Further Development of Material and Raw Material Input Indicators – Methodological Discussion and Approaches for Consistent Data Sets

Input paper for expert workshop

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Table of contents

List of tables and figures

1 AP 1.1 – Background study – review of existing approaches

1.1 Executive Summary

The **present report** is part of an ongoing project of UBA Germany on **further development of material use indicators**. It is reviewing the current state of the art with respect to the feasibility of calculating more comprehensive indicators as those currently in use.

Material use indicators build on the concept of **(Economy-Wide) Material Flow Analysis (EW-MFA)** as standardised by Eurostat and recognised by the OECD. MFA constitutes a description of the economy in physical units, more specifically, in mass units of inputs and outputs of the national economy. On the basis of EW-MFA data a **large number of indicators** can be calculated – all of them quantifying environmental pressure; some of them take a fully territorial perspective, i.e. Domestic Extraction Used (DEU); others including the direct mass of imported and exported products, i.e. Domestic Material Input (DMI) or Domestic Material Consumption (DMC).

DMC is currently the most widely used material flow-based indicator and is at the core of national statistical reporting to and by Eurostat. In recent years, the necessity to apply more comprehensive indicators on a broad basis has been articulated by a large number of stakeholders, including policy makers (for example, in the context of the "Roadmap to a Resource Efficient Europe"), civil society as well as scientists. The main point of critique on the **DMC indicator** is that domestic material extraction and imports/exports are not accounted on the same basis, as **indirect (or embodied) materials of imported (and exported) products are not considered**. It thus allows countries to reduce their apparent national material consumption and improve their resource productivity by shifting material-intensive industries or processes to other countries and substituting domestic extraction by imports.

As a response, different methodological concepts have been developed which aim at calculating **indicators that embrace direct as well as indirect material flows** related to international trade (e.g. RMI – Raw Material Input, or RMC – Raw Material Consumption). RMI and RMC account both domestic resource extraction and imports/exports on a comparable basis, by transforming direct imports and exports into so-called Raw Material Equivalents (RMEs). Beyond RMI and RMC, there are even more comprehensive indicators which incorporate also so-called unused domestic extraction (UDE; e.g. overburden and parting materials from mining, by-catch from fishing) related to materials extracted domestically as well as to the RMEs of traded goods (TMR – Total Material Requirement, and TMC – Total Material Consumption).

When discussing the use and expressiveness of specific material flow indicators it is essential to bear in mind the policy question which shall be answered by using specific indicators. Further development of MFA-based indicators towards reflecting the global consequences of national production and consumption is important, but it does not mean that the established DMI/DMC indicators are no longer useful. **DMC is a widely accepted MFA indicator**, in particular in statistical institutions, as it can to a large extent be constructed based on official national production and trade statistics. DMC data have thus been compiled for a much larger number of countries, with much longer time series and from a large variety of statistical and academic institutions compared to other more complex indicators, which consider upstream material flows of imports and exports and often build on modelled data, such as Raw Material Consumption (RMC). Further, DMC has a significant relevance as an indicator of potential environmental pressure on the domestic territory. Finally, when designing national strategies for resource management, DMC and its components are easier to address by governments compared to indicators which include material flows in other countries along the supply-chains of imported products and thus require international policy cooperation.

Generally, the **calculation of comprehensive material use and productivity indicators** can be carried out with **three different methodological approaches**: various forms of economic-environmental input-output analysis, coefficient approaches based on process analysis, and hybrid approaches combing elements from both basic approaches. For each methodology the team identified the main models, and for each of them the major scientific publications of the last years were considered in the review. Also for each publication the data source for the underlying material flow data was identified. The different models in use were evaluated according to criteria groups covering methodological as well as data aspects, such as avoidance of double counting or availability of time series.

The review revealed **specific advantages and draw backs for each of the three approaches**; hence, no “ideal” approach to calculate comprehensive material input and productivity indicators has so far been identified. Additionally, experiences show that a direct comparison of calculation results among different methodologies is not straight forward, as basic data applied in the methodologies differ and classifications are not the same, e.g. regarding the level of product detail. Therefore, various adaptation steps have to be carried out, in order to make the indicators directly comparable; and exercise, which has hardly been undertaken so far. In this context, one additional aim of the evaluation also was to analyse which approach has the highest potential for the future, provided that the identified disadvantages are eliminated.

The analysis showed that **input-output approaches as well as hybrid approaches** are constantly further developed by various groups in academia and statistics, while approaches fully relying on coefficients are scarce in the current literature.

The following table summarises the key advantages and disadvantages of each of the three main approaches according to different aspects of analysis.

Table 1: Key advantages and disadvantages of the different approaches to calculate comprehensive material input and productivity indicators

