sizeable difference in the estimation of re-exports for Belgium between WIOD and UpdateSUT for all years between 1995 and 2007. It amounts to almost 30 billion USD in 1995, is relatively stable at that level until 2003 and then grows to more than 50 billion USD in 2007. As re-exports are subtracted from both exports and imports, the trade balance remains unchanged.

Graph 2 Estimations of re-exports in WIOD and UpdateSUT, 1995-2007
Million USD



[9] By definition, services cannot be re-exported. Hence, re-exports are only goods. The small amount of re-exports in the 'services' product category in Table 4 is due to certain goods that are part of merchandise trade statistics but classified in service categories in the CPA 2002 because they are closely linked to specific service categories, e.g. architectural plans and drawings, music (printed or in manuscript), and original works of art.

3. WIODBEL methodology and results

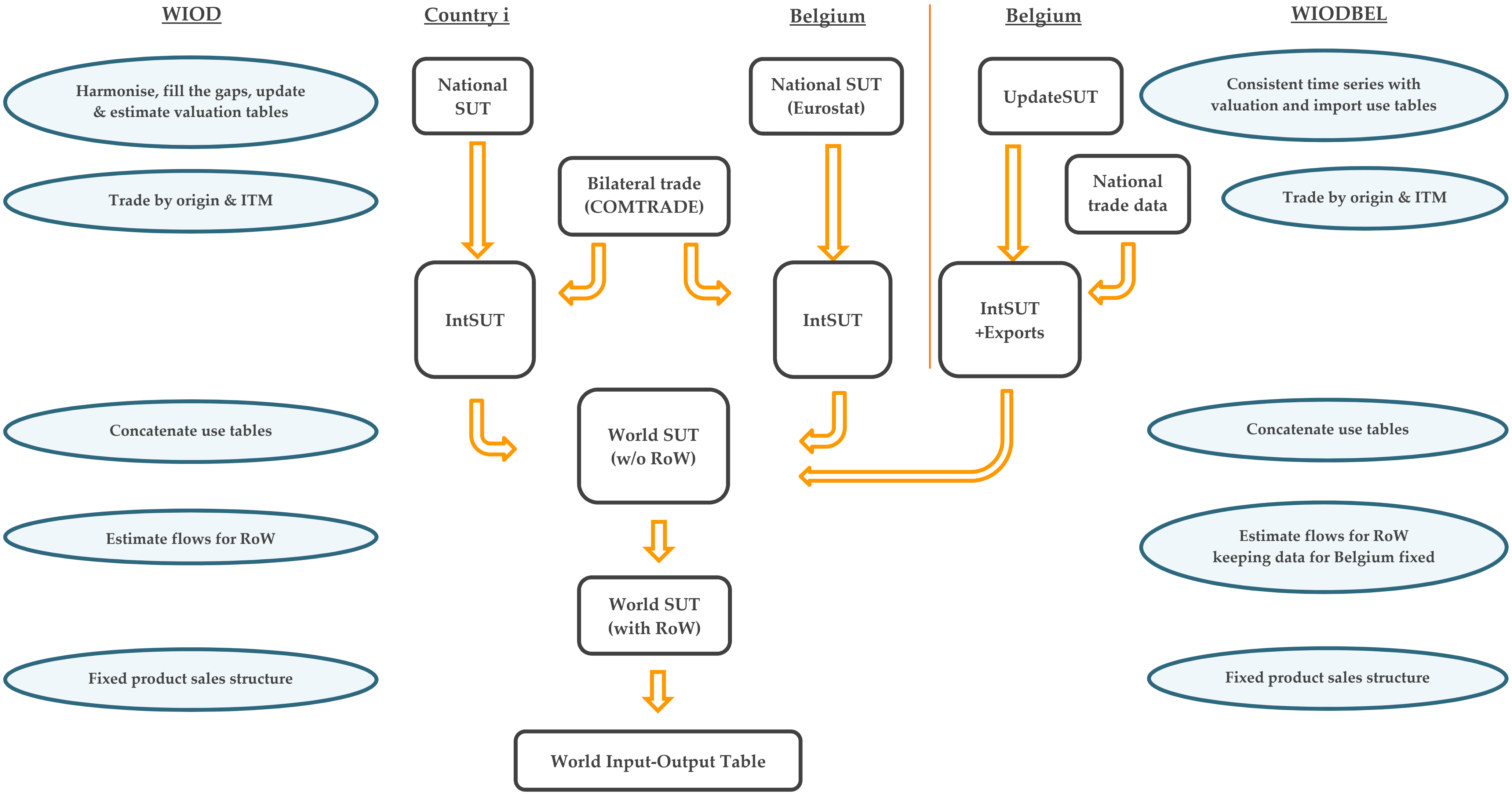
The results of the comparison of the WIOD IntSUT for Belgium with national data (UpdateSUT tables) have prompted us to produce alternative WIOD MRIO tables that are consistent with national data for Belgium and which we refer to as WIODBEL. For this purpose, we proceed in two steps. First, we replace the WIOD IntSUT for Belgium by tables in the same format based on data from UpdateSUT and a specifically computed distribution of imports over countries of origin. Moreover, we also distribute Belgian exports from UpdateSUT over destination countries. Second, we estimate flows for the RoW and build world SUT from the IntSUT keeping data for Belgium unchanged. The industry-by-industry WIODBEL MRIO tables are then derived from the world SUT following the standard method (fixed product sales structure assumption).

Before injecting UpdateSUT-based Belgian national data (IntSUT and exports) into WIOD, some preliminary work on the UpdateSUT data was required:

- Supply-and-use tables from the UpdateSUT project in EUR were converted to USD at the exchange rates used by WIOD.
- Imports and exports from the UpdateSUT project's supply-and-use tables were distributed over countries of origin and destination. To determine the distributions, we rely on 8-digit Combined Nomenclature merchandise trade data in national concept for goods and on service trade data by EBOPS category matched to the CPA-based WIOD product categories.[10]
- Supply-and-use tables from the UpdateSUT project were aggregated from a work format breakdown (approximately 120 industries and 320 product categories) to the level of 2-digit Nace Rev.1.1 and CPA, i.e. 59 industries and product categories. Data for Belgium are thus slightly more disaggregated at the industry level than in the WIOD IntSUT (35 industries).

[10] We distribute Belgian exports over use categories in the country of destination according to the countries' imports from Belgium reported in WIOD.

Figure 1 Overview of the MRIO construction in WIOD and in WIODBEL



To make sure that we obtain results comparable to the original WIOD MRIO tables, we first implemented the construction procedure with the original WIOD IntSUT for Belgium and all other countries. Data for Belgium were allowed to change in this procedure (see Figure 1). Just like Edens et al. (2015) for the Netherlands, we tried to match the WIOD construction procedure as described in Timmer et al. (2012) as closely as possible.[11] We refer to this as WIOD redone. Our results are reasonably close to the original WIOD MRIO tables. Row and column totals are identical and the mean cell-wise absolute difference over all years amounts to 0.6 million USD with the main differences occurring in domestic flows for the RoW region.[12] In what follows, WIOD redone (rather than the original WIOD) will be used as basis for comparing results so as to maintain a methodological consistency.

For deriving the WIODBEL MRIO tables, we then injected Belgian national data and re-implemented the construction procedure keeping data for Belgium unchanged. This yields results that are relatively close to WIOD redone. Naturally, they mainly differ in flows for Belgium: while there are only minor discrepancies in the row totals and none in the column totals, the structure of the flows for Belgium is different. The overall mean cell-wise absolute difference between the WIODBEL and WIOD redone MRIO tables amounts to 0.2 million USD over all years and for all flows involving Belgium it stands at 3.7 million USD.

