



D9.3 Report with recommendation on EE IO data simplification

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About DESIRE

DESIRE is a FP7 project that will develop and apply an optimal set of indicators to monitor European progress towards resource-efficiency. The project runs from September 2012 to February 2016. We propose a combination of time series of environmentally extended input output data (EE IO) and the DPSIR framework to construct the indicator set. Only this approach will use a single data set that allows for consistent construction of resource efficiency indicators capturing the EU, country, sector and product group level, and the production and consumption perspective including impacts outside the EU. The project will:

- Improve data availability, particularly by creating EE IO time series and now-casted data
- Improve calculation methods for indicators that currently still lack scientific robustness, most notably in the field of biodiversity/ecosystem services and critical materials. We further will develop novel reference indicators for economic success.
- Explicitly address the problem of indicator proliferation and limits in available data that have a 'statistical stamp'. Via scientific analysis we will select the smallest set of indicators giving mutually independent information, and show which shortcuts in (statistical) data inventory can be made without significant loss of quality.

The project comprises further Interactive policy analysis, indicator concept development via 'brokerage' activities, Management, and Conclusions and implementation including a hand over of data and indicators to the EU's Group of Four of EEA, Eurostat, DG ENV and DG JRC.

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1 Introduction

One fundamental challenge in indicator development by European institutes like EEA and Eurostat is the consumption-based perspective. In this perspective, in essence all impacts along the (global) value chains related to European consumption should be taken into account. This implies that insight is needed in the 'pollution and resources embodied in trade'. Europe can ensure that high quality statistical data for its own territory are available. It is much more difficult to ensure such data from trade partners is available.

Next to EXIOBASE as enriched in this DESIRE project, there is a number of other databases around that reflect a full Global Multiregional, Environmentally Extended Input Output table (GMR EE IO). From a point of view of official statistics, these so-called science based MR EE IOs are problematic. These databases by nature have to adjust the national IO data, if alone since the total imports and exports contained in country MR IOs do not match, leading to unbalanced trade. All global MR EE IOs hence in one way or another take national IO tables, combine them, make estimates about trade relations, and in the end apply an optimization routine to end up with a globally balanced table. The result is that national tables have been adjusted. A specific feature of the DESIRE project and EXIOBASE is further that we assumed that for specific sectors (agriculture, energy extraction, mining) a much higher detail is needed as in regular IO tables (often just one sector for agriculture, energy and mining), simply since the environmental impacts related to different agricultural products, different energy carriers and different metals, for instance, are very different. This, in turn, implies that EXIOBASE v3 as developed in DESIRE has adapted national tables even more, by applying detailing procedures. The results are science-based MR EE IOs, in which national IO tables are adjusted and disaggregated. For National Statistical Institutes (NSIs), such tables adjusted for research purposes are difficult to use – they prefer using their official statistics. But since they have no insight in the origin of imports and destination of exports, and IO tables from other countries usually have a different structure as of a specific NSI, an NSI usually is not able to compile information on pollution embodied in imports and exports, let alone MREEIOs for the world, themselves.

On the basis of a number of papers written in the context of the DESIRE project, and work done outside DESIRE, this deliverable will analyse the following issues that can help to identify how NSIs can be provided with information on pollution embodied in trade in a manner that for them may be acceptable to be used. For this purpose, this deliverable discusses:

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- a) A review of methods that can be used by NSIs to get insight in pollution embodied in trade and a first analysis of preferred approaches (chapter 2)
 - b) A review of various global MR EE IOs available, and their pro's and cons (chapter 3)
 - c) A review of analysis of uncertainties in MR EE IOs (chapter 4)
 - a. The added value of aggregated versus disaggregated tables - working with aggregated tables would remove the problem that national tables are adjusted by disaggregation
 - b. A review of the main factors causing uncertainties in country footprints as calculated by different MR EE IOs – this of course helps to analyse which data have to be controlled best in case NSIs would like to set up an 'official' Global MR EE IO
 - c. Insight in the level of which pollution embodied in exports of a specific country is visible in that country's imports – as will be explained in chapter 4, this has implications for the way how a country can calculate pollution embodied in imports
 - d) Conclusions with regard to EE IO data simplification and possibilities for moving forward to 'more official' international statistics on pollution embodied in trade (Chapter 5).

2 Methods for assessing pollution embodied in trade

2.1 Introduction

In principle, there is a number of approaches to deal with the issue of pollution embodied in trade. We will discuss them in section 2.2, and analyse some key pro's and con's in section 2.3. The analysis is in part based on Tukker et al. (2013), and a recent paper of Eisenmenger et al (2016) written in part in the context of the DESIRE project, now accepted for publication in Ecological Economics (see Annexes).

2.2 Review of methods

2.2.1 Introduction

In general, the following methods can be discerned to assess pollution embodied in trade of countries (e.g. Tukker et al. 2013; Brückner et al., 2015; Eisenmenger et al, 2016):

1. Using emission and resource use coefficients for foreign countries derived with LCAs in combination with trade data on imported products
2. Domestic technology assumption
3. Applying the Domestic Technology Assumption (DTA) corrected for purchasing power parities, or relative prices of imports compared to European production
4. Using emission and resource coefficients for foreign countries derived with EE IO data for these countries, taking into account bilateral trade only.
5. Using an available Global MR EE IO at face value, and calculating footprints of a country with such an GMRIO
6. As per 5), using official data for a central country, and implementing that data in an existing MREE IO model. This is also called a "single-country national accounts consistent (SNAC) footprint "
7. As per 6), using official data for a central country but just using a full MR EE IO model to calculate pollution and resources in imports.

Brückner et al. (2015) highlights further a hybrid approach for particularly land use, that combines the high level of detail of physical data from FAOSTAT and land use coefficients (point 1) with the better value chain perspective of MR EE IO (point 5-7). Such detailed combined hybrid databases currently are not yet available, so for that reason we do not take this into account in this report¹. We discuss below the approaches mentioned above in more detail.

2.2.2 Applying Life cycle inventory (LCI) data for imports.

A practitioner may use LCI databases to estimate the impacts in the life cycle of imported products (Eurostat, 2012). For material footprints, in this way so-called 'Raw Material Equivalents (RMEs)' are calculated that identify for imported products how much primary materials have been extracted for producing them. LCI data have however [often](#) limits in

¹ Authors have used however the approach to set up physical satellite accounts measuring water and/or land use related to agricultural products; see e.g. Ewing et al., 2012; Steen-Olsen et al., 2012; Weinzettel et al., 2013, 2014.

the sense that they are mostly available for European, US and Japanese processes. This could lead to similar errors as in the method for Domestic Technology Assumption (DTA, see below), simply since the LCI data for developed countries may not apply well to countries from which is imported. At best one can expect some differentiation by country on the use of energy carriers and electricity sources in LCAs for products made abroad. A further problem is that LCI data cover unit processes in great detail. Scaling up from specific product LCAs to (e.g.) 60 broad product categories of imports can lead to further errors. Two fundamental problems however are the following:

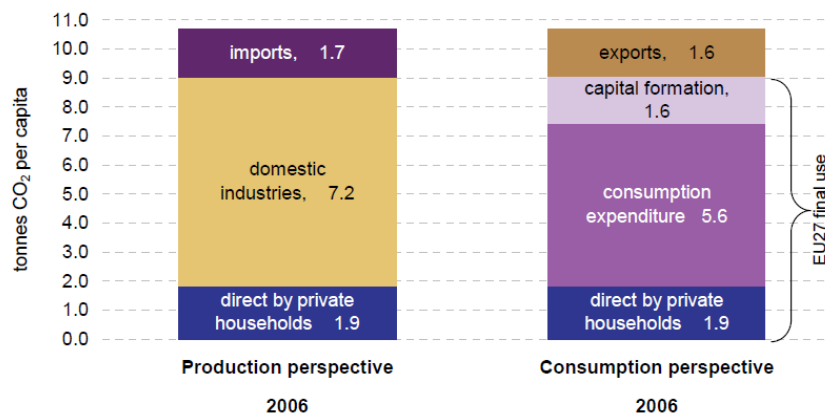
- A GMR EE IO approach merely re-distributes the global extraction of resources and global emissions to final demand. The pollution and extractions embodied in final demand is hence by nature identical to global pollution and extractions, as they should be. When LCI data are used for imports, and combined with domestic extraction and emission data, the resources and emissions embodied in imports will be based on a different data set. Inevitably, the pollution and resource extraction embodied in final demand then hence will differ from the global resource extraction and emissions.
- A GMR EE IO approach truly follows value chains through the global economy. The LCI / coefficient based approach assumes that an imported products is made in full in the country of exports. In practice, components of the imported products are made in third countries, etc. Giljum et al. (2016) investigated how global supply chains in relation to embodied materials developed over time, and found that over time the higher tiers in the supply chain have become more relevant.