Topic	Input-output approaches	Coefficient approaches	Hybrid approaches
Coverage of whole product supply chain	+ Full coverage of supply chains of all products / product groups, as the whole (global) economy sets the boundary for the assessment - Use of monetary use structures of industries and product groups to allocate material extraction to final demand via supply chains, which differ from physical use structures, in particular for raw materials, leading to distortions in the results	- High level of effort to construct solid coefficients for highly processed products, thus availability of coefficients for finished products with highly complex supply chains very restricted	+ In some hybrid approaches: Better reflection of flows of materials through an economic system through creation of mixed-unit tables through integration of physical use data + Exploiting the complementary strengths of input-output analysis (coverage of supply chains) and coefficient approaches (high resolution for key products), thus producing very accurate results in terms of comprehensiveness and preciseness
Avoidance of double counting	+ Avoidance of double counting as supply-chains clearly distinguished from each other	- Double-counting possible in case products are passing more than one border in one or different process stages	See advantages and disadvantages of two basic approaches
System boundary / cut-off level regarding secondary effects	+ Calculating material footprints for all products and all sectors, also those with very complex supply chains – avoidance of “truncation errors”, as all indirect effects are covered + Precise definition of system boundaries	- Truncation errors, as indirect material requirements not traced along entire industrial supply chains - Underestimation of total environmental consequences of national economy, as life-cycle data for services are largely missing and infrastructure inputs are often neglected	See advantages and disadvantages of two basic approaches
Potential for modular expansion to calculate indicators at different levels (direct/indirect use, used/unused)	+ IO approaches allow calculating indicators at different levels of detail – results include indirect uses, and calculations can be expanded by data on unused extraction to calculate also TMR and TMC indicators.	+ Coefficient approaches allow calculating indicators at different levels of detail – results include indirect uses, and calculations can be expanded by data on unused extraction to calculate also TMR and TMC indicators.	+ Hybrid approaches allow calculating indicators at different levels of detail – results include indirect uses, and calculations can be expanded by data on unused extraction to calculate also TMR and TMC indicators.

Topic	Input-output approaches	Coefficient approaches	Hybrid approaches
Specification of consumption	+ Disaggregation of comprehensive material consumption indicators by different categories of final demand (e.g. private consumption, government consumption, investment, etc.) + Disaggregation of indicators by industries or product groups contributing to overall RMC or TMC + Disaggregation by material group	- Only disaggregation by material group, as concept of "apparent consumption" (i.e. intermediate plus final consumption) is applied	+ Disaggregation of comprehensive material consumption indicators by different categories of final demand (e.g. private consumption, government consumption, investment, etc.) + Disaggregation of indicators by industries or product groups contributing to overall RMC or TMC + Disaggregation by material group
Regional/country detail	+ In the case of multi-regional models: full consideration of different material intensities in a large number of countries	- Limited national differentiation for coefficients regarding countries of origin	- Approaches only applied for a small number of countries and aggregated EU with very limited comparability; even pilot data are missing for many countries. - All hybrid approaches so far apply the "Domestic Technology Assumption" for a large number of imports, thus creating mistakes. No MRIO hybrid approach tested so far.
Level of sector/product coverage	- Assumption of a homogenous product output for aggregated economic sectors and product groups, leading to distortions of results, in particular when price to weight ratios are very different for various products aggregated into one sector	+ Very high level of product detail, as coefficients can be calculated for a large number of single products + No restrictions of sector or product group definition, as products can be aggregated according to any selected classification	See advantages and disadvantages of two basic approaches.
Source, credibility and transparency of data	+ Accounting framework closely linked to standard economic and environmental accounting. - Procedures for manipulating IO tables, e.g. for disaggregating existing tables or harmonizing IO tables from different national sources, often not well documented.	- No consistent database for material intensity coefficients available so far; coefficients vary with regard to quality and transparency	+ Large control over input data, as material flow data as well as trade and input-output data can be taken from official national statistics + High acceptance especially among European statistical institutions - No consistent database for material intensity coefficients available so far; coefficients vary with regard to quality and transparency

Topic	Input-output approaches	Coefficient approaches	Hybrid approaches
Data availability / quality	- Quality of data for input-output tables of particularly non-OECD countries often difficult to evaluate	- Coefficients mostly available only for one point in time and hence do not reflect technological improvements	- Approaches which developed mixed-unit input-output tables used detailed and unpublished data from the German statistical office and Eurostat, limiting the replicability.

This shows that, in order to make comprehensive material flow-based indicators more robust and comparable, most scientific work will be needed in the near future in the **compilation of a comprehensive, quality-checked and up-to-date database on material inputs or "raw material equivalent" coefficients**. The task is challenging because material inputs differ significantly among materials and products, countries and over time. Metal ore grades change between deposits and over time; production technologies applied differ between countries and even within countries over the years due to technological advances. However, for a meaningful analysis of material requirements related to final consumption this level of detail and international harmonisation is imperative.

Another key aspect for further development is the **harmonisation of available international data bases for input-output tables and bilateral trade data**. So far, different approaches use different economic databases for their calculations, which lead to significantly differing results e.g. for the RMC indicator, even if the material input data were the same. This is because the economic information in input-output tables is not consistent across various sources. It would therefore be important that input-output tables and trade data are being reviewed and harmonised by international organisations, such as the OECD and the UN, in order to reduce the variance of results and thus contribute to the acceptance of comprehensive MFA-based indicators in policy making.

1.2 Introduction

The present report is embedded in an ongoing project of UBA Germany and is trying to accommodate the demand for more comprehensive indicators by reviewing the current state of the art with respect of the feasibility to calculate such indicators.

The concept of Material Flow Analysis (MFA) as standardised by Eurostat (EUROSTAT, 2013) and recognised by the OECD (2007) constitutes a description of the economy in physical units, more specifically, in mass units of inputs and outputs of the national economy respectively. "Economy-wide material flow accounts (EW-MFAs)" are compiled and submitted to Eurostat by Member States on a regular basis.

On the basis of the data system of EW-MFAs a large number of indicators can be calculated (EUROSTAT, 2001; Femia and Moll, 2005; OECD, 2007). Some of them take a fully territorial perspective, i.e. Domestic Extraction Used (DEU). DEU accounts for the domestically extracted materials in "Raw Material Equivalents (RME)", i.e. the overall mass entering the economic system; for instance, in the case of metal ore extraction, the crude ore of a metal is accounted, not only the net metal content.

Other indicators include the direct mass of imported and exported products, i.e. Domestic Material Input (DMI; DEU plus direct imports) or Domestic Material Consumption (DMC; DEU plus direct imports minus direct exports). It is important to state that in DMI and DMC domestic extraction (DEU) is accounted for in RMEs while imports and exports are measured in their actual mass. Hence, the indirect flows associated with imported products (e.g. the metal ore needed to extract a metal incorporated in a traded product) are not taken into account.