11 All these calculations were programmed in LArray, a Python module developed at the FPB. The module and code can be made available upon request.

12 An exact replication of the construction procedure is not possible just based on descriptive sources without getting a view of the original code. Even though the description in Timmer et al. (2012) is fairly detailed, it does not shed light upon all problems that come up in the course of the construction process. For sure, there are some differences in the estimation of flows for the RoW in our procedure with respect to the original, e.g. the treatment of negative exports that are the counterpart of changes in inventories and the treatment of product flow imbalances for uranium and thorium ores. These differences have repercussions for domestic flows of the RoW.

4. Carbon footprint calculations

For calculating carbon footprints and emissions embodied in trade for Belgium, we use single-region input-output (SRIO) models based on national IO tables derived from UpdateSUT and the multiregional input-output (MRIO) model based on WIOD and WIODBEL MRIO tables. In what follows, we briefly derive and explain formulas for these calculations and then report results for Belgium.

4.1. Theory

Wiedmann et al. (2007) distinguish two SRIO models for calculating carbon footprints and emissions embodied in trade: the open economy model and the closed economy model. The former is focused on emissions from domestic production, while the latter also includes emissions from imports as if they were produced domestically. The starting point of the open economy model is the standard IO accounting identity for domestic output. That is

$$\mathbf{x} = \mathbf{Z^d}\boldsymbol{\iota} + \mathbf{y^d} + \mathbf{e} \qquad (1)$$

for *i = 1,…,n* industries with $\mathbf{x}$ the (*nx1*) output vector, $\mathbf{Z^d}$ the (*nxn*) matrix of domestic intermediate demand for domestic output, $\boldsymbol{\iota}$ a (*nx1*) vector of 1's for summation, $\mathbf{y^d}$ the (*nx1*) vector of domestic final demand for domestic output[13], and $\mathbf{e}$ the (*nx1*) vector of exported domestic output.[14] We assume that there are no re-exports. Defining the domestic input requirements matrix as $\mathbf{A^d} = \mathbf{Z^d}(\hat{\mathbf{x}})^{-1}$, equation (1) can be rewritten as $\mathbf{x} = \mathbf{A^d}\mathbf{x} + \mathbf{y^d} + \mathbf{e}$ and transformed into:

$$\mathbf{x} = \mathbf{L^d}(\mathbf{y^d} + \mathbf{e}) \qquad (2)$$

where $\mathbf{L^d} = \left(\mathbf{I} - \mathbf{A^d}\right)^{-1}$ is the (*nxn*) Leontief inverse matrix for domestic input requirements. This equation links output to final demand. An industry's output (one element of vector $\mathbf{x}$) is generated to serve final demand either directly or indirectly through intermediate input deliveries to other industries.

At this stage, we introduce greenhouse gas emissions into the model defining the (*nx1*) vector $\mathbf{p}$ as production-related emissions by industry and the scalar p as country-wide production-related emissions, which corresponds to the sum of all elements of $\mathbf{p}$. At the industry-level, emission intensities are described by the (*nx1*) vector $\mathbf{w} = \mathbf{p}(\hat{\mathbf{x}})^{-1}$. Then, the Leontief inverse matrix premultiplied by the diagonalised emission intensity vector gives us the emission multiplier matrix $\hat{\mathbf{w}}\mathbf{L^d}$. Any element $\left(\hat{\mathbf{w}}\mathbf{L^d}\right)_{\mathbf{ij}}$ represents (direct and indirect) domestic emissions in industry *i* for satisfying final demand for output of industry *j*. The full domestic production chain is taken into account: final demand for output of industry *j* leads, in a first step, to industry *j* sourcing intermediate inputs from its suppliers, among which industry *i*. In a second step, all the industries supplying *j* will require, for their extra output, intermediate

[13] We do not consider the individual final demand categories (household consumption, government consumption,…) separately but only total final demand.

[14] Bold capital letters are used for matrices, bold lowercase letters for column vectors and letters in italics for scalars. A prime indicates transposition and a circumflex diagonalisation of a vector.

inputs from their supplying industries among which i. And so on. This gives rise to emissions: direct emissions in the production for final demand and indirect emissions in the different stages of intermediate input production.

When only national IO tables are available, it is necessary to formulate some hypothesis about foreign technology (emission intensities and input requirements). In this setting, it is standard to assume that the technology for producing imports is identical to domestic technology. This has been referred to as the domestic technology assumption (DTA). It basically hinges upon the idea of avoided emissions. The question that can be answered is to what extent a country reduces its emissions through imports. But this does not give a realistic picture of how much carbon has actually been emitted abroad for producing those imports. In the open economy SRIO model, the carbon footprint is generally not calculated. Since all foreign emissions due to imported intermediates are excluded, it does not provide a realistic picture of consumption-based emissions.[15] Emissions embodied in exports (eex) comprise direct and indirect emissions, and are calculated through multiplication of exports by $\mathbf{w}'\mathbf{L^d}$. Based on the DTA, the expression for emissions embodied in imports (eem) is analogous.

$$eex = \mathbf{w}'\mathbf{L^d}\mathbf{e} \tag{3}$$

$$eem = \mathbf{w}'\mathbf{L^d}\mathbf{m}$$

$$beet = \mathbf{w}'\mathbf{L^d}(\mathbf{e} - \mathbf{m})$$

As explained in Turner et al. (2007), there is also a closed economy SRIO model. In this model, the Leontief inverse matrix $\mathbf{L^d}$ based on only domestic input requirements is replaced by the Leontief inverse matrix $\mathbf{L}$ based on total – both domestic and imported – input requirements, i.e. $\mathbf{L^d} = \left(\mathbf{I} - \mathbf{A^d} - \mathbf{A^m}\right)^{-1}$ where $\mathbf{A^m} = \mathbf{Z^m}(\hat{\mathbf{x}})^{-1}$ and $\mathbf{Z^m}$ stands for the (nxn) imported intermediate use matrix. Hence, in this case, emissions through the imported input requirements are considered as if they were domestic emissions. Given that these emissions are taken into account, consumption-based emissions (c), i.e. the carbon footprint, can be calculated by multiplying domestic and imported final demand by $\mathbf{w}'\mathbf{L^d}$. They comprise direct and indirect emissions. Emissions embodied in trade are computed in an analogous way.

$$c = \mathbf{w}'\mathbf{L}\mathbf{y^d} + \mathbf{w}'\mathbf{L}\mathbf{y^m} \tag{4}$$

$$eex = \mathbf{w}'\mathbf{L}\mathbf{e}$$

$$eem = \mathbf{w}'\mathbf{L}\mathbf{m}$$

$$beet = \mathbf{w}'\mathbf{L}(\mathbf{e} - \mathbf{m})$$

The closed economy SRIO model can also be derived from the IO accounting identity according to which total supply equals total use. This can be written as $\mathbf{x} + \mathbf{m} = \mathbf{Z}\boldsymbol{\iota} + \mathbf{y} + \mathbf{e}$ where $\mathbf{Z} = \mathbf{Z^d} + \mathbf{Z^m}$ and

[15] In this setting, the difference between total production-based emissions (p) and the footprint would not be equal to the balance of emissions embodied in trade ($beet$).

$\mathbf{y} = \mathbf{y^d} + \mathbf{y^m}$. When we transform this and pre-multiply by diagonalised domestic emission intensities, we obtain $p = \mathbf{w}'\mathbf{L}(\mathbf{y} + \mathbf{e} - \mathbf{m})$. From this, it is clear that the balance of emissions embodied in trade ($beet$) is equal to the difference between production-based emissions (p) and consumption-based emissions (c) in the closed economy model.