2.2.3 Domestic technology assumption

The use of the Domestic Technology Assumption (DTA) has been used often, since it is simple. It assumes that imports are made with domestic technology. It hence just needs the data in the existing EE SUIOT to make an estimate. However, this method can lead to erroneous results since impact intensities of imported goods can differ from those produced domestically (Peters and Hertwich, 2006a and 2006b; Weber and Matthews, 2007; Ghertner and Fripp, 2007). Figure 2.1 shows the results of the DTA as applied in a project for Eurostat (Tukker et al, 2013). It suggests that the CO₂ emissions in imports and exports of the EU27 are similar (1.7 versus 1.6 ton per capita). Studies calculating impacts of imports using specific data for non EU countries showed major differences, up to 3 ton per capita (e.g. Brückner et al. 2010, Davis and Caldeira, 2010).

This all is not surprising. Particularly small countries will have fundamentally different production structure as the countries from which they import. This implies that the domestic emissions and resource extractions per Euro production per sector will be very different as from other countries. Next to this, the input-output efficiency of a domestic sector may differ from sectors abroad, while finally the price of domestic outputs may differ from the price of imports. All this implies that the DTA can at best be used as a 'last resort method' in cases where really no other information is available.

Figure 2.1: Carbon emissions per capita for the EU27 in 2006 (Tukker et al, 2013)



2.2.4 Price adjusted Domestic Technology Assumption

Tukker et al. (2013) proposed an alternative for the DTA, considering that there can be three main reasons why the DTA may not give correct results

- For the same industry and product, the direct pollution per unit of production abroad is higher as in Europe (i.e. there is a difference in emission coefficients in the producing industries);
- For the same industry and product, the intermediate inputs and/or the pollution related to production of intermediate inputs per unit of production is higher as in Europe (i.e. there is a difference in the technical (input) coefficients in the producing industries, and/or higher emission coefficients in the downstream industries);
- For the same product, one Euro of imports represents more physical imports as one Euro of production in Europe (i.e. countries abroad are able to produce more stuff for less money)

This leads to a simple possibility to improve the DTA with statistical data available from NSIs only. NSIs and organisations such as Eurostat usually have already available (EE) SUT/IOT with an export vector, for EUROSTAT typically at the level of 60 product categories. NSIs have however also insight in trade flows. Eurostat's COMEXT database for instance contains both data on the economic value as the physical quantity of imported and exported products. COMEXT's detailed trade data can easily be aggregated to the 60 product categories in EU EE SUIOT. With both economic value as physical quantity known, an average price per product group can be calculated for imports and exports. Assuming price homogeneity in the EE SUIOT, the price of the exports equals the price of domestic production. The ratio of domestic (=export) price and import price now can be used to adjust impacts per imported product group calculated via the DTA. This factor corrects in essence how much more physical imports takes place per Euro spent compared to physical output per Euro production in Europe.

This method hence corrects for point c) above. However, no insight is provided in the points a) and b) above, whereas like the DTA also no insight in the full value chains across countries is provided. It is hence not possible to assess how imports drive emissions and resource extractions abroad per country; only the total emission and resource extraction abroad is estimated.

2.2.5 Including bilateral trade based on national EE IO tables

A practitioner may identify the main trading partners of a central country for which environmental footprints need to be calculated, make available EE I-O tables for these countries or country groups, and calculate the embedded pollution and resource use in bilateral trade (see e.g. Weidema et al. (2005, Denmark); Peters and Hertwich (2006b; Norway), Nijdam et al, (2005; Netherlands), Weber and Matthews (2007, US) and Norman et al (2007, Canadian-US trade)).

National EE IO Tables by country usually only give an aggregated import vector and do not specify the countries of origin. Usually, auxiliary trade data (e.g. from COMEXT, or UN COMTRADE) are used to calculate import shares to split up the import vector to countries of origin.

Using then any EE IO table available from these exporting countries, the resources and pollution embodied in imports are calculated. The main drawback of this method is obvious – again, the full value chains are not followed and it is assumed that pollution embodied in trade is only related to production of the full product in the country of exports. Trade between countries other than the central country is ignored.

2.2.6 Using a GMRIO database at face value

A next option is simply to use a Global MR IO like EORA, WIOD or EXIOBASE at face value. In that case the practitioner simply uses one of the global MR EE IOs to calculate footprints of emissions and resource use per country, as e.g. done by Tukker et al (2014) using V2 of EXIOBASE.

The advantage is obviously that with a ready to use GMRIO the analysis is relatively straightforward and quick. The disadvantage, as indicated, is that virtually all GMRIOs have to adjust national SUT and IOT to arrive at global MR EE SUT in which trade is balanced. For NSIs, it is often difficult to accept the use of national SUT and IOT that differ from their own published data.

2.2.7 Single-country national accounts consistent (SNAC) footprint

Edens et al. (2015) proposed a method for calculating a footprint that is consistent to national (in their case: Dutch) and environmental accounts called a “single-country national accounts consistent” or “SNAC footprint”. They used the WIOD database as in their example. Simply said, in the step before WIOD produced its global MR EE IOT from individual country IOTs, the Dutch IOT from WIOD was replaced by a ‘country national accounts consistent’ EE IOT. Particularly for the Netherlands transit trade and re-export data need to be properly accounted for, something that an NSI simply can do better as research teams like the one producing GMRIOs like WIOD. Once an official EE IOT for the country for which footprints have to be calculated is available, this data is ‘fixed’. Then, the trade linking as applied in WIOD is again applied on the SUT/IOT of the central country and all other countries in the WIOD database – but again, under the constraint that the data of the central country cannot be adjusted.

The advantage is that official statistics are used for the central country for which a footprint is calculated. The disadvantage is that the data available in an existing GMRIO

cannot be used directly, but that the MR EE IO has to be reconstructed with as constraint that the SUT of IOT of the country central in the analysis cannot be adjusted. If for all 40 countries covered by WIOD this procedure would be applied, one would end up with 40 slightly different versions of WIOD, with each version a different country for which data are fixed consistent with national accounts. The underlying problem, that in the end all officially published SUT and IOTs by NSIs lead to an imbalance in trade globally, is not addressed, but hidden.

2.2.8 Single-country national accounts consistent (SNAC) footprints with imports from GMRIO

An alternative to the approach discussed in section 2.2.7 is that the pollution and resource extraction embodied in imports to a country is calculated with an existing Global MR EE IO model, while for the EE SUT / IOT of the country central in the analysis is precisely the one as provided by the NSI. This approach hence avoids that the specific country SUT/IOT has to be embedded in the GMRIO database that is chosen for the analysis, which is a major undertaking. There is just one drawback. In principle exports from the country central in the analysis are not included in the GRMIO analysis anymore, which can lead to errors if the export of components by that country are likely to show up, after traveling through the value chains, in the imports of that country. One can assume this problem may be more significant for big economies as small ones.

2.3 Initial assessment of pro's and con's

An initial assessment of the pro's and con's of each method would use probably the following criteria

- a) Ease of the assessment
- b) Fit with official national statistics
- c) Theoretical reliability
- d) Other advantages and drawbacks.