DMC is currently the most widely used material flow indicator and is at the core of national reporting to and by Eurostat. Also, the Commission's "Roadmap to a Resource Efficient Europe" (European Commission, 2011) identifies GDP/DMC as the headline indicator for measuring resource productivity. The DMC indicator is also widely available outside Europe, including for the OECD countries (OECD, 2011), the Asian and Pacific region (Giljum et al., 2010; Schandl and West, 2010; UNEP, 2013a), Latin America (Russi et al., 2008; UNEP, 2013b; West and Schandl, 2013) and Africa (UNCTAD, 2012). Also, several studies provided comparative assessments of DMC across all countries world-wide (Dittrich et al., 2012b; Giljum et al., 2014; Steinberger et al., 2010; Steinberger et al., 2013).

In recent years, especially in the course of the public consultation process of the Roadmap, the necessity to apply more comprehensive indicators on a broad basis (e.g. integrating them into the Roadmap) has been articulated by a large number of stakeholders – equally by policy makers and civil society as well as by scientists. The main point of critique on the DMC indicator is that domestic material extraction and imports/exports are not accounted on the same basis, as indirect (or embodied) materials of imported (and exported) products are not considered (see above), thus countries can apparently reduce their national material consumption and improve their resource productivity by dislocating material-intensive industries and substituting domestic extraction by imports.

As a response to the demand for indicators, which are robust against dislocation of environmental burden and reflect the true global material flows related to the consumption in a country, different methodological concepts have been developed which aim at calculating indicators which embrace direct as well as indirect material flows related to international trade. Examples for such indicators are RMI (Raw Material Input) and RMC (Raw Material Consumption). For these indicators the mass of imports as well as of imports and exports respectively are accounted for in terms of RMEs; hence including the quantities of DEU which were necessary along the value chain to produce the traded product.

Beyond RMI and RMC, there are still more comprehensive indicators which incorporate also the so-called unused domestic extraction (UDE) related to materials extracted domestically as well as to the RMEs of traded goods. UDE is defined as materials moved in the course of material extraction that never enters the economic system. UDE comprises overburden and parting materials from mining, by-catch from fishing, wood and agricultural harvesting losses, as well as soil excavation and dredged materials from construction activities (see box in Chapter 4). The material input indicator including unused extraction is Total Material Requirement (TMR) and the related consumption indicator Total Material Consumption (TMC).

When discussing the use and expressiveness of specific material flow indicators it is essential to bear in mind the policy or research question which has to be answered. Further development of MFA-based indicators towards reflecting the global consequences of national production and consumption is important, but it does not mean that the established DMI/DMC indicators are no longer useful.

While DEU gives an insight on pressures put on the local (i.e. national) environment brought about by the extraction of biotic and abiotic raw materials, DMC should rather be seen as a potential pressure indicator than as a resource use indicator, as it comprises all materials that are directly used in the domestic economy and thus contribute to a country's environmental pressures on the material output side in terms of waste and emissions (Marra Campanale and Femia, 2013). Hence, the DMI/DMC indicators reflect material flows, which actually occur within the territory of a country. Therefore, when designing strategies for resource management, DMC and its components will be easier to address by national governments, compared to material flows which occur in other countries along the supply-chains of imported products where policy design requires action in the consuming as well as in the producing countries. Consequently, for elaborating national strategies for reducing material consumption and increasing material productivity, the DMI/DMC indicators will keep playing an important role in the future.

In contrast, only indicators which take into account all direct and indirect flows (i.e. trade flows in RME) can give a comprehensive picture regarding a country's global material requirements, as omitting these indirect flows allows for improving the material balance by shifting extractive industries (and related environmental) burdens to other countries (see above). GDP/RMC includes material flows outside the national boundaries and thus is an indication of the resource productivity related to final consumption in a country. TMR and TMC as most comprehensive indicators draw a picture of the overall pressure created by extracting and directly and indirectly using and consuming materials, including pressures generated by the unused extraction of raw materials.

The policy questions asked differ and are often not clearly defined, and the different indicators can only provide specific insights on quantities of or efficiency in resource use. Hence, sometimes the wrong indicators are selected to support statements. The following table provides a list of (policy-related) questions, which can be addressed by the various MFA-based indicators (see also Femia and Moll, 2005; OECD, 2008a). It shall be emphasised that each of the listed questions can either be addressed on a very aggregated level across all material categories, or disaggregated on the level of material groups (e.g. fossil fuels, metal ores) or even single materials, depending on the used data source and calculation procedure (see review of the various approaches in this report). Using material flow data in relation to economic data, in particular input-output tables, furthermore allows a disaggregation by economic activity (i.e. identifying which economic sectors contribute to the overall material input/consumption of a country).