Beyond the severely simplifying domestic technology assumption, both SRIO models described here do not allow for feedback effects between countries. Such effects arise when domestic final demand gives rise to demand for foreign intermediate inputs, which, in turn, leads to demand for domestic intermediate inputs. In national IO tables, there is no information on whether exports serve intermediate or final demand in the destination country. A MRIO model is required to account for such effects.

Although in practice there are many countries in an MRIO model, it can be conveniently illustrated for two countries (see Serrano and Dietzenbacher, 2010): the focal country, which is Belgium in our case, and the RoW region. The tables provide full information for both countries including how exports are used in the destination country and emission intensities. Thus, the MRIO model does not require the simplifying DTA and allows for feedback effects. As before, there are $i = 1,\dots,n$ industries (in each country). The standard input-output demand equation indicating output delivered to intermediate and final demand can be written in partitioned form. In all submatrices and subvectors with two superscript indices, the first one stands for the country of origin and the second one for the country of destination.

$$\begin{pmatrix}\mathbf{x^1}\\ \mathbf{x^2}\end{pmatrix} = \begin{bmatrix}\mathbf{A^{11}} & \mathbf{A^{12}}\\ \mathbf{A^{21}} & \mathbf{A^{22}}\end{bmatrix}\begin{pmatrix}\mathbf{x^1}\\ \mathbf{x^2}\end{pmatrix} + \begin{pmatrix}\mathbf{y^{11}} + \mathbf{y^{12}}\\ \mathbf{y^{21}} + \mathbf{y^{22}}\end{pmatrix} \tag{5}$$

Here, $\mathbf{x^1}$ is the (n x 1) output vector for Belgium, $\mathbf{x^2}$ is the (n x 1) output vector of the RoW, $\mathbf{A^{11}}$ and $\mathbf{A^{22}}$ are the (n x n) domestic input requirement matrices of the two countries, $\mathbf{A^{12}}$ and $\mathbf{A^{21}}$ are the (n x n) imported input requirement matrices, $\mathbf{y^{11}} + \mathbf{y^{12}}$ is the (n x 1) final demand vector for Belgian output and $\mathbf{y^{21}} + \mathbf{y^{22}}$ is the (n x 1) final demand vector for RoW output. Defining p^1 and p^2 as total production-based emissions for the two countries and transforming (5) as previously done for (1), we obtain:

$$\begin{pmatrix}p^1\\ p^2\end{pmatrix} = \begin{bmatrix}\mathbf{w^1} & \mathbf{0}\\ \mathbf{0} & \mathbf{w^2}\end{bmatrix}'\begin{bmatrix}\mathbf{L^{11}} & \mathbf{L^{12}}\\ \mathbf{L^{21}} & \mathbf{L^{22}}\end{bmatrix}\begin{pmatrix}\mathbf{y^{11}} + \mathbf{y^{12}}\\ \mathbf{y^{21}} + \mathbf{y^{22}}\end{pmatrix} \tag{6}$$

For Belgium, production-based emissions are then:

$$p^1 = \mathbf{w^1}'\mathbf{L^{11}}\mathbf{y^{11}} + \mathbf{w^1}'\mathbf{L^{12}}\mathbf{y^{21}} + \mathbf{w^1}'\mathbf{L^{11}}\mathbf{y^{12}} + \mathbf{w^1}'\mathbf{L^{12}}\mathbf{y^{22}} \tag{7}$$

And the country's consumption-based emissions, i.e. its carbon footprint, and emissions embodied in trade are:

$$c^1 = \mathbf{w^1}'\mathbf{L^{11}}\mathbf{y^{11}} + \mathbf{w^1}'\mathbf{L^{12}}\mathbf{y^{21}} + \mathbf{w^2}'\mathbf{L^{21}}\mathbf{y^{11}} + \mathbf{w^2}'\mathbf{L^{22}}\mathbf{y^{21}} \tag{8}$$

$$eex^1 = \mathbf{w^1}'\mathbf{L^{11}}\mathbf{y^{12}} + \mathbf{w^2}'\mathbf{L^{21}}\mathbf{y^{12}} + \mathbf{w^1}'\mathbf{L^{12}}\mathbf{y^{21}} + \mathbf{w^1}'\mathbf{L^{12}}\mathbf{y^{22}}$$

$$eem^1 = \mathbf{w^2}'\mathbf{L^{22}}\mathbf{y^{21}} + \mathbf{w^1}'\mathbf{L^{12}}\mathbf{y^{21}} + \mathbf{w^2}'\mathbf{L^{21}}\mathbf{y^{11}} + \mathbf{w^2}'\mathbf{L^{21}}\mathbf{y^{12}}$$

$$beet^1 = \mathbf{w^1}'\{\mathbf{L^{11}}\mathbf{y^{12}} + \mathbf{L^{12}}\mathbf{y^{22}}\} - \mathbf{w^2}'\{\mathbf{L^{21}}\mathbf{y^{11}} + \mathbf{L^{22}}\mathbf{y^{21}}\}$$

Belgium's footprint comprises all (direct and indirect) domestic and foreign emissions for satisfying Belgian final demand. In the MRIO case, emissions embodied in Belgian exports can be domestic emissions and also foreign emissions. They comprise three elements: domestic direct and indirect emissions for satisfying the RoW's final demand for Belgian output (exports for final demand), foreign indirect emissions for satisfying this same final demand (exports for final demand), and domestic indirect emissions for satisfying (all) final demand for the RoW's output (exports for intermediate demand). In this two-country setting, emissions embodied in Belgian imports are equivalent to emissions embodied in the RoW's exports. They can thus be written in analogy to the emissions embodied in Belgian exports. It is easy to verify that the difference between production-based and consumption-based emissions corresponds to the balance of emissions embodied in trade for Belgium (and, by the same token, also for the RoW). In practice, a setting with more countries will split up the domestic part of the RoW and the trade flows between Belgium and the RoW in equations (5) and (6) and lead to more complicated expressions for equations (7) and (8).

4.2. Results for Belgium

There are few prior estimations of the CO_2 or GHG footprint (c) and the balance of CO_2 or GHG emissions in trade ($beet$) for Belgium with SRIO and MRIO models in the literature. Sissoko and Vandille (2008) have calculated CO_2-emissions embodied in Belgian trade over 1995-2004 based on the open economy SRIO model. According to their results, Belgium is a net exporter of CO_2-emissions over this entire period. This strongly contrasts with Belgium's consumption-based CO_2-emissions calculated with MRIO tables, which always largely exceed production-based emissions. Peters and Hertwich (2008) find a carbon footprint of 181.9 Mt CO_2 in 2001 for Belgium based on data from the GTAP-MRIO database. According to calculations by Tukker et al. (2014) with EXIOBASE, Belgium's carbon footprint amounted to 174.9 Mt CO_2 in 2007. Finally, Arto et al. (2012) report a GHG footprint of 184 Mt CO_2-eq. in 2007 for Belgium based on data from WIOD.[16]

Here, we first look at CO_2 footprints and emissions embodied in trade for Belgium and then add CH_4 and N_2O later for results in terms of a GHG index. We take national data on CO_2-emissions for Belgium from the country's air emission accounts (AEA).[17] The emission levels are actually very close to those published by WIOD for Belgium, both overall and at the industry level. We exclude direct emissions of households, which amount to approximately 30 Mt CO_2 and are relatively stable over the entire period.