The assessment is summarized in Table 2.1. The table suggests that methods like the DTA and price-corrected DTA best are not used. Co-efficient approaches have the significant drawback that the global footprint of consumption calculated in this way, is not equal to the territorial global emissions and resource extraction. They further cannot be used for full analyses along the value chain. This drawback is valid for bilateral trade approaches too.

The conclusion is that approaches based on GMRIO probably are best to be used. Using a GMRIO at face value once it is constructed is relatively easy. The disadvantage is that for countries central in the analysis probably other data is used as present in national statistics. Using one of the two 'SNAC' approaches overcomes this, but the SNAC approach as proposed by Edens et al (2015) has as main disadvantage that de facto a GMRIO has to be rebuilt using individual country data underlying the GMRIO, with national statistics (here dubbed: SNAC-GMRIO) A SNAC approach that simply uses pollution and resources embodied in imports is easy to implement (here dubbed: SNAC with imports from GMRIO), but has as theoretical drawback that pollution and resources embodied in exports that come back to a country via imports is neglected.

To make a further choice between methods insight is needed in:

- a) Empirical differences in results between co-efficient and GMRIO approaches
- b) Factors that cause most uncertainty in results of GMRIO approaches, and particularly to what extent deviations from national statistics are relevant
- c) Empirical insight how important the lost 'loop' in SNAC with imports from GMRIO is, i.e. what fraction of the exports of a country end up via global value chains in the imports of a country.

We discuss such issues chapter 4, after having discussed available GMRIO databases in chapter 3.

Table 2.1: Pro's and con's of various ways of dealing with pollution and resources embodied in imports

	Ease of use	Fit with official national statistics	Theoretical reliability	Remark
Co-efficient approaches	Difficult if RMEs unavailable	Good	Unknown. Will cause difference between global extraction /emissions and footprints, which by definition are equal	Misses value chain perspective, less relevant for water and land footprints.
Domestic technology assumption	Easy	Good	Low	Assumption that production abroad is equal to production domestic has empirically shown to be flawed
Price corrected DTA	Medium	Good	Medium	Misses value chain perspective, and differences in production efficiency and emission intensities abroad
Bilateral trade	Medium	Good	Medium	Misses value chain perspective; assumes products made in full in country of exports
GMRIO	Easy	Variable	Good, covers full value chain	Country SUT/IOT in GMRIO may differ from official statistics
GMRIO-SNAC	Difficult	Good	Good, has as advantage official statistics for country central in the analysis is used	GMRIO must be re-built with official statistics for one country
SNAC with imports from GMRIO	Easy	Good	See remark	If exports of the country central in the analysis end up in its imports, theoretically this approach fails.

3 Available MR EE IO databases²

Compiling Global Multi-regional Input Output (GMRIO) databases encounters a number of complexities. First, compiling such a GMRIO database demands a high level of harmonisation and consolidation of different (and frequently conflicting) data sources. Particularly when constructed for the first time this is a laborious job. Second and equally important, GMRIO tables usually rely on (significant) adaptation of statistical data and other estimates³ This need for significant transformation of data originally validated in national statistical systems makes it difficult for the National Statistical Institutes to build GMRIO tables themselves or even participate in their building. With the exception of the OECD, until now supranational organisations did not embark on constructing GMRIO tables either⁴

As a result, such harmonization of national IOTs has usually been done by individual groups in the research community. IDE-JETRO did so for a number of Asian countries and their tables go back to 1975. The GTAP team at Purdue University were pioneers with their global collection of IOTs and corresponding aggregate trade statistics since the 1990s. Being a database built primarily for economic modelling purposes, it initially was not suited for environmental analyses. This changed around 2005 when practitioners started to add emissions as extensions and adapted GTAP in such a way that true EE GMRIO analysis became possible (see e.g. Peters and Hertwich, 2008; Hertwich and Peters, 2009a,b; Davis and Caldeira, 2010; Peters *et al.*, 2011). Such analyses are typically confined to one or two emissions of substances, most notably CO₂, and use the 57 sector detail of GTAP. Somewhat earlier, the OECD combined their harmonized IOTs and bilateral trade database with estimated CO₂ emissions (using IEA statistics) to perform one of the first global assessments of carbon embodied in trade (Ahmad and Wyckoff, 2003). SERI and the GWS used the OECD datasets for creating their Global Resource Accounting Model, GRAM (Bruckner *et al.*, 2012). It is probably fair to say that these efforts created EE GMRIO tables and models through efficient and pragmatic adaptations of readily available building blocks. They however still faced the drawbacks such as limited sector/product detail, lack of consistent time series, or inclusion of just a limited number of extensions.

It is with the aim of tackling the latter problems that projects resulting in databases by WIOD, EXIOPOL and EORA were set up with funding of the EU (WIOD, EXIOPOL) and the Australian Research Council (EORA). More recently the OECD started work its Trade in Value Added (TiVA) database. Table 3.1 reviews characteristics of these databases.

² Section part based on Tukker and Dietzenbacher (2013)

³ Examples are emission data in most countries (which, if available at all, do usually not adopt the same sector classification as applied in the SUTs or IOTs), the countries of origin of imports (which are usually not given in national SUTs/IOTs), differences between trade data in SUTs/IOTs and in the trade statistics, imbalances in trade data (i.e. imports from country X reported by country Y do not equal the reported exports by country X to country Y), differences between countries in the type of SUT/IOT that they compile (e.g. some publish SUTs, other IOTs, which can be of the industry-by-industry or the product-by-product type), valuation differences (e.g. producer's, purchaser's and basic prices), differences in sector and product classifications.

⁴ For instance, Wiedmann *et al.* (2011) express the hope that the so-called 'Group of Four' in the EU (EU DG ENV, Eurostat, EEA, and DG JRC) could be a vehicle for GMRIO development initiated by Europe. For practical purposes, it is in the meantime unclear whether the Go4 will remain active in the future. Another experience is that in a project for Eurostat it proved to be impossible to create even an MRIO table for the EU27 countries due to confidentiality problems, so that eventually an aggregated EU27 EE IOT was constructed (e.g. Eurostat, 2011, Tukker *et al.*, 2013).

Table 3.1.: Review of the main GMRIO databases

Database name	Countries	Type	Detail (ixp)*	Time	Extensions	Approach
EORA	World (around 150)	MR SUT/ IOT	Variable (20-500)	1990-2012	Various	Create initial estimate; gather all data in original formats; formulate constraints; detect and judge inconsistencies; let routine calculate global MR SUT/IOT
EXIOPOL	World (43+RoW)	MR SUT	163-200	1995-2012	30 emissions, 60 IEA energy carriers, water, land, 80 resources	Use COMTRADE/BACI in combination with imports and exports from SUT to create a harmonized trade database, impose trade on national SUT, detail and harmonize national SUT; use global statistics and national SUT as constraints to create time series
WIOD	World (40+RoW)	MR SUT	35x59	1995-2011, annually	Detailed socio- economic and environmental satellite accounts	Harmonize SUTs; create bilateral trade database for goods and services; adopt import shares to split use into domestic and imported use; trade information for RoW is used to reconcile bilateral trade shares; add extensions
GTAP-MRIO	World (129)	MR IOT	57x57	1990, 1992, 1995, 1997, 2001, 2004, 2007	5 (GWP), Land use (18 AEZ), energy volumes, migration	Harmonize trade; use IOTs to link trade sets; IOT balanced with trade and macro-economic data
GRAM	World (40)	MR IOT	48x48	2000, 2004	Various	Use harmonized OECD IOTs; neglect differences like ixi and pxp; use OECD bilateral trade database to trade link.
IDE-JETRO	Asia-Pacific (8: 1975) (10: 1985-2005)	MR IOT	56x56 (1975) 78x78 (1985-1995), 76x76 (2000, 2005)	1975-2005	Employment matrices (2000, 2005)	Harmonize IOTs based on cross-country survey information; link via trade, manual balancing to reduce discrepancies within a certain bounds.
OECD Trade in Value Added / ICOA	World (61 – EU28, G20, other major economies)	MR IOT	34	1995, 2000, 2005 and 2008 to 2011	Value added. Carbon, materials investigated	Based on OECD's harmonized bilateral trade databases and IOTs