Table 2: Indicators derived from EW-MFA and related (policy) questions

Indicator	Main policy questions
Domestic Extraction Used (DEU)	• Which environmental pressures are generated on the territory of a country through extraction of raw materials? • Which trends in domestic extraction of raw materials can be observed?
Direct Material Input (DMI) / Domestic Material Consumption (DMC)	• Which environmental pressures occur within the territory due to materials used in an economic system (which either end up as increase in physical stock or as waste and emissions back to the environment)? • What is the relation of domestically-extracted versus imported materials, i.e. how dependent is an economy (or specific industries) from raw material imports? • Which are the (policy) hot-spots for resource management measures related to the domestic flows of materials?
Raw Material Input (RMI) / Raw Material Consumption (RMC)	• Which global material flows are related to (final) consumption in a country? • To what extent have countries substituted domestic material extraction through imports over time (i.e. through comparing DEU with imports in Raw Material Equivalents)? • Are countries net-importers or net-exporters of embodied material flows and environmental burden related to material extraction and processing

	– and, depending on the methodology, which are the source countries for the indirect flows? • Which are the (policy) hot-spots for resource management measures along the whole international supply-chain of products (sectors, source countries, etc.)?
Total Material Requirement (TMR) / Total Material Consumption (TMC)	• What are the global material flows related to (final) consumption in a country, including pressures related to unused material extraction? • Which are the (policy) hot-spots for resource management measures along the whole international supply-chain of products, when unused material extraction is also considered?
GDP/DMI GDP/DMC	• How much economic value is being generated by a unit of material directly used on the territory of a country? • Has a de-coupling between economic growth and direct resource use occurred in the national economy?
GDP/RMI GDP/RMC	• How much economic value is being generated with relation to the domestic consumption of materials used along global product supply chains? • Has a de-coupling between economic growth and the domestic consumption of materials used along global supply chains occurred?
GDP/TMR GDP/TMC	• How much economic value is being generated with relation to the domestic consumption of materials used along global product supply chains, including unused extraction? • Has a de-coupling between economic growth and the global domestic consumption of materials used along global product supply chains, including unused extraction, occurred?

However, the applicability of these specific indicators is not just a question of their ability to answer specific research or policy questions. It also depends on the robustness of the methodologies behind the indicator calculation and the availability of the required data. The current picture painted – and substantiated with the review undertaken in this document – is that the more comprehensive the indicator strived for, the less developed the methodology and the less reliable the necessary data. Also this circumstance is one of the reasons why DMC is still the most widely applied indicator, as the underlying methodology is far developed and available data are satisfying. However, this should be seen rather as incentive than as an obstacle to further develop the methodologies and data foundations needed to calculate RMI/RMC or TMR/TMC.

1.3 Scope of the document

This report analyses the main existing approaches for calculating material use and efficiency indicators, with a focus on comprehensive indicators, which include indirect material flows of internationally traded products as well as unused material extraction, such as Raw Material Input (RMI) and Raw Material Consumption (RMC) or Total Material Requirement (TMR) and Total Material Consumption (TMC). These comprehensive material flow-based indicators have recently also been termed “Material Footprints” in the literature. Hence, the aim is not to compare DMC and similar indicators with the Material Footprints and their respective potentials or shortcomings, but to compare the different Material Footprint methodologies among each other with regard to their state of development and readiness for implementation. The results of this review and evaluation will be used to identify needs for methodological and data harmonisation and to identify key areas for further improvement of these indicators.

It is planned to complement the review with inputs from relevant actors in the field of material use and efficiency via semi-structured interviews. Thereby, the different points of view held by the following groups of stakeholders can be integrated: statistics, policy makers, academia, civil society, and international organisations. Through the stakeholder interviews it will be possible to draw a comprehensive picture of current challenges which will be the foundation for a series of workshops (Task 2.1 and 2.2). The result of these workshops will be recommendations regarding stakeholder cooperation, methodological development as well as data collection to further develop and harmonise the different approaches. The discussion will be facilitated by means of an input paper from AP1.3 that will feed into the workshops.

In the first section of the document we provide an overview of the methodology set up for the review of existing approaches. We explain which main groups of approaches to calculate material productivity indicators have been identified and which criteria were used to analyse and comparatively evaluate the different approaches. The aim of this evaluation was to identify similarities and differences as well as strengths and weaknesses as the basis for formulating recommendations for further work.

1.4 Review concept

As mentioned earlier, the scope of this review is to analyse different methodologies capable of calculating comprehensive indicators which account not only for direct material flows associated with the production and consumption activities in a country but also the indirect flows, i.e. materials needed along the international supply chain of traded goods and products. Generally, the calculation of such comprehensive material use and productivity indicators is carried out by one of the following three methodologies. More detailed descriptions of each methodology will be provided at the beginning of each methodology chapter.

(1) The first group of approaches is based on economic **input-output analysis**, which integrates physical data on material use. Input-output analysis is a top-down approach, i.e., a methodology, which starts the assessment from the macro-economic (economy-wide) level, but includes a disaggregation to economic sectors (product groups or industries) via the input-output tables. Material extraction, which can comprise only used extraction or used and unused extraction, is allocated to the corresponding extraction sector(s) and by means of the monetary trade interlinkages within a country (input-output table) and between countries (trade data) attributed to the final consuming country. Hence, this approach allows for identifying the final consumer responsible for specific amounts of material extraction, which takes places either in the country itself or in other countries. Input-output models can refer to a single region, i.e., one country, or to various regions, i.e., multi-regional or multi-country models.

(2) The second common group of methodologies are **coefficient approaches based on process analysis**. This type of approaches accounts for the indirect material flows associated with traded goods and products by means of supply-chain wide material

intensity coefficients, which are derived from process analyses such as Life Cycle Assessment (LCA) or similar methods. This is a bottom-up approach, because it starts the calculation from the level of single products or product groups and aggregates them up to the economy-wide level.

(3) **Hybrid approaches** are the third principal type of methodologies and combine elements from both input-output analysis and coefficient approaches. Hybrid approaches typically split up the total number of products, which should be considered in the assessment. Indirect material flows are calculated partly applying input-output analysis, and the remaining part using material intensity coefficients.

All of these methodologies have in common that they allow for the calculation of indirect material flows associated with traded goods and products. Depending on the input data (input-output) or coefficients used, indicators accounting only for used extraction (RMI/RMC) or used and unused extraction (TMR/TMC) can be calculated. They are hence more comprehensive than indicators accounting only for direct flows, such as the DMI or DMC. In Chapter 4 for each of the three main methodologies the main indicators to be derived will be illustrated.