Graph 3 provides an overview of Belgium's carbon footprint calculated according to different models and data. All results cover the years 1995-2007. The carbon footprints for Belgium based on the original WIOD MRIO tables and those based on the WIOD redone MRIO tables turn out to be very close. Therefore, we only report the latter.[18] Total production-based emissions (p) from the national AEA excluding direct household emissions are also reported. They amount to 100 Mt CO_2 in 1995 and remain relatively stable over the entire period with a slight downturn at the end of the period. The carbon footprint based

[16] Note that all these estimations include direct emissions by households. As a reference, production-based CO_2-emissions for Belgium amount to 131 Mt in 2001 and 124 Mt in 2007, and production-based GHG emissions stand at 141 Mt CO_2-eq. in 2007 in the Belgian AEA.

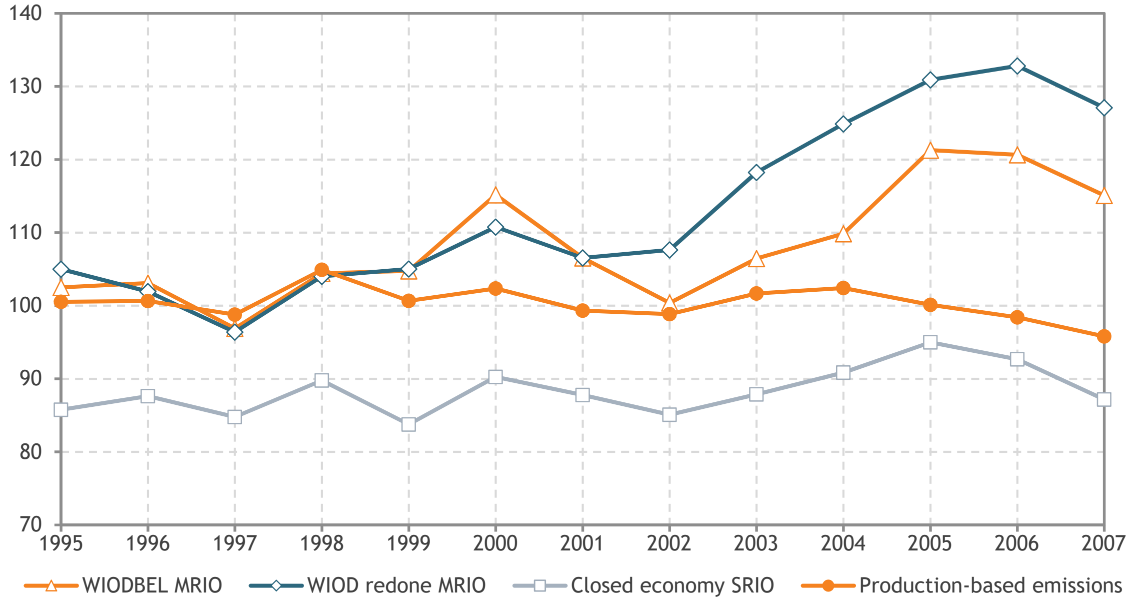
[17] See Vandille and Janssen (2012) for a methodological description.

[18] Results based on the original WIOD MRIO tables are available upon request.

on the closed economy SRIO model amounts to 86 Mt CO_2 in 1995 and remains relatively stable over the entire period with a slight peak in 2005. It is lower than production-based emissions for all years.[19]

Graph 3 Belgium's carbon footprint and production-based emissions, 1995-2007

Mt CO_2



The results can also be presented in terms of the balance of emissions embodied in trade (*beet*). A positive balance means that Belgium is a net exporter of emissions and a negative balance means that Belgium is a net importer of emissions.[20] Graph 4 shows that in the closed economy SRIO model, Belgium is a net exporter of emissions in all years. The *beet* is also positive in the open economy SRIO model for all sample years except 2005 and 2006, i.e. Belgium is a net importer of emissions in these years. The results for the open economy SRIO model are comparable to those of Sissoko and Vandille (2008), which are based on the same type of model.[21]

The results for Belgium's carbon footprint and emissions embodied in trade change radically with the use of the MRIO model and data. MRIO-based carbon footprints are always higher than SRIO-based carbon footprints.[22] Based on the WIOD redone MRIO tables, we find a carbon footprint that stands at 105 Mt CO_2 in 1995 and, after remaining relatively stable until 2002, starts to grow fast from 2003 onwards reaching a peak of 133 Mt CO_2 in 2006 (Graph 3). The results based on the WIODBEL MRIO tables are similar to the ones based on the WIOD redone MRIO tables until 2001 both in levels and in the trend over time. Starting at 103 Mt CO_2 in 1995, the WIODBEL-based carbon footprint remains relatively stable until 1999, then increases slightly to reach 115 Mt CO_2 in 2000 and falls again to 100 Mt CO_2 in 2002. From that year onwards, it rises just like the WIOD redone carbon footprint but at a slower pace in the first two years, i.e. between 2002 and 2004. It reaches its peak at 121 Mt CO_2 in 2005, first levelling off

[19] In line with our prior explanation, we have not calculated a carbon footprint for the open economy SRIO model.

[20] Recall that in the closed economy SRIO model the *beet* is equal to the difference between production-based emissions and consumption-based emissions, whereas in the open economy SRIO model this is not the case.

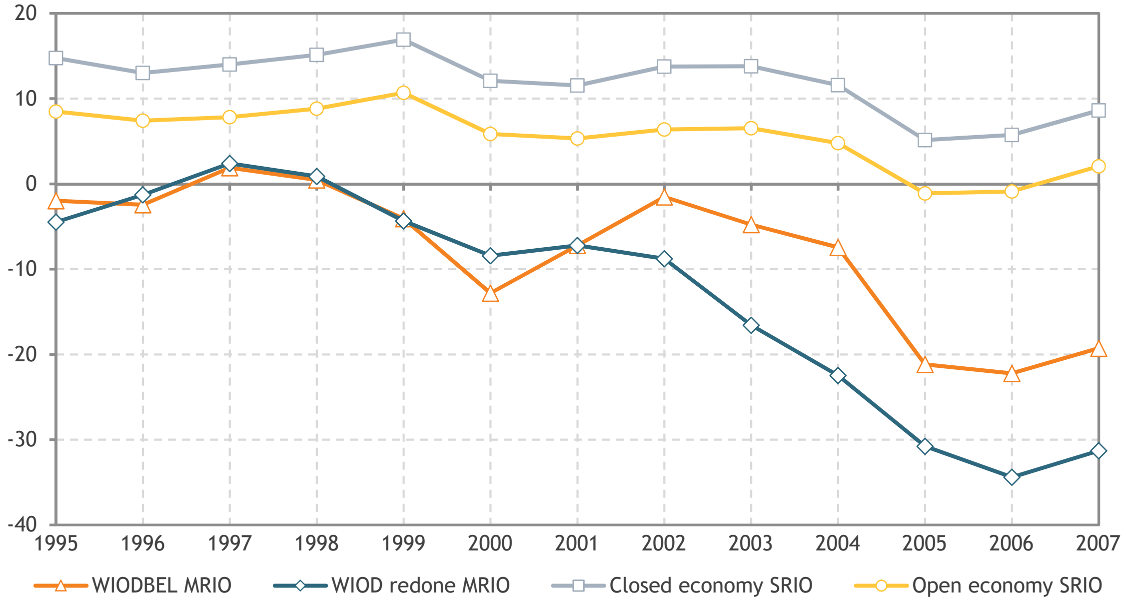
[21] The small differences in results come from differences in the data due to NA revisions.