* i = number of industries, p = number of products, **

To conclude, there are currently around six main GMRIO databases available. Their main characteristics are summarized in Table 2.1. It concerns:

1. EORA (Lenzen *et al.*, 2012a, b, 2013).
2. EXIOBASE (the database from EXIOPOL, Tukker *et al.*, 2009, 2013)
3. WIOD (Dietzenbacher *et al.*, 2013)
4. GTAP-MRIOT (Peters *et al.*, 2011b)
5. GRAM (EE GMRIO tables on the basis of OECD IOTs, Bruckner *et al.*, 2012, Wiebe *et al.*, 2012a, b)
6. IDE-JETRO's Asian International Input-Output Tables (Meng *et al.*, 2013; currently focusing on the Asian Pacific only, but to be expanded with other main economies in the future, including BRICs economies.)
7. OECD's Trade in Value Added database

All these databases have their own specific strengths and weaknesses.

- EXIOPOL has the highest level of sector detail (of 163 sectors and 200 product groups) applied to all countries covered in its database. This can be advantageous e.g. when analyzing the impacts for agriculture or resource extraction when consumption patterns change.
- IDE-JETRO's AIIOTs, in contrast, offer tables that go back the furthest (1975), with a relatively detailed product classification (76 sectors). Also, non-mechanical, manual handling of data transformation enables a high level of harmonisation among constituent national tables. The weakness, however, is explicit in its small country coverage.
- EORA and GTAP discern considerably more countries specifically than WIOD, EXIOPOL, IDE's AIIOT or GRAM. This has important advantages in assessing impacts of final consumption that take place in relatively poor countries with a low GDP not covered in other databases (Lenzen *et al.*, 2012b) and is also important to attribute impacts to individual countries (as opposed to a large aggregated RoW).
- Overall, with its broad coverage of countries and varying sector detail per country, EORA seems to split up the global economy in most products and sectors and it is the only database that provides uncertainty information for its estimates.
- WIOD, like the OECD TiVA database has a rather aggregated industry classification, in particular for the agriculture and the energy-producing sector where detail is important when it comes to analysing issues on land use, water use, or resource use. On the other hand, WIOD is the only database with a consistent annual time series in both current and previous year's prices, which is highly relevant for analyses (e.g. applications indicate the substantial and instantaneous effect in 2001 of China's accession to the WTO). Also, WIOD is fully consistent with the National Accounts statistics which is important when a link is required to other (socio-)economic data (e.g. for productivity analyses).

4 Empirical evidence about uncertainty in GMRIO footprint calculations

4.1 Introduction

To make a further choice between methods insight is needed in:

1. The added value of aggregated versus disaggregated tables - working with aggregated tables would remove the problem that national tables are adjusted by disaggregation
2. Factors that cause most uncertainty in results of GMRIO approaches, and particularly to what extent deviations from national statistics are relevant
3. Empirical insight how important the lost 'loop' in SNAC with imports from GMRIO is, i.e. what fraction of the exports of a country end up via global value chains in the imports of a country.

4.2 Aggregation errors

For assessing the relevance of using disaggregated versus aggregated SUT and IOT, in the context of DESIRE two papers were written by de Koning et al. (2015.; in prep.). While the relevance of disaggregation was identified earlier by other authors, these studies for the first time looked at a broad range of footprints. The assessments were based on v2 of EXIOBASE and merely analysed the impact of aggregation of extensions, industry sectors and countries on country footprints etc. The differences are hence merely aggregation effects; it does not concern differences due to the use of different, underlying data.

Some illustrative results are provided below.

1. Figure 4.1 shows the impact of the reduction of the product resolution from 200 to 60 products on the country material footprints. Changes are typically in the 2-10% range, with occasionally higher numbers.
2. Figure 4.2 shows again differences in country footprints for carbon, water, land and materials when the resolution in EXIOBASE is reduced from 200, to 60, to 31 and 17 products. We see a number of things
 - a. The differences rise substantially when product resolution is reduced to 31 and further to 17.
 - b. The differences are consistently more prominent for the land, water and materials footprint as for the carbon footprint. This less critical role of carbon was also found by Stadler and Wood (in prep.).
 - c. The differences are limited for value added embodied in final demand, regardless of the aggregation level
3. Figure 4.3 shows the differences in the material footprint of countries when using detailed materials extensions (46 materials categories), versus more aggregated extensions. While for many countries the difference in footprint is below 10%, in several countries this changes the material footprint some 20% or more

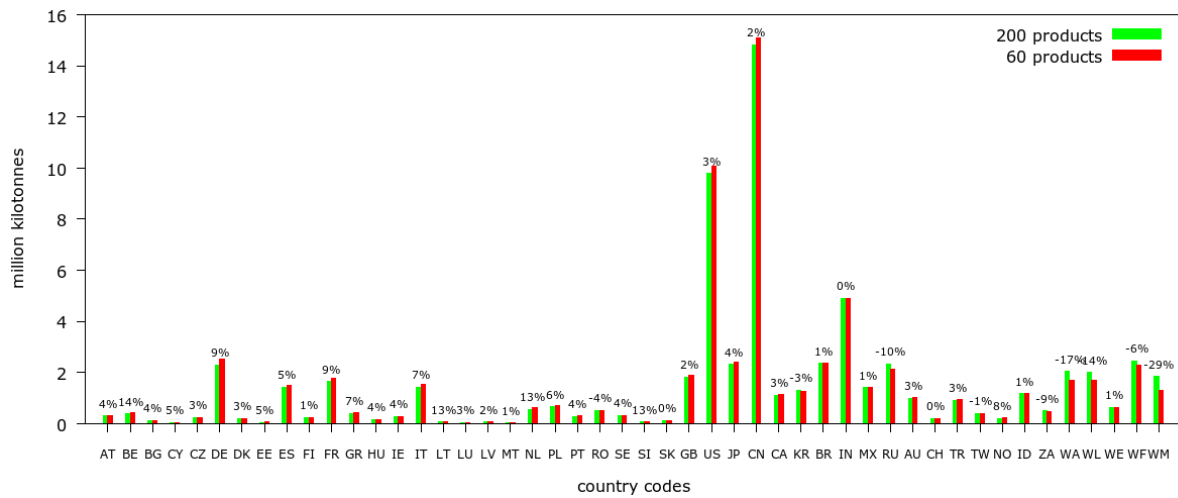


Figure 4.1 (de Koning et al, 2015): Product aggregation scenario: effect of reducing the product resolution from 200 to 60 products on the material footprint of countries. The percentage at the top is the percentage change between the default scenario (green bar) and the product aggregation scenario (red bar).