For each methodology the main models or approaches have been identified and for each of them all major scientific publications of the last years were considered in the review. Also for each publication the data source for the material flow data in use was identified. The following table gives an overview of the relevant literature:

Table 3: Methodologies for indicator calculations with main models, used databases, and most relevant publications

Methodology	Organisation (model name)	Materialflows database	Publications
Input-output approaches	WU (GTAP-MRIO)	SERI/WU database	Giljum et al. forthcoming
	JRC et al. (WIOD)	SERI/WU database	Dietzenbacher et al. 2013
	GWS et al. (GRAM)	SERI/WU database	Bruckner et al. 2012
			Wiebe et al. 2012
	TNO et al. (EXIOBASE)	SERI/WU database	Tukker et al. 2013
	University of Sydney (EORA)	CSIRO database	Wiedmann et al. 2013
	Eurostat	Eurostat MFA data	Watson et al. 2013
Coefficient Approach	Wuppertal Institute / SERI	Wuppertal database	Dittrich et al. 2012; Dittrich et al. 2013; Schütz and Bringezu 2008
Hybrid approaches	Eurostat	Eurostat MFA data	Schoer et al. 2012, a, b; Schoer et al. forthcoming; Marra Campanale and Femia 2013
	ISTAT	ISTAT	Marra Campanale and Femia 2013
	CUEC	Czech Statistical Office	Kovanda 2013, Weinzettel and Kovanda 2008, 2009; Kovanda and Weinzettel 2013

	SEC/IFF	Austrian MFA accounts	Schaffartzik et al. 2009; Schaffartzik et al. 2013; in press
	DESTATIS / UBA	German MFA accounts	Destatis 2009; Lansche et al. 2007

The different models in use were evaluated according to the following criteria groups – where the criteria group A focuses on the type of approach (input-output, coefficient, hybrid) and the B criteria groups focus on data-related aspects:

- A.1. Methodology
- A.2. Compatibility
- B.1. Input-output data
- B.2. Monetary trade data
- B.3. Physical trade data
- B.4. Material extraction data
- B.5. Material coefficients

In the following we briefly describe the main criteria foreseen for each criteria group. Note that for group B on data the table shows section B.1 as example, as the criteria are the same for sections B.2 to B.5 – with the exceptions that the other sections do not contain a criterion on extractive sectors (B.1.3.) and B.4 and B.5 also include a criterion asking for the coverage of data on unused extraction.

Table 4: Criteria groups with specific criteria and related descriptions

A.1. Methodology	A.1.1. Coverage of whole product supply chain	How are supply chains – especially of manufactured products – considered?
	A.1.2. Specificity regarding origin/destination of imports/exports	In which detail are trade data specified with regard to countries of origin and destination?
	A.1.3. Avoidance of double counting	Is the methodology designed in a way that double counting is avoided?
	A.1.4. System boundary / cut-off level regarding secondary, etc effects	Where are system boundaries drawn – especially with regard to the cut-off of up-stream inputs and supply chains?
	A.1.5. Transparency and comprehensiveness of the technical model documentation	Are clear specifications of the underlying methodology available (e.g. protocols, standards, technical descriptions), and can the results be easily reproduced?
A.2. Compatibility	A.2.1.Potential for modular expansion to calculate indicators at different levels (direct/indirect use, used/unused)	Is it possible to use the same methodology to calculate indicators at different levels of detail – for instance, including indirect uses or unused extraction?
	A.2.2. Compatibility with the system of environmental and economic accounts	Are the used data and the methodology in accordance with system of environmental and economic accounts
B.1-5. Da-	B.1.1. Regional/country detail	For which countries and regions are disaggre-

		gated data available? Which constraints do exist with regard to regional explicity?
	B.1.2. Level of sector/product coverage	Which products and sectors are covered and which are left out?
	B.1.3. Level of coverage regarding material extractive sectors	How many sectors are disaggregated which are responsible for the extraction of specific materials?
	B.1.4. Timeliness	With which delay are data published and can calculations be carried out?
	B.1.5. Availability of time series	Do time series exist? (and thus allow analysis of historical trends as well as provide input for models of future scenarios)
	B.1.6. Periodicity of data updates	Are data updated on a regular basis? How often?
	B.1.7. Source, credibility and transparency of data	Does the data stem form an official source, with known credibility and transparency with regard to compilation and quality?

The review consists of four parts:

(1) A review table providing the main results at a glance with traffic light colouring (green: criterion completely fulfilled, yellow: partly fulfilled, red: not fulfilled) and key-word text explaining the choice of the colouring.

(2) The detailed evaluation of each model, explaining its performance regarding the different criteria.

(3) A résumé section for each methodology approach (IO, coefficient, hybrid) explaining the general strengths and weaknesses of the methodologies.

(4) A section comparing the three different résumés across key issues, drawing conclusions for future steps regarding harmonisation, data, and institutional proceeding.

1.5 Review tables

In the following Table 5 and Table 6 we present a summary of the review tables providing the main results at a glance with traffic light colouring (green: criterion completely fulfilled, yellow: partly fulfilled, red: not fulfilled).