[22] The fact that the SRIO-based carbon footprints are always lower than the MRIO-based carbon footprints is in line with findings for Japan reported in Nansai et al. (2009).

and then even decreasing thereafter. There is a difference between the WIODBEL and the WIOD redone footprint from 2001 onwards, the WIOD redone footprint being higher than the WIODBEL footprint.

Graph 4 Belgium's balance of CO_2-emissions embodied in trade, 1995-2007

Mt CO_2



The carbon footprints calculated with both WIODBEL and WIOD redone data exceed production-based emissions for all years except 1997 and 1998. Hence, these results suggest that Belgium has a negative balance of CO_2-emissions embodied in trade over almost the entire period (see Graph 4), i.e. is mostly a net importer of CO_2. Moreover, the negative *beet* increases in absolute value in the early 2000's amounting to 20-30% of production-based emissions.

Graph 5 Aggregation bias of carbon footprint results

% of results with disaggregated tables

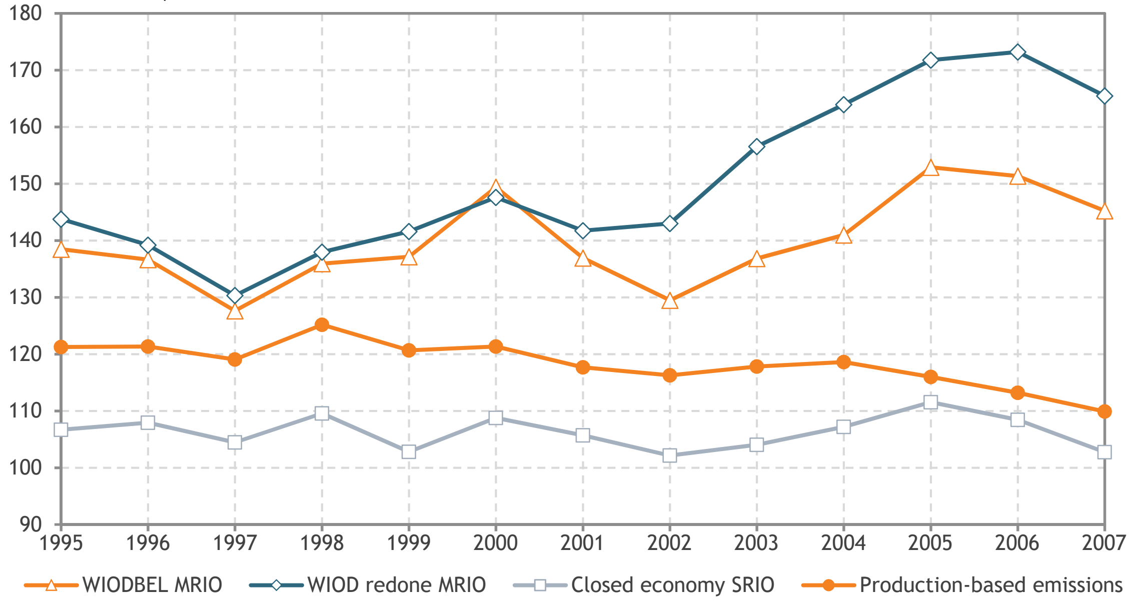
Furthermore, we can test for aggregation bias in the footprint results given that compared to WIOD we have a more detailed industry breakdown for Belgium in the national IO tables and the WIODBEL MRIO tables. The results are shown in Graph 5. Carbon footprints calculated with data from aggregated tables are always higher. The aggregation bias is 3% or less (of results for disaggregated tables) in all sample years for the closed economy SRIO-based carbon footprint as well as for the WIODBEL MRIO-based carbon footprint.

Finally, we have also computed GHG footprints and GHG emissions embodied in trade. Expressed in CO_2-equivalents, the GHG-index we use here is based on the global warming potential of CO_2, CH_4 (methane) and N_2O (nitrous oxide).[23] The results are

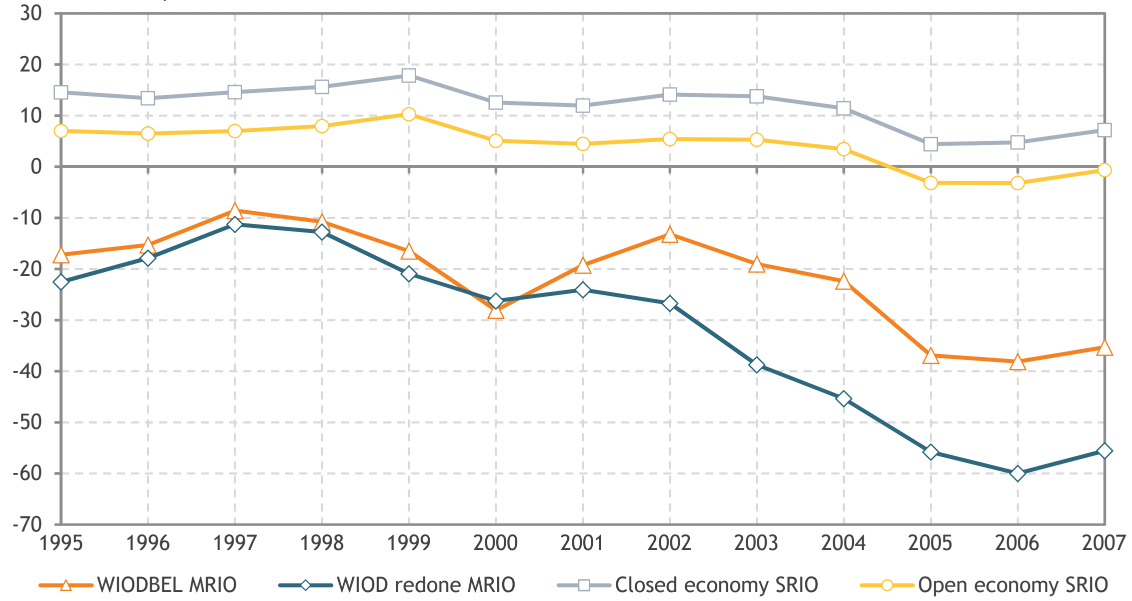
[23] Due to a lack of emission data in WIOD, we restrict our GHG-index to these three standard gases. In line with global warming potentials reported in IPCC (1995, p.22), it is computed as GHG-index = $CO_2 + 21 * CH_4 + 310 * N_2O$.

reported in Graphs 6 and 7. As before, Belgian production-based GHG emissions come from the country's AEA. They are very close in levels to WIOD emission data. For all models and data, the results on GHG footprints and emissions embodied in trade for Belgium are very similar to the results with CO_2-emissions only. The only difference worth mentioning is that MRIO-based GHG footprints exceed production-based GHG emissions for all sample years without any exception.

Graph 6 Belgium's GHG footprint and production-based emissions, 1995-2007
Mt CO_2-equivalents



Graph 7 Belgium's balance of GHG-emissions embodied in trade, 1995-2007
Mt CO_2-equivalents



5. Structural decomposition analysis of WIOD and WIODBEL footprints

In order to shed more light on the difference in footprint results for Belgium based on WIODBEL MRIO tables and on WIOD redone MRIO tables, we compare the two by means of a structural decomposition analysis (SDA).[24] From a methodological point of view, this is an SDA to compare two different databases, which makes it different from a standard intertemporal SDA (see e.g. Hoekstra et al., 2016, or Edens et al., 2011). Most importantly, we do not require constant price data because it is applied separately for each sample year. Our approach is comparable to prior use of SDA for comparing carbon footprints calculated with different MRIO databases. Owen et al. (2014) do so for GTAP, WIOD and Eora and Arto et al. (2014) for WIOD and GTAP. These authors compare carbon footprints for all countries in the global MRIO tables, while we specifically focus on Belgium. It is noteworthy that Owen et al. (2014) find that the differences in footprint results between MRIO databases are biggest for Belgium.