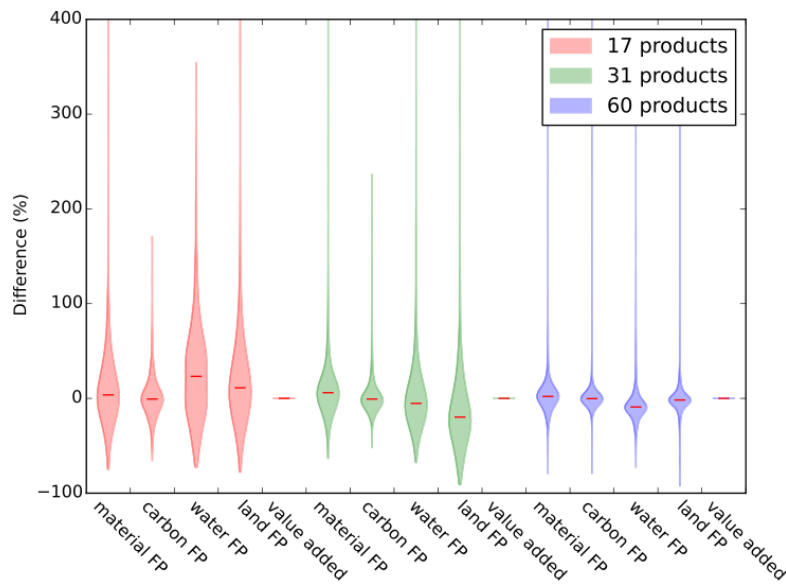


Figure 4.2 (de Koning et al, in prep): Box and whisker plot of the differences between country footprints calculated with the default scenario (detail of 200 products) and the product aggregation scenarios

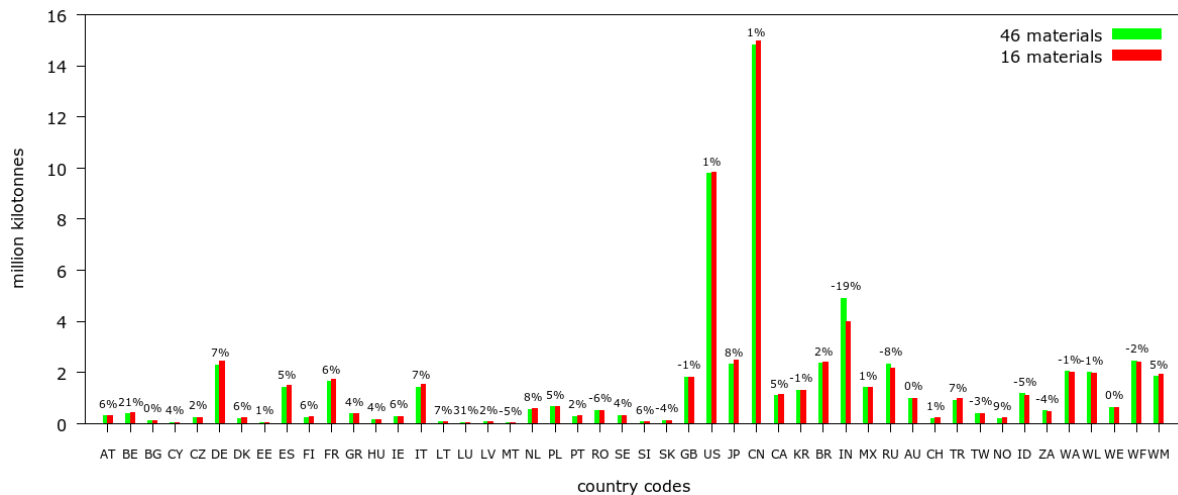


Figure 4.3 (de Koning et al, 2015): Effect of the aggregation of the 46 material categories into the 16 EW-MFA categories on the calculated material footprints of countries/regions. The percentage change between the default scenario and the material aggregation scenario is given at the top of the bars.

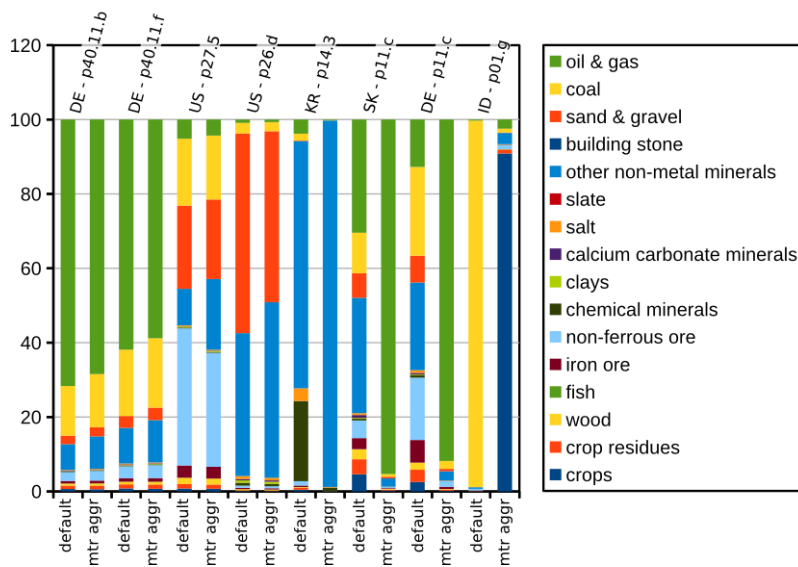


Figure 4.4 (de Koning et al, 2015): Some examples of the effect of aggregation of the 46 EXIOBASE material categories into the 16 EW-MFA categories on the embodied material composition of four different products. p40.11.b = Electricity by gas; p40.11.f = Electricity by petroleum and other oil derivatives; p26.d = Cement, lime and plaster; p27.5 = Foundry work services; p14.3 = Chemical and fertilizer minerals; p11.c = other hydrocarbons; p01.g = plant-based fibers; DE = Germany; US = United States of America; KR = South Korea; SK = Slovak Republic; ID = Indonesia.

4. Figure 4.4, finally, shows the impact of aggregation of material extensions on the calculated % of different embodied materials for specific products and countries. This analysis at specific product level shows clearly that high differences in embodied materials are calculated.

The conclusion of this exercise is fairly straightforward.

1. For any assessment at individual product level rather than country footprint level, detailed tables and material extensions are to be preferred (Figure 4.4)
2. Materials extensions should be as detailed as possible, or at least as detailed as the available sector resolution requires (Figure 4.3)
3. For land, water and materials footprint, a high level of product and sector resolution is essential; in any case databases with lower than 60 sectors or products will show significant aggregation errors. This is probably due to the fact that the land, water and materials intensity of the 200 different products/sectors in EXIOBASE varies significantly. This implies that GMRIOs with a very low sector detail (such as WIOD or the OECD TiVA database, around 30 sectors, and probably also GRAM, 48 sectors) are not well suited to calculate water, materials and land footprints.
4. For carbon, this effect is less pronounced, but still visible. This is probably due to the fact that the carbon intensity of the 200 products/sectors as discerned in EXIOBASE is less pronounced as their land, water and materials intensity. Hence, aggregated databases like WIOD and the OECD TiVA database may still give a good estimate of the carbon footprint of a country.
5. For value added, (dis)aggregation is least relevant. This probably has to do with the fact that any economic sector will have a certain level of profit, depreciation etc. compared to turnover, that will not deviate significantly between sectors. For instance, companies or sectors with negative profits will disappear; companies or sectors with very high profits, say above 10% on turnover, will attract competition bringing profits down. The result is that profits are likely to hover between 0 and 10% of turnover, which is a very low variation compared to e.g. carbon, water, land and materials intensity per sector.

In conclusion, we see that for land, water and material footprint calculation no simplification of GMRIOs in terms of a low sector resolution is possible. It is likely that detailed databases such as EXIOBASE will provide superior results over less detailed databases. For carbon footprints and particularly value added, this sector resolution is less relevant.

4.3 Factors contributing most to uncertainty in footprint calculations with GMRIOs

Most of the GMRIO databases discussed in chapter 2 have been constructed recently. It is only recently that in-depth comparisons have been made between different GMRIO databases, and the factors that cause uncertainty and differences in environmental footprints.

Most of this work has concentrated on CO₂ emissions or greenhouse gases. Peters et al. (2012) highlighted a number of fairly straightforward factors such as:

- a) Fundamental differences in allocation of emissions and resource uses. In a true GMRIO approach, exports from country A to B will embody emissions/resource uses from earlier in the value chain (i.e. the imports of country A). There are however allocation principles that assume that the full embodied emissions in the exports from country A to B are caused by country A⁵. Since we want to allocate emissions and resource uses embodied in trade flows to the country where these are taking place, a GMRIO approach is the way forward.
- b) Using the territorial principle rather than the residential principle. A simple example: petrol is cheap in Luxembourg so a lot of people from neighbouring countries buy petrol in Luxembourg. A territorial approach would see this as consumption in Luxembourg. A residential approach would allocate this consumption and related emissions to the countries whose citizens buy this petrol. For footprint analyses, related to final consumption of (citizens of) countries, we would argue a residential approach is to be followed.
- c) Neglecting bunker fuels and related emissions. For international shipping and aviation transports, companies buy so-called bunker fuels in various countries. Ideally these bunker fuels first are allocated to the country in which a shipping company and airline is based (residential principle), and then further allocated to the countries who make use of the shipping and airline services. Due to the complications of such allocation methods, some practitioners simply neglect the bunker fuels, leading under-representation of carbon emissions and the like in the calculations.