				A.1. Methodology					A.2. Compatibility		B.1. Input-output data							B.2. Monetary trade data						B.3. Physical trade data						B.4. Material extraction data							B.5. Material coefficients						
Metho-dology	Organisa-tion (model name)	Material-flows database	Publica-tions	A.1.1. Coverage of whole product supply chain	A.1.2. Specificity regarding origin/destination of trade	A.1.3. Avoidance of double counting	A.1.4. System boundary / cut-off level regarding secondary effects	A.1.5. Transparency and compre-hensiveness of documentation	A.2.1.Potential for modular expansion to calculate indicatorsat different levels (direct/indirect use, used/unused)	A.2.2. Compatibility with the system of environmental and economic accounts (SEEA)	B.1.1. Regional/country detail	B.1.2. Level of sector/product coverage	B.1.3. Level of coverage regarding material extractive sectors	B.1.4. Timeliness	B.1.5. Availability of time series	B.1.6. Periodicity of data updates	B.1.7. Source, credibility and transparency of base data	B.2.1. Regional/country detail	B.2.2. Level of sector/product coverage	B.2.3. Timeliness	B.2.4. Availability of time series	B.2.5. Periodicity of data updates	B.2.6. Source, credibility and transparency of base data	B.3.1. Regional/country detail	B.3.2. Level of sector/product coverage	B.3.3. Timeliness	B.3.4. Availability of time series	B.3.5. Periodicity of data updates	B.3.6. Source, credibility and transparency of base data	B.4.1. Regional/country detail	B.4.2. Level of material category coverage	B.4.3. Timeliness	B.4.4. Availability of time series	B.4.5. Periodicity of data updates	B.4.6. Coverage of used / unused extraction	B.4.7. Source, credibility and transparency of base data	B.5.1. Regional/country detail	B.5.2. Level of material category coverage	B.5.3. Timeliness	B.5.4. Availability of time series	B.5.5. Periodicity of updates	B.5.6. Coverage of used / unused extraction	B.5.7. Source, credibility and transparency of data
Input-output approa-ches	WU (GTAP-MRIO)	SERI/WU database	Giljum et al. Forth-coming																																								
	JRC et al. (WIOD)	SERI/WU database	Dietzen-bacher et al. 2013																																								
	GWS et al. (GRAM)	SERI/WU database	Bruckner et al. 2012; Wiebe et al. 2012																																								
	TNO et al. (EXIOBASE)	SERI/WU database	Tukker et al. 2013																																								
	University of Sydney (EORA)	CSIRO database	Wied-mann et al. 2013																																								
	Eurostat	Eurostat data	Watson et al. 2013																																								

Table 5: Review overview of input-output approaches (above)

Table 6: Review overview of coefficient and hybrid approaches (below)

				A.1. Methodology					A.2. Compatibility		B.1. Input-output data							B.2. Monetary trade data						B.3. Physical trade data						B.4. Material extraction data							B.5. Material coefficients						
Metho-dology	Organisa-tion (model name)	Material-flows database	Publica-tions	A.1.1. Coverage of whole product supply chain	A.1.2. Specificity regarding origin/destination of trade	A.1.3. Avoidance of double counting	A.1.4. System boundary / cut-off level regarding secondary effects	A.1.5. Transparency and compre-hensiveness of documentation	A.2.1.Potential for modular expansion to calculate indicatorsat different levels (direct/indirect use, used/unused)	A.2.2. Compatibility with the system of environmental and economic accounts (SEEA)	B.1.1. Regional/country detail	B.1.2. Level of sector/product coverage	B.1.3. Level of coverage regarding material extractive sectors	B.1.4. Timeliness	B.1.5. Availability of time series	B.1.6. Periodicity of data updates	B.1.7. Source, credibility and transparency of base data	B.2.1. Regional/country detail	B.2.2. Level of sector/product coverage	B.2.3. Timeliness	B.2.4. Availability of time series	B.2.5. Periodicity of data updates	B.2.6. Source, credibility and transparency of base data	B.3.1. Regional/country detail	B.3.2. Level of sector/product coverage	B.3.3. Timeliness	B.3.4. Availability of time series	B.3.5. Periodicity of data updates	B.3.6. Source, credibility and transparency of base data	B.4.1. Regional/country detail	B.4.2. Level of material category coverage	B.4.3. Timeliness	B.4.4. Availability of time series	B.4.5. Periodicity of data updates	B.4.6. Coverage of used / unused extraction	B.4.7. Source, credibility and transparency of base data	B.5.1. Regional/country detail	B.5.2. Level of material category coverage	B.5.3. Timeliness	B.5.4. Availability of time series	B.5.5. Periodicity of updates	B.5.6. Coverage of used / unused extraction	B.5.7. Source, credibility and transparency of data
Coeffi-cient Approach	Wupper-tal Institute / SERI	Wupper-tal database	Dittrich et al. 2012, 2013; Schütz and Bringezu 2008																																								
Hybrid approa-ches	Eurostat	Eurostat data	Schoer et al. 2012, a, b, forth-coming																																								
	ISTAT	ISTAT	Marra Campana-le and Femia 2013																																								
	CUEC	Czech Statistical Office	Kovanda 2013, Weinzettel and Kovanda 2008, 2009, 2013																																								
	SEC/IFF	Austrian MFA accounts	Schaffart-zik et al. 2009, 2013, in press																																								
	DESTATIS / UBA	IO-table DE & DESTATIS & miscella-neous	Destatis 2009; Lansche et al. 2007																																								

1.6 Input-output approaches

Input-output economics was founded by the Russian-American economist Wassily Leontief, who investigated how changes in one economic sector affect other sectors (Leontief, 1936; Leontief, 1986). Input-output tables represent the interdependencies between different branches of a national economy or different regional economies. Input-output models are comprehensive models in terms of integrating economic data for a whole economic system. They are also flexible tools, which allow integrating environmental data (either in physical or monetary units) as production inputs equal to e.g. labour or capital. Thus, in particular in the past 15 years, input-output analysis became an increasingly popular tool for environment-related assessments.