In our SDA formulation, we specifically look at the effects of changes in the underlying data for Belgium on the country's carbon footprint so as to get a clearer picture of how the consistency with Belgian national data in WIODBEL influences footprint results with respect to WIOD redone. For this purpose, we apply a decomposition technique that is similar to the one developed in Hoekstra et al. (2016) and allows to isolate individual countries in terms of their input requirements and final demand.

Our SDA is based on the expression for calculating the carbon footprint for Belgium in the MRIO model (equation (8) in the previous section). We add subscript index s for the dataset used in the calculation – either WIODBEL or WIOD redone – and rewrite it as follows:

$$c_k^1 = \mathbf{w}_\mathbf{s}'\mathbf{L}_s\mathbf{y}_s^{\cdot\mathbf{1}} = \begin{pmatrix}\mathbf{w}_\mathbf{s}^1 \\ \mathbf{w}_\mathbf{s}^2\end{pmatrix}' \begin{bmatrix}\mathbf{L}_\mathbf{s}^{11} & \mathbf{L}_\mathbf{s}^{12} \\ \mathbf{L}_\mathbf{s}^{21} & \mathbf{L}_\mathbf{s}^{22}\end{bmatrix} \begin{pmatrix}\mathbf{y}_\mathbf{s}^{11} \\ \mathbf{y}_\mathbf{s}^{21}\end{pmatrix} \tag{9}$$

This is the footprint calculation for one year. We compare the WIODBEL footprint ($s = b$) and the WIOD redone footprint ($s = r$) for Belgium for each sample year.

$$\Delta c^1 = c_b^1 - c_r^1 = \mathbf{w}_\mathbf{b}'\mathbf{L}_\mathbf{b}\mathbf{y}_\mathbf{b}^{\cdot\mathbf{1}} - \mathbf{w}_\mathbf{r}'\mathbf{L}_\mathbf{r}\mathbf{y}_\mathbf{r}^{\cdot\mathbf{1}} \tag{10}$$

To determine contributions of differences in the three terms on the right hand side ($\Delta\mathbf{w}'$, $\Delta\mathbf{L}$, $\Delta\mathbf{y}^{\cdot\mathbf{1}}$) to the difference in c^1 (Δc^1) we apply the Sun (1998) decomposition formula, which is based on a linear interpolation of a Paasche and a Laspeyres index.[25] In our case, there are three effects.

$$\Delta c^1 = d_w + d_L + d_y \tag{11}$$

[24] Recall that Belgian footprints based on WIOD redone tables are almost identical to those based on the original WIOD tables.

[25] As noted in Hoekstra et al. (2016), this is equivalent to the widely-used approach of computing the average of the *k*! complete weight decompositions where *k* is the number of terms in the expression to be decomposed (Dietzenbacher and Los, 1998).

Here, d_w is the contribution of differences in emission intensities to the difference in footprints between WIODBEL and WIOD, d_L is the contribution of differences in the Leontief inverse matrix, and d_y the contribution of differences in Belgian final demand. The Sun (1998) decomposition method yields the following expressions for the effects:

$$d_w = \Delta\mathbf{w}'\mathbf{L}_{\mathbf{r}}\mathbf{y}_{\mathbf{r}}^{\cdot\mathbf{1}} + \frac{1}{2}\Delta\mathbf{w}'\Delta\mathbf{L}\mathbf{y}_{\mathbf{r}}^{\cdot\mathbf{1}} + \frac{1}{2}\Delta\mathbf{w}'\mathbf{L}_{\mathbf{r}}\Delta\mathbf{y}^{\cdot\mathbf{1}} + \frac{1}{3}\Delta\mathbf{w}'\Delta\mathbf{L}\Delta\mathbf{y}^{\cdot\mathbf{1}} \tag{12}$$

$$d_L = \mathbf{w}_{\mathbf{r}}'\Delta\mathbf{L}\mathbf{y}_{\mathbf{r}}^{\cdot\mathbf{1}} + \frac{1}{2}\Delta\mathbf{w}'\Delta\mathbf{L}\mathbf{y}_{\mathbf{r}}^{\cdot\mathbf{1}} + \frac{1}{2}\mathbf{w}_{\mathbf{r}}'\Delta\mathbf{L}\Delta\mathbf{y}^{\cdot\mathbf{1}} + \frac{1}{3}\Delta\mathbf{w}'\Delta\mathbf{L}\Delta\mathbf{y}^{\cdot\mathbf{1}}$$

$$d_y = \mathbf{w}_{\mathbf{r}}'\mathbf{L}_{\mathbf{r}}\Delta\mathbf{y}^{\cdot\mathbf{1}} + \frac{1}{2}\Delta\mathbf{w}'\mathbf{L}_{\mathbf{r}}\Delta\mathbf{y}^{\cdot\mathbf{1}} + \frac{1}{2}\mathbf{w}_{\mathbf{r}}'\Delta\mathbf{L}\Delta\mathbf{y}^{\cdot\mathbf{1}} + \frac{1}{3}\Delta\mathbf{w}'\Delta\mathbf{L}\Delta\mathbf{y}^{\cdot\mathbf{1}}$$

We further decompose these effects to isolate changes in data for Belgium. For d_w, this is not necessary as the only difference in emission intensities between WIODBEL and WIOD redone is in the data for Belgium. Moreover, these differences are small as already mentioned before. For d_y, we split Belgian final demand into final demand for domestic output and imported final demand, i.e. Belgian final demand for output of other countries – in this case, the RoW. In terms of our formulation, this comes down to additively splitting the variation in Belgian final demand into two terms:

$$\Delta\mathbf{y}^{\cdot\mathbf{1}} = \begin{pmatrix}\Delta\mathbf{y}^{\mathbf{11}}\\ \Delta\mathbf{y}^{\mathbf{21}}\end{pmatrix} = \begin{pmatrix}\Delta\mathbf{y}^{\mathbf{11}}\\ \mathbf{0}\end{pmatrix} + \begin{pmatrix}\mathbf{0}\\ \Delta\mathbf{y}^{\mathbf{21}}\end{pmatrix} = \Delta\mathbf{y}_{\mathbf{d}}^{\cdot\mathbf{1}} + \Delta\mathbf{y}_{\mathbf{m}}^{\cdot\mathbf{1}} \tag{13}$$

and deriving two final demand effects: d_{y_d} and d_{y_m}. They measure the contributions of differences in Belgian final demand for domestic output and for foreign output.