The PhD thesis of Anne Owen (2016) of Leeds University is at this point probably the most comprehensive comparative assessment between three of the major available GMRIO databases, i.e. WIOD, GTAP and EORA. Her thesis did the following analysis:

- She created a 'common (aggregated) classification' of sectors and countries so that a direct comparison between the three databases became possible, the GMRIO matrices now being in an identical format. She further showed that for her case (CO₂ emissions) this aggregation of sectors had limited impact on footprint results (consistent with our findings in the previous sections)
- She then applied matrix difference statistics, structural decomposition analysis, and structural path decomposition analysis to highlight which part of the GMRIO matrices differed most, and which differences lead to the highest differences in country footprints for CO₂.

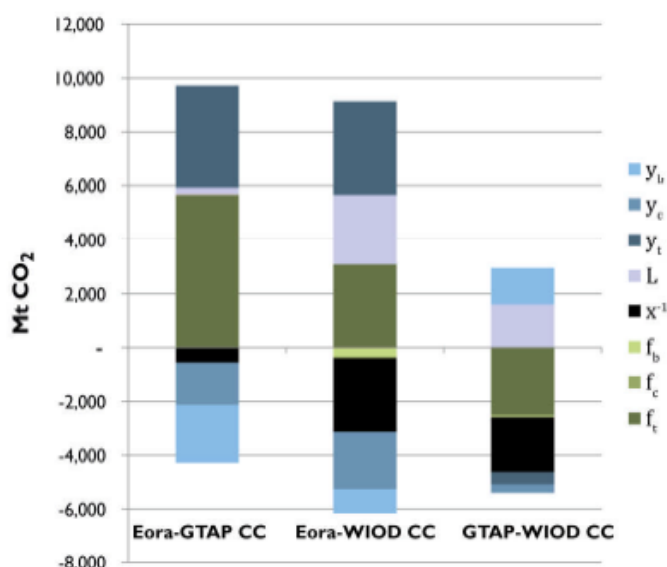
⁵ A similar difference is at stake with the monetary value of exports from A to B. This monetary value is usually NOT only produced country A; the monetary value consists of bits of added value created in country A and the countries from which country A imports.

Her results, reflected by Figure 4.5, are the following.

- The industrial emission totals as estimated in the different databases have the greatest effect on variation between footprints calculated with different databases. This confirms earlier research of Peters et al. (2012) and more recent research by Moran and Wood in the context of the EU FP7 Carbon CAP project (yet unpublished results). It is hence quite interesting to see that a simple data set such as the territorial emissions of CO₂, widely used in climate negotiations, apparently makes the highest contribution to uncertainties in the calculated carbon footprint of nations.
- The total output by region and sector (y_t), and the total final demand per region (x^{-1}) are also important contributors to differences. This is not surprising – if a country in one database has a relatively high final demand compared to the global GDP, this will result in a high share in the global footprint.
- The Leontief matrix is another important contributor to differences, particularly in the comparisons between WIOD and EORA/GTAP. Owen also showed that the structure of the domestic Leontief matrix is most relevant, and not the structure of the off diagonal matrices (trade). Her matrix comparisons showed that in relative terms the matrix differences were highest in the trade blocks, but since the absolute flows are highest in the domestic blocks, differences in the economic structure reflected by the domestic blocks apparently contribute most to uncertainty.

In a comparison of material footprints for Austria, Eisenmenger et al. (2016) confirmed the relevance of using harmonized extensions, see Table 4.1. The difference in domestic extraction for Austria between the EORA database and other databases was no less as 70%, with obvious implications for differences in the calculated material footprints.

Figure 4.5: Decomposition of difference in global emissions for each database pairing (from: Owen, 2016).



With: f_t = total global industrial emissions; f_c = vector or proportion of total global industrial CO₂ emissions that each country's production emissions represents; f_b : vector of proportion of each country's emission that each domestic industry sector represents; x^{-1} = total output by region and sector; L = Leontief matrix; y_b = proportion of the total region's final demand that each global product represents; y_c = proportion of the region's total final demand supplied by each import country. y_t = total final demand of region

Table 4.1: Main Economy Wide Material Flow Analysis indicators for Austria, incl. material extraction data (taken from the supplementary information from Eisenmenger et al., 2016)

Austria, 2007 [1000 t]	DE	DMC	PTB	DE (Eora)
total	173 753	205 854	32 101	101 180
biomass	40 535	41 417	882	34 043
fossil energy carriers	2 408	25 809	23 401	2 411
metallic minerals	2 596	9 611	7 015	2 153
non-metallic minerals	128 214	130 368	2 154	62 572
other products	0	-1 351	-1 351	0

These findings give a number of straightforward suggestions for future harmonization of GMRIO databases:

- a) Ensure that basic principles with regard to allocation (true GMRIO), using a residential instead of a territorial approach, and accounting for all activities/emissions and resource uses (rather than neglecting e.g. bunkers) are applied.
- b) Harmonize extensions like CO₂ emissions, other emissions, resource extractions, water use and land use between databases, which is likely the single biggest cause for differences in calculated country footprints.
- c) Ensure further that total final demand and total product output by country form the same share of global GDP.
- d) Ensure that the domestic / national IO matrix is sound, i.e. having an as good as possible fit with official statistics.

Particularly points a) and b) are relatively easy to implement, with significant reductions in uncertainty of footprints.

4.4 Assessment of 'feedback emissions'

Recent research in the context of a project UL-CML, NTNU and others executed in parallel to DESIRE, using however also EXIOBASE, analysed the following interesting question. In a GMRIO, each country has exports and imports. In principle, the exports of a country (particularly in the form of primary materials and intermediate products) may be used to make finished products in other countries in the value chain, and then turn back to the original country as part of a finished product, etc. So, in principle it is possible that the embodied emissions and resource uses in the exports of country A, to some extent come back in the form of imports to this country A. This is an important issue in relation to the question of how to simplify the analysis of pollution embodied in imports of a country.

Simply said, if such 'feedback emissions' are small, it would be simply be possible work as follows:

- Take the official SUT/IOT for a country including official import/export data and the official national emission data and resource extractions as a starting point.
- Calculate with an appropriate available GMRIO the emissions and resource extractions embodied in imports
- Use 1) and 2) to calculate the resource and emission footprint of a country.

This has the advantage that for the data of the country central in the assessment the official statistics can be used, and that the pollution and resource use embodied in imports can be performed without creating a full GMRIO in which that country's official statistics are embedded. The calculation of pollution and resource extraction embodied per Euro imports simply can be calculated with any available GMRIO separately. These footprints of imports then can be multiplied with the official statistics with regard to value of the imports. In this way, a very simple 'SNAC' procedure can be performed that avoids the complicated re-building of a GMRIO. The main problem in this approach could be that the exports from the country central in the analysis have different values in the GMRIO as in the official statistics. If however just a fraction of the exports feed back into the imports, this gives just a minor error.

In a paper submitted to Economic Systems Research, Moran et al. (2016) did an assessment of such feedback emissions per country, using EXIOBASE v3 for 2012. The results are presented in Table 4.2 below. The results are illuminating. For virtually all countries, the 'feedback emissions' are 1% or less. The exceptions are Germany (2.4%), Japan (1.4%), China (14.9 %) and the US (5.7%). We would argue that only for China and the US neglecting the feedback loops caused by their exports may lead to relevant errors in assessing the footprints of their imports. For the vast majority of the countries, it hence seems feasible to apply what we dubbed the 'SNAC with imports from GMRIO' approach: using single-country national accounts consistent (SNAC) information for the national economic structure and environmental pressures, and pollution embodied in imports calculated with a GMRIO.