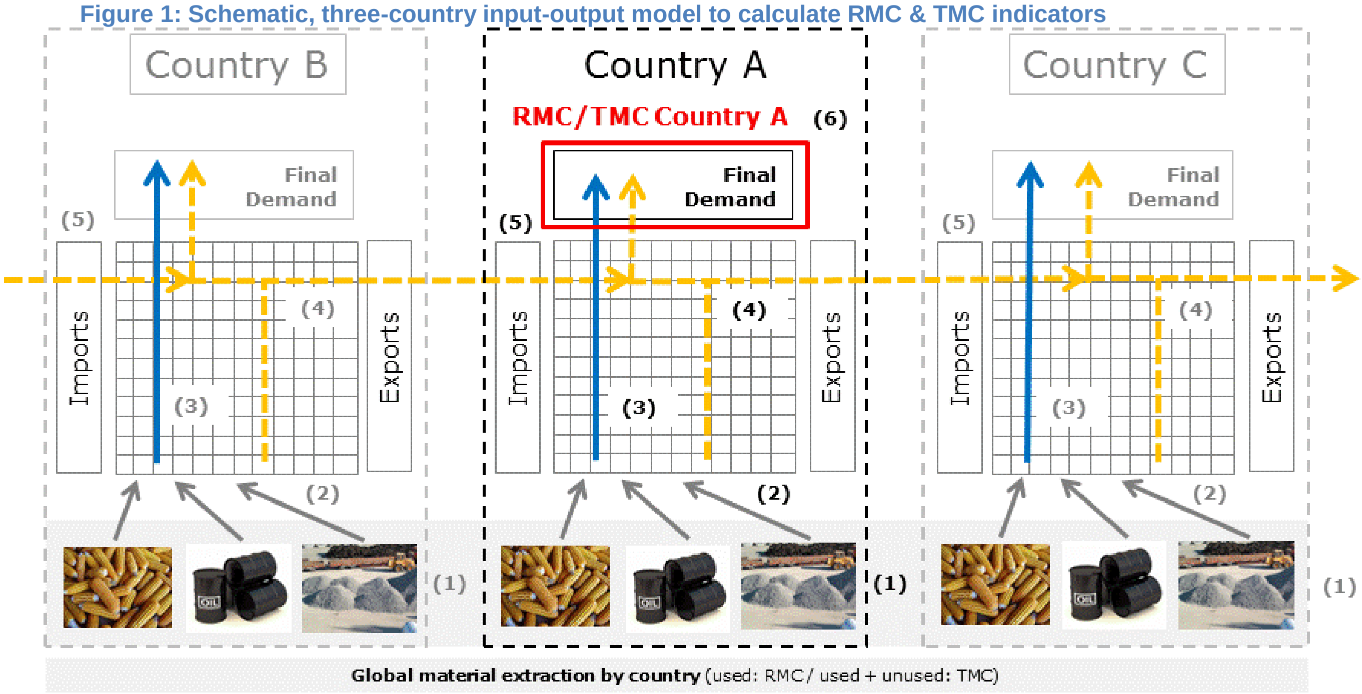
Input-output analysis allows tracing monetary flows and embodied environmental factors from its origin (e.g. raw material extraction) to the final consumption of the respective products. The Leontief inverse, a matrix generated from an input-output table, shows, for each commodity or industry represented in the model, all direct and indirect inputs required along the supply chain. When this model is extended to include environmental data, e.g. on material extraction, the total upstream material requirements to satisfy final demand of a country can be determined.

A major advantage of input-output based approaches to calculate comprehensive MFA-based indicators is that input-output tables disaggregate final demand into various categories (e.g. private consumption, government consumption, investments, etc.). Therefore, the RMC or TMC indicators can be specified for these categories, which is not possible with the coefficient-based approach. Furthermore, the indicators can be broken down by industries or product groups and thus allow identifying the main products contributing to the overall RMC or TMC.

Multi-region input output (MRIO) models link together input-output tables of several countries or regions via bilateral trade flows. These models have a major advantage compared to single models, i.e., they trace not only domestic but global supply chains (Feng et al., 2011) and thus allow taking into account the different resource intensities in different countries (Tukker et al., 2013). The disadvantage is that MRIO systems are highly data intensive and require specific technical skills to be used in the calculation of footprint-type indicators.

The following figure illustrates the calculation procedure of multi-regional input-output methodologies. In order to keep it simple, a model with only 3 countries or world regions is shown.

Figure 1: Schematic, three-country input-output model to calculate RMC & TMC indicators



The first step is the compilation of data on material extraction of biotic and abiotic materials for all countries included in the MRIO model (1). In case the model has global coverage, material extraction data are compiled for all countries world-wide. If material extraction data only cover used extraction, the RMC indicator can be calculated for each country of the MRIO model. If the extraction data additionally covers unused material extraction (such as overburden or harvest losses), the model allows calculating TMC.

Each category of material extraction is allocated to a corresponding extraction sector in the input-output tables of each country, e.g. harvest of agricultural crops is allocated to the agricultural sector/s or metal ore extraction to the mining sector/s (2).

The monetary structures of the input-output tables are used to allocate material extraction along the supply chains. A large part of domestic material extraction serves the final demand for goods and services within the country itself (full arrows) (3).

Other parts of domestic extraction are used for the production of exports and thus delivered to other countries (dotted arrows) (4).

Exports of one country become imports of another country (5). These imports can either serve domestic final demand of the importing country, or the imports are further processed and become parts of exports.

Finally, the RMC (or TMC) indicator of Country A is calculated by summing up the domestic material extraction of Country A, which was used for serving domestic final demand, plus foreign material extraction, which was required to produce the imported products consumed in Country A (6).