For splitting d_L, we rely on the standard formula that links differences in the Leontief inverse to differences in the input requirement matrices (see Miller and Blair, 2009, pp.602-603): $\Delta\mathbf{L} = \mathbf{L}_{\mathbf{r}}\Delta\mathbf{A}\mathbf{L}_{\mathbf{b}}$ with $\Delta\mathbf{A} = \mathbf{A}_{\mathbf{b}} - \mathbf{A}_{\mathbf{r}}$ the difference in the input requirement matrices. In line with Hoekstra et al. (2016), we further subdivide $\Delta\mathbf{A}$ into four additive terms:

$$\begin{aligned}\Delta\mathbf{A} &= \Delta\mathbf{A}_{\mathbf{bel\_d}} + \Delta\mathbf{A}_{\mathbf{bel\_m}} + \Delta\mathbf{A}_{\mathbf{bel\_x}} + \Delta\mathbf{A}_{\mathbf{nbel}} \\ &= \begin{bmatrix}\Delta\mathbf{A}^{\mathbf{11}} & \mathbf{0}\\ \mathbf{0} & \mathbf{0}\end{bmatrix} + \begin{bmatrix}\mathbf{0} & \mathbf{0}\\ \Delta\mathbf{A}^{\mathbf{21}} & \mathbf{0}\end{bmatrix} + \begin{bmatrix}\mathbf{0} & \Delta\mathbf{A}^{\mathbf{12}}\\ \mathbf{0} & \mathbf{0}\end{bmatrix} + \begin{bmatrix}\mathbf{0} & \mathbf{0}\\ \mathbf{0} & \Delta\mathbf{A}^{\mathbf{22}}\end{bmatrix}\end{aligned} \tag{14}$$

This yields four effects: $d_{L\_bel\_d}$, $d_{L\_bel\_m}$, $d_{L\_bel\_x}$ and d_{L_nbel}. They measure contributions of differences in input requirements to differences in the carbon footprint via the Leontief effect: the first one of differences in Belgian domestic input requirements, the second one of differences in Belgian imported input requirements, the third one of differences in foreign input requirements for Belgian output, and the last one of differences in foreign input requirements for all other (non-Belgian) output. The latter two only have an indirect effect on the Belgian carbon footprint.[26]

[26] In practice, there are many countries in the MRIO tables so that the RoW region is further subdivided. But this does not alter the number of effects in our decomposition of the Belgian footprint.

Thus, expanding (12) we have the following effects in our SDA:

$$\Delta c^1 = \underbrace{d_w}_{(1)} + \underbrace{d_{L\_bel\_d}}_{(2)} + \underbrace{d_{L\_bel\_m}}_{(3)} + \underbrace{d_{L\_bel\_x}}_{(4)} + \underbrace{d_{L\_nbel}}_{(5)} + \underbrace{d_{y\_d}}_{(6)} + \underbrace{d_{y\_m}}_{(7)} \quad (15)$$

(1) Emission intensity effect

(2) Belgian domestic input requirements effect

(3) Belgian imported input requirements effect

(4) Foreign input requirements effect for Belgian output (exports)

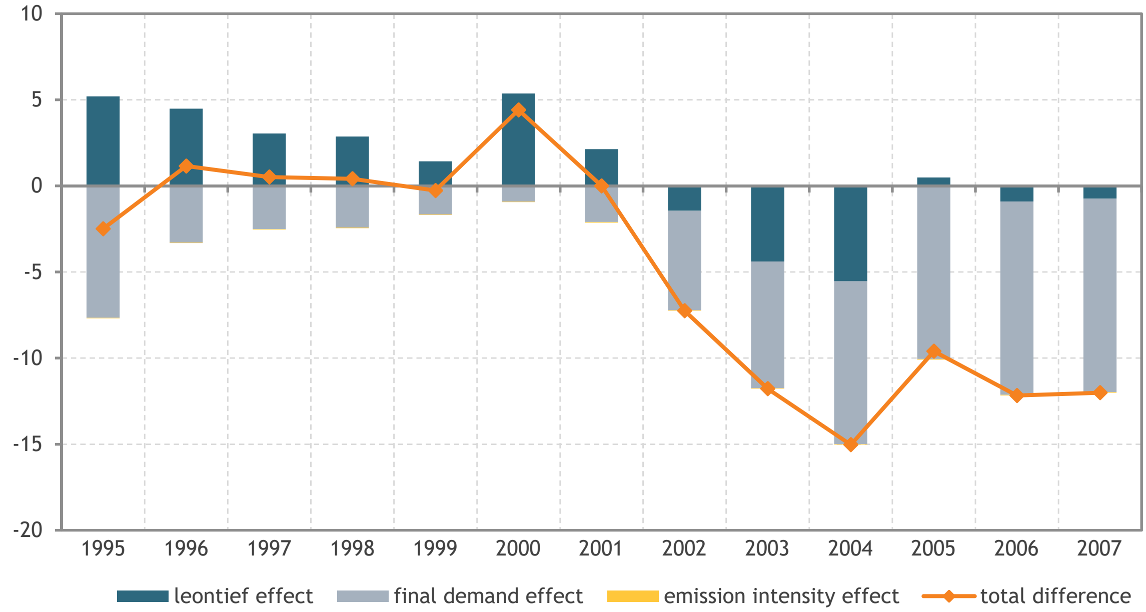
(5) Foreign input requirements effect for all other output

(6) Belgian domestic final demand effect

(7) Belgian imported final demand effect

The difference between the carbon footprint for Belgium based on WIODBEL and on WIOD redone is reported as a line in Graph 8. It is relatively small during the first half of the sample period, never exceeding 5 Mt CO_2 in absolute value or 5% of production-based CO_2-emissions. From 2002 onwards, it becomes negative and sizeable, i.e. the WIOD redone footprint largely exceeds the WIODBEL footprint. The difference is largest in absolute value in 2004 when it amounts to 15000 Mt CO_2 or 15% of Belgium's production-based emissions.

Graph 8 SDA of the difference between the WIODBEL and WIOD redone carbon footprint - 3 effects
Mt CO_2



The bar chart part of Graph 8 shows the year-by-year decomposition results for the three effects of equation (12). These are results for the CO_2 footprint differences. Those for GHG footprint differences are qualitatively equivalent.[27] The emission intensity effect is very small and its influence on the overall difference between the two footprints can be neglected. As mentioned before, emission intensities in

27 The decomposition results for GHG footprint differences are not reported but can be made available upon request.

WIOD and WIODBEL differ only for Belgium and these differences are very small. Hence, the overall difference is determined by the two other effects: the Leontief effect and the final demand effect.

Between 1995 and 2001, the Leontief effect is positive, i.e. the differences in intermediate input requirements between WIODBEL and WIOD redone lead to a higher carbon footprint for WIODBEL. The opposite holds for differences in final demand, i.e. the final demand effect is negative over the period 1995-2001. Overall, the two effects more or less compensate so that the difference between the WIODBEL footprint and the WIOD redone footprint remains close to zero.