Table 4.2: Feedback emissions (fraction of the embodied emissions in imports originally emitted in the country, i.e. exports feeding back into imports) as calculated with EXIOBASE V3, for 2012 (Moran et al, submitted).

	Feedback emissions		Feedback emissions
Austria	0.2%	Slovenia	<0.1
Belgium	0.2%	Slovakia	0.1%
Bulgaria	0.1%	UK	0.5%
Cyprus	<0.1	USA	5.7%
Czech Republic	0.4%	Japan	1.4%
Germany	2.4%	China	14.9%
Denmark	0.1%	Canada	1.6%

Estonia	<0.1	South Korea	1.0%
Spain	0.5%	Brazil	0.5%
Finland	0.1%	India	1.1%
France	0.5%	Mexico	1.1%
Greece	0.2%	Russia	2.7%
Croatia	<0.1	Australia	0.5%
Hungary	0.1%	Switzerland	0.1%
Ireland	0.1%	Turkey	0.2%
Italy	0.5%	Taiwan	0.6%
Lithuania	<0.1	Norway	0.1%
Luxembourg	<0.1	Indonesia	0.4%
Latvia	<0.1	South Africa	0.7%
Malta	<0.1	Rest of Asia/Pacific	2.4%
Netherlands	0.4%	Rest of America	0.8%
Poland	0.5%	Rest of Europe	1.2%
Portugal	0.1%	Rest of Africa	0.4%
Romania	0.1%	Rest of Middle East	1.5%
Sweden	0.1%		

5 Summary, conclusions and recommendations

5.1 Introduction

Due to the rising importance of international trade, emissions and resource extractions at national level usually do not reflect the emissions and resource extractions needed for satisfying the final demand in a country. National and supra-national environmental and statistical agencies (like Eurostat and the European Environment Agency) hence are interested in calculating the 'footprint' of final consumption in their country/region, including emissions and resource extraction abroad.

Chapter 2 reviewed a number of approaches for assessing such footprints. The use of Global Multi-regional Environmentally Extended Input Output databases is probably the most versatile and consistent approach⁶:

1. Full value chains are covered, and it is possible to assess in which countries pollution and resource extraction embodied in trade takes place;
2. There is consistency between the production perspective and consumption perspective (i.e. total emissions and resource extraction by all economic sectors in all countries globally equals the footprints of final demand)

Compiling Global Multi-regional Input Output (GMRIO) databases however is not a panacea. First, compiling such a GMRIO database demands a high level of harmonisation and consolidation of different (and frequently conflicting) data sources. Particularly when constructed for the first time this is a laborious job. Second and equally important, GMRIO tables have no option but to adapt (sometimes significantly) official statistical data from National Statistical Institutes (NSIs). One key reason is that all imports as reported in national IO tables published by NSIs, do not match the total of exports in these tables. Since obviously at global level trade must be balanced, practitioners building GMRIOs have no option but to override NSI data. Also since NSIs just have a national mandate, until now almost all GMRIO databases have been built by (consortia of) scientific institutes. Such databases include WIOD, GTAP, GRAM, EORA, and EXIOBASE. Only the so-called Trade in Value Added (TiVA) database has been built by a supranational organisation, i.e. the OECD.

The above leads to three pertinent questions. The first is: can GMRIO construction be simplified, e.g. by reducing sector resolution? The second one is: how can we reduce uncertainty in footprint analysis with GMRIOs? The final one is: how can we move forward to the calculation of footprints with a 'statistical stamp'?

⁶ For water and land footprints, the so-called co-efficient approach probably still is workable, since they are mainly related to agricultural production. It is unlikely that for the production of agricultural products in a specific country there are still major parts of preceding value chains in other countries. Brückner et al. (2015) suggest for land use hybrid approaches to combine the strength of both methodologies.

5.2 Potential for simplification and improvements of GMRIOs

5.2.1 Reducing sector detail

Our analysis in section 4.2 gives a simple and straightforward answer on the question if construction of GMRIO tables can be simplified. We found that if the GMRIO tables are used for economic purposes, such as assessment of trade in value added, an aggregated sector structure as e.g. in the OECD TiVA of 30 sectors is quite appropriate. For carbon footprint analyses, aggregated databases like WIOD or GRAM probably also will still give reliable answers.

Our analysis showed however as well that when calculating water, material or land footprints, a high level of disaggregation is essential. Aggregating EXIOBASE to 60 or less sectors, led to clear changes in country footprints. If one wants to look even deeper, e.g. at the level of the environmental footprint of specific product groups, detail certainly is essential. The reason behind this is simple: the material intensity, water intensity and land intensity of specific product categories/industry sectors varies much more than e.g. the carbon intensity or the created value added.

The conclusion is obvious. If one wants to do a broad, comprehensive assessment of environmental footprints of nations that includes emissions, water, land and resources, a detailed GMRIO must be used. Aggregated databases such as WIOD, the TiVA database, and probably GRAM and GTAP, are not suitable for this.

5.2.2 Harmonizing GMRIOs and reducing uncertainty between GMRIOs

Chapter 4.3 showed that, surprisingly, some simple factors currently cause the main differences in country footprints calculated with different MRIOs. It concerns differences in allocation principles, definitions, using different databases for extensions, and the like. Many of such differences can be corrected relatively easily. It concerns:

- a) Ensure that basic principles with regard to allocation (true GMRIO), using a residential instead of a territorial approach, and accounting for all activities/emissions and resource uses (rather than neglecting e.g. bunkers) are applied.
- b) Harmonize extensions like CO₂ emissions, other emissions, resource extractions, water use and land use between databases, which is likely the single biggest cause for differences in calculated country footprints.
- c) Ensure further that total final demand and total product output by country form the same share of global GDP.
- d) Ensure that the domestic / national IO matrix is sound, i.e. having an as good as possible fit with official statistics.

Particularly points a) and b) should be relatively easy to implement across the major GMRIO databases such as WIOD, EORA, GTAP and EXIOBASE, with significant reductions in uncertainty of footprints.

5.2.3 Creating footprint data with a 'statistical stamp'

As indicated, one of the main problems of using any of the currently available GMRIOS, is that they usually by necessity must deviate from official National statistics. There are two routes to overcome this.

One: the Royal route. The main reason why GMRIO practitioners override national statistics is due to the fact that trade data, as reported by NSIs, are in fact not mutually consistent if one looks at global scale. NSIs until now probably were not fully aware of this, simply since most GMRIOS that make such inconsistencies explicit only have been constructed recently. The fundamental solution of this problem is obvious. Within the context of e.g. the UN Commission of Economic and Environmental Accounts (UN CEEA), the NSIs in the world should collaborate and organise a data exchange platform that allows NSIs to end up with SUT, IOT, and trade data that is mutually consistent between countries. This however is likely to be a long-term endeavour, unlikely to give results that can be used operationally in the coming 5 years.

Two: using the "Single-country national accounts consistent (SNAC)" footprint approach. This approach, as suggested by Edens et al. (2015), works as follows:

1. Take an existing GMRIO
2. Use for the country for which the footprints have to be calculated the IO data and extensions from existing national accounts
3. 'Plug in' these national accounts data in the GMRIO, fix them, and rebalance the total GMRIO in such a way that in the resulting GMRIO the country for which footprints have to be calculated data fit precisely with national accounts.
4. Use this 'SNAC GMRIO' to calculate the footprint of consumption.