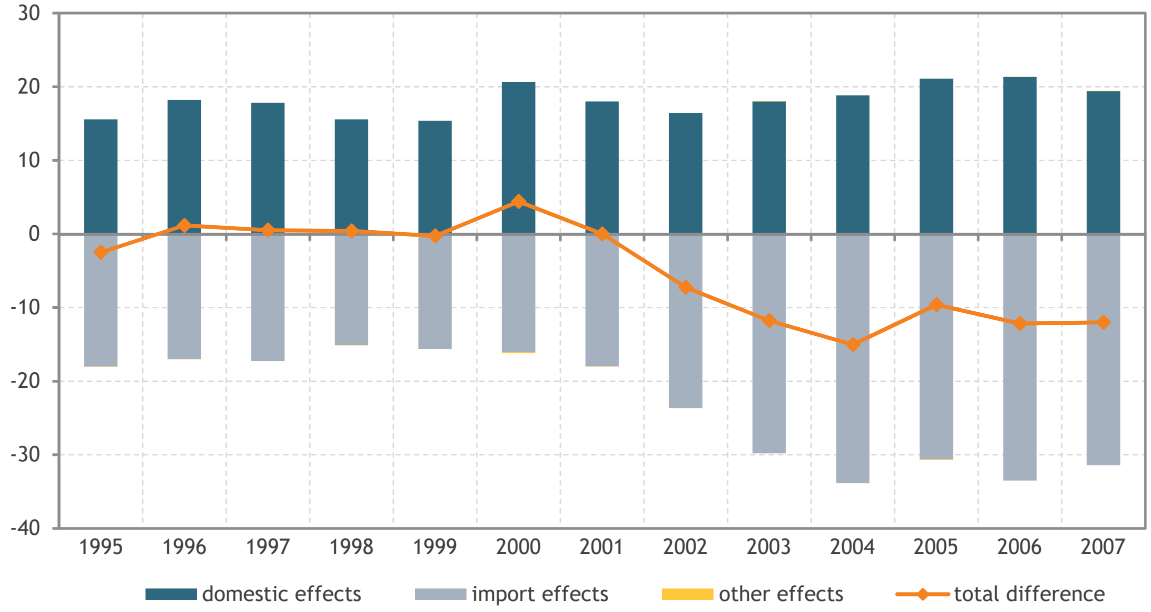
Things change from 2002 onwards. The Leontief effect turns negative in that year and remains negative in all subsequent years except for 2005. The final demand effect is negative over the entire period 2002-2007. Compared to the years 1995-2001, the magnitude of the effect increases in absolute value. So, differences in intermediate input requirements and, in particular, differences in final demand contribute to our finding that the WIODBEL-based carbon footprint for Belgium is lower between 2002 and 2007.

The compensation between the final demand effect and the Leontief effect can be partly attributed to differences between WIODBEL and WIOD redone in the distribution of taxes and subsidies on production intermediate and final demand. Indeed, when it comes to deriving use tables in basic prices for Belgium, a larger share of taxes and subsidies on production is subtracted from final demand in WIODBEL than in WIOD redone. The opposite holds for intermediate demand. This is illustrated in Graph 1. Hence, Belgian final demand in basic prices is globally higher in WIOD redone, which leads to a negative final demand effect, and Belgian intermediate demand is globally higher in WIODBEL, which leads to a largely compensating positive Leontief effect.

The extra decomposition terms in equation (15), which are specifically focused on differences in data for Belgium, provide further insights into where the difference between WIODBEL and WIOD redone carbon footprints comes from. Results are shown in aggregated form in Graph 9. We have summed effects so as to highlight how much of the difference in Belgium's footprints is due to differences in Belgian domestic demand (domestic effect) and to differences in Belgian imports (import effect). The domestic effect is the sum of the Belgian domestic input requirements effect ($d_{L\_bel\_d}$) and the Belgian domestic final demand effect (d_{y_d}), and the import effect is the sum of the Belgian imported input requirements effect ($d_{L\_bel\_m}$) and the Belgian domestic final demand effect (d_{y_m}). The other three effects (d_w, $d_{L\_bel\_x}$ and d_{L_nbel}), which all turn out to be small, are aggregated on the graph into one term, which we name 'other effects'.

The domestic effect is positive and the import effect is negative in all years. This means that differences in Belgian domestic demand make for a higher WIODBEL than WIOD redone carbon footprint, while the opposite holds for differences in Belgian imports. The domestic effect is relatively stable at 15-20 Mt CO_2. In absolute value, the import effect amounts to approximately 15-20 Mt CO_2 between 1995 and 2001 leading to a rather small overall difference in footprints for those years. From 2002 onwards, the import effect grows in absolute value to reach 34 Mt CO_2 in 2004. Hence, for the years 2002-2007, it more than compensates the positive domestic effect so that the difference between the WIODBEL and the WIOD redone footprint is negative. This is related to the increase in the difference in Belgian re-exports between WIODBEL and WIOD redone from 2002 onwards, which entails a greater difference in Belgian imports between the two datasets and hence a greater import effect in absolute value.

Graph 9 SDA of the difference between the WIODBEL and WIOD redone carbon footprint - 7 effects aggregated
Mt CO_2



6. Discussion and conclusion

The work presented in this article is a first effort to establish consumption-based GHG emission accounts for Belgium that are consistent with both detailed Belgian national accounts and international standards for calculating a country's carbon footprint and balance of GHG emissions embodied in trade. We have calculated Belgium's carbon footprint for the years 1995-2007 based on a global MRIO table that respects Belgian national data. For this purpose, we have reproduced the construction process of MRIO tables in the WIOD project and injected detailed supply-and-use tables for Belgium from national sources into the process. We refer to the resulting MRIO tables as WIODBEL tables. From a national perspective, WIODBEL tables allow for an improvement of carbon footprint calculations (1) in terms of methodology with respect to national IO tables for which the domestic technology assumption is necessary, and (2) in terms of data with respect to MRIO tables that are not consistent with the Belgium's detailed national accounts.

Belgium's carbon footprint based on WIODBEL tables amounts to 138 Mt CO_2-eq. in 1995 and 145 Mt CO_2-eq. in 2007. This concerns total GHG emissions excluding direct emissions of households and is substantially higher than production-based GHG emissions which stand at 121 Mt CO_2-eq. in 1995 and 110 Mt CO_2-eq. in 2007. Hence, according to our calculations with WIODBEL tables, Belgium is a net importer of GHG emissions over the entire sample period. This confirms prior results based on global MRIO tables that are not consistent with the Belgium's detailed national accounts (Peters and Hertwich, 2008; Arto et al., 2012; Tukker et al., 2014). Moreover, it allows to revise the – counterintuitive – finding based on national IO tables that Belgium is a net exporter of emissions (Sissoko and Vandille, 2008).

The comparison of Belgium's carbon footprint calculated with the original WIOD MRIO tables and WIODBEL MRIO tables reveals sizeable differences in the second half of the sample period. Footprints are similar in levels and trend until 2001, but from 2002 onwards the difference between the two starts to grow, and the original WIOD-based footprint is systematically higher than the WIODBEL-based footprint. The difference quickly becomes sizeable: it amounts to 14% on average between 2003 and 2007. The original WIOD footprint increased by 15% between 1995 and 2007, whereas the WIODBEL footprint only grew by 5% over the same period. According to the results of our decomposition analysis, this difference in footprint results can be attributed to a large extent to the growing difference in the estimated magnitude of re-exports for Belgium, which are higher in WIODBEL than in the original WIOD tables. Since re-exports are subtracted from imports in the MRIO construction process, Belgium's imports are globally lower in WIODBEL, and this leads to a lower carbon footprint.

All in all, our findings show that consistency with detailed national accounts does matter for MRIO-based carbon footprint calculations, in particular for a small open economy like Belgium. MRIO tables that are not consistent with detailed data for Belgium from national sources tend to overestimate the country's carbon footprint in the last years of the sample period, confirming findings for the Netherlands for 2003 and 2009 (Edens et al., 2015). Due to the growing discrepancy in the estimation of re-exports, the gap widens between the footprint based on MRIO tables that are consistent with detailed national accounts and the footprint based on MRIO tables for which this is not the case.

Finally, two issues should be addressed in future work. First, MRIO-based carbon footprint estimations for more recent years would be valuable from a policy perspective. However, such estimations would require substantial preliminary data work for Belgium as, for the moment, there is no time series of consistent supply-and-use tables for the years after 2007. This is a prerequisite before injecting Belgian national data into the MRIO construction process. Second, calculating carbon footprints with IO data in previous year prices would allow to gain further insights on technological factors underlying carbon footprints by excluding the influence of relative prices movements. It would also allow for a decomposition analysis to identify factors that contribute to changes in carbon footprints over time. Again, this would require considerable preliminary data work to build previous year price MRIO tables that are consistent with Belgian national data.

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