The main drawback of this approach is that step 3 has to be performed, which is quite laborious. In section 4.4 we found that for the vast majority of countries the exports they produce, hardly show up back (via international value chains) in their imports. Or, otherwise stated, the pollution and resources embodied in imports can be calculated without taking into account that countries' exports. The only exceptions are the US and China, with feedbacks of 5.7% and 14.9% in 2012 respectively. This finding allows simplifying the SNAC approach considerably:

1. Take an existing GMRIO
2. Use for the country for which the footprints have to be calculated the IO data, import volumes and extensions from existing national accounts
3. Calculate emissions and resource use embodied in imports with the GMRIO and use this in combination with 2 to calculate the footprint of consumption.

A further refinement of this approach could be the following. Currently, most GMRIOS are produced by scientists and hence lack a 'statistical stamp'. The only GMRIO that goes beyond this is the TiVA database of OECD, that is produced by a supra-national organisation. The TiVA database however is with just 30 sectors far too aggregated to be of use of calculating water, materials, land and emissions footprints. A way forward here however could be:

1. Use the OECD TiVA database as a starting point, which provides a trade-balanced GMRIO for some 60 countries at global scale.
2. Use the detailing procedures as developed particularly for EXIOBASE, and the optimization procedures as developed for EORA, to detail the TiVA database to a

level that is appropriate to perform proper footprint analyses (100-200 industry sectors)

3. Develop harmonized data sets for carbon emissions (e.g. based on IPCC or IEA energy flows plus emission factors), materials (e.g. the recently published UNEP International Resources Panel), land and water, and add these to the more detailed TiVA database.

In this way, a database could be created that at an aggregated level has the 'statistical stamp' provided by the OECD, uses extensions that are harmonized / commonly accepted, but also can provide higher level detail information (a procedure backed by a number of credible, scientific institutes). This would, for the first time, give a GMRIO that probably has a higher level of credibility as the individual scientific databases such as WIOD, EXIOBASE, GTAP or EORA. If such a database that holds a middle ground between official statistics and scientific work is available, a good compromise GMRIO database is readily available for any NSI or practitioner to be used.

5.3 Overall conclusions and recommendations

To conclude, the calculation of environmental footprints is best based on the principle of Global Multi-regional Environmentally Extended Input Output databases (GMRIOs). Approaches like the Domestic Technology Assumption and co-efficient approaches have clear drawbacks. GMRIOs in contrast cover the full value chains through the global economy and create the required consistency between the global footprint of consumption and the total emissions and resource use of production.

The main problem is that production of GMRIOs is a lot of work. Further by necessity GMRIOs override the national accounts since these national accounts for all countries together are not consistent at global level: global imports and exports do not match. We further found that particularly for calculating e.g. water, land and materials footprint, a high level of detail of the GMRIO of 100-200 sectors, particularly in agriculture, energy extraction and mining is essential to avoid significant aggregation errors.

To overcome this situation, we recommend the following.

On the **long term**, bodies such as the UN Commission on Environmental and Economic Accounts (UN CEEA) should work with NSIs to make national accounts, and particularly import and export data consistent at the global level. While practitioners may be 'accused' that they overwrite national accounts data when they create a balanced GMRIO, the fundamental cause is this inconsistency of NSI data at the global level. Only NSIs are in the position to deliver data with a statistical stamp, but that also are consistent at global level. Ideally they should use the experiences from the GMRIO practitioners to identify the most pressing inconsistencies at international level, as input to the continuous improvement processes they already apply in their regular data inventory and reconciliation work.

On the **short term**, basic harmonization of the existing GMRIOs constructed by scientists could be realised as follows. First, a number of fairly simple agreements should be made on the basis of footprint accounting (i.e. using a true GMRIO approach rather than other

allocation mechanisms; taking the residential principle as a starting point; and avoiding neglecting emissions or resource uses related to e.g. international bunkers). Furthermore, harmonized databases for extensions should be developed or used, such as the resource extraction database recently developed by the UN International Resources Panel (IRP). Here, particularly work on water, land and emission extensions remains. It is likely that such simple measures will reduce the differences in calculations of footprints of nations with different databases with over 50%.

A further step towards a higher level of credibility of GMRIO database could be made as follows. The OECD produces currently the TiVA GMRIO, which has a (too) high level of aggregation of 30 sectors, to do footprint analyses. Using procedures developed for EXIOBASE and EORA, TiVA could be detailed to an appropriate level for footprint analyses, and combined with the aforementioned, common extension databases⁷. This would lead to a GMRIO database with an appropriate level of detail, but in which important elements (the structure at the level of 30 sectors globally, and extensions) are harmonized and endorsed by important organisations such as the OECD and UN IRP.

Finally, the problem that even such a GMRIO overrides national accounts data can be overcome by applying the 'simplified SNAC' procedure described in the former section. This simplified SNAC procedure can be applied for all countries that have limited 'feedback emissions' (i.e. emissions and resource use in their exports, that via global value chains appear also in their imports). This is the case for almost all countries except China and the US. The procedure would work as follows

1. Take the semi-harmonized/semi-official GMRIO indicated above (or any other GMRIO deemed appropriate)
2. Use for the country for which the footprints have to be calculated the IO data, import volumes and extensions from existing national accounts
3. Calculate emissions and resource use embodied in imports with the GMRIO and use this in combination with 2 to calculate the footprint of consumption.

With a semi-standardized GMRIO available, combined with available national accounts data, in this way the calculation of country footprints should be a rather straightforward exercise⁸.

⁷ In this, we assume the TiVA database is using also harmonized data that ensure the GDP or final demand in a country is a sound representation of the % of the global GDP, another factor that can influence footprint calculations significantly (see chapter 4.3)

⁸ For water and land, combining detailed physical statistics of e.g. FAOSTAT and land use and water use coefficients, in combination with MR EE IOs, will lead to a hybrid approach that may be the best of both worlds (see e.g. Brückner et al., 2015). Creating a comprehensive hybrid database is work for the future though. As an intermediate step, the approach of e.g. Ewing (2012), Steen Olsen et al. (2012) and Weinzettel et al. (2013, 2014) may be followed: setting up physical satellite accounts measuring water and/or land use related to agricultural products., and link this satellite account to a GMRIO. This approach was for instance followed in the FP7 CREEA project where a satellite account with detailed water use per river basin per crop type was constructed, and linked to the detailed EXIOBASE GMRIO.

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Annexes

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1. Arjan de Koning, Martin Bruckner, Stephan Lutter, Richard Wood, Konstantin Stadler, Arnold Tukker (2015). Effect of aggregation and disaggregation on embodied material use of products in input-output analysis. *Ecological Economics*, *Ecological Economics* 116 (2015) 289–299
2. Arjan de Koning, Konstantin Stadler, Stephan Lutter, Martin Bruckner, Stefan Giljum, Richard Wood and Arnold Tukker (2016). The effect of aggregation in supply-use tables on calculated footprints (in preparation – can be obtained from the first author at koning@cml.leidenuniv.nl).
3. Nina Eisenmenger, Anke Schaffartzik, Dominik Wiedenhofer, Stefan Giljum, Martin Bruckner, Heinz Schandl, Thomas O. Wiedmann, Manfred Lenzen, Arnold Tukker, Arjan Koning (2016). Consumption-Based Material Flow Indicators – Comparing Six Ways of Calculating the Austrian Raw Material Consumption Providing six Results. *Ecological Economics*, Volume 128, August 2016, Pages 177–186
4. Stefan Giljum, Hanspeter Wieland, Stephan Lutter, Martin Bruckner, Richard Wood and Arnold Tukker (2016). Identifying priority areas for European resource policies: a MRIO-based material footprint assessment. Accepted for publication, *Journal of Economic Structures (JECS)*, special issue “MRIO for global resource policy”, accepted
5. Martin Bruckner, Günther Fischer, Sylvia Tramberend, Stefan Giljum (2015). Measuring telecouplings in the global land system: A review and comparative evaluation of land footprint accounting methods. *Ecological Economics* 114 (2015) 11–21
6. Konstantin Stadler, Richard Wood (in prep). Exploring resource efficiency through individual supply chains - precision and accuracy in analysing the impacts of apparel (in preparation – can be obtained from the first author at Konstantin.stadler@ntnu.no)