In the following, we provide detailed descriptions of existing MRIO-based models to calculate comprehensive material flow indicators.

1.6.1 GTAP-MRIO (WU Vienna)

The **Global Trade Analysis Project (GTAP)** database is an economic database of harmonized input-output tables and bilateral trade data established and maintained at Purdue University, Indiana, USA1. The latest version 8 of GTAP disaggregates 129 countries / world regions and thus represents a very high geographical coverage. GTAP8 contains information for 57 product groups, of which 15 refer to primary material extraction. This disaggregation level also determines the extent to which material extraction data linked to agricultural, forestry, fishing or mining activities can be disaggregated. In addition to these primary production sectors, a number of manufacturing sectors are being distinguished. So far, the only study using GTAP for material footprint calculations, i.e. calculations of the indicator Raw Material Consumption (RMC), was carried out by Giljum et al. (forthcoming).

GTAP – as well as all other MRIO databases – allow separate calculations of the material footprint of private household consumption as well as for government consumption, investments, inventory changes and exports as well as imports. GTAP data exist for various points in time, the latest data referring to the year 2007, and they are updated every 3 to 4 years. In addition to this rather large time lag, another shortcoming is the comparatively crude identification of only 15 specific, mainly agricultural, extractive sectors in a total of 57 sectors. This should be born in mind when using this framework for environmental-economic evaluations. For example, there is only one sector relevant for abiotic materials (mining and quarrying activities). In general, assessment results improve with increasing numbers of total and extractive sectors, as environmental pressure exerted by material extraction can more specifically be allocated to the sector responsible for it. So far different abiotic materials have to be allocated to the construction sector.

Compatibility with the system of national accounts is generally high across all MRIO approaches (including GTAP), as the establishment of input-output tables is closely connected with the structure of national economic accounts and by definition it takes a sector perspective, which is also the basis of e.g. the NAMEA system. Regarding transparency, GTAP has some clear deficits, as the data manipulation procedures necessary to transform original IO tables into the standardized GTAP format are not well documented. In many cases, the quality of the underlying IO data cannot be properly evaluated. National tables are collected from uncountable sources and provided by experts from all over the world. Data quality varies and cannot be assured. Furthermore, type and structure of the underlying national tables are not consistent (e.g. following different industry or commodity classifications and applying different technology or sales assumptions).

Trade data used to link the IO tables stem from UN COMTRADE with high credibility and transparency standards. The database encompasses 98 different commodities (at the 2-digit level); in GTAP the HS 6-digit classification was used which provides information for ~5,000 products, with time series from 1962 to the current year. For bilateral services flows data from UN, Eurostat, and OECD were used.

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[1] See https://www.gtap.agecon.purdue.edu/databases/v8

Material extraction data for GTAP-based material footprint assessments were exclusively taken from the global material flows database compiled and maintained by SERI and WU in Vienna (SERI, 2013). This database comprises data on used and unused extraction for more than 300 different material categories and more than 200 countries for the time period 1980-2010. It is based on official data sources such as IEA, FAO, BGS or USGS, and necessary data estimation or harmonisation steps follow official handbooks such as those by Eurostat (2012) or the OECD (2008b). The database is the worldwide most comprehensive data source for material flow data.

Unused domestic extraction (UDE)

The category of used materials is defined as the amount of extracted resources, which enters the economic system for further processing or direct consumption. All used materials are transformed within the economic system. In comparison *unused domestic extraction are materials extracted or otherwise moved on a nation's territory on purpose and by means of technology which are not fit or intended for use. Examples are soil and rock excavated during construction, dredged sediments from harbours, overburden from mining and quarrying and unused biomass from harvest. Agricultural soil that is eroded is not moved on purpose but may be included as an optional memorandum item* (EUROSTAT, 2001).

The rationale behind the accounting for unused extraction is that every movement or transfer of materials or energy from one place to another potentially affects the environment in some way. Examples are the alteration of landscapes, the pollution of air, water or soil, or the disruption of habitats. In many cases (e.g. overburden) the unused values can be considerably larger than the used values (OECD, 2008b).

Depending on the category of material flow estimations of unused extraction and data sources differ. In the case of biomass, in recent years extensive research has been carried out regarding geographically specific shares in overall harvest of specific crops which are used as straw or as feed, or not used and accounted for as unused extraction respectively (for instance, Krausmann et al., 2009). Data on unused extraction related to mining and quarrying activities are provided by official agencies for geosciences or are the result of very laborious research.

Technically, the incorporation of unused materials into the calculation of comprehensive indicators, which also include indirect material flows associated with traded goods and products, is done via material-specific factors (UDE factors). For each material, this factor calculates the amount of unused material related to one unit of used extraction. Hence, in input-output models the sum of used and unused extraction is used as material input data allocated to the extractive sectors. Regarding coefficient approaches, the traded products are first converted into raw material equivalents (RME; see above) via the eponymous coefficients which are then up-scaled to total material values with the help of the UDE factors.

It has to be stated though that UDE factors still are the results of "experts' guesses", as no precise information is available for none of the material categories. UDE has also not been (yet) considered as an important element in national MFA accounts as compiled by Eurostat or Destatis.

Only a few MFA databases contain information on UDE. The most comprehensive calculations of UDE are provided by the www.materialflows.net Portal, established by SERI and WU in cooperation with the Wuppertal Institute.

1.6.2 WIOD (JRC et al.)

The second MRIO database, which has been explicitly applied to calculate material footprints (i.e. the indicator RMC) of EU-27 countries (see Arto et al., 2012) is the **World Input-Output Database (WIOD)** (Dietzenbacher et al., 2013). In comparison to GTAP, WIOD disaggregates a smaller number of countries (40 countries plus Rest of the World) and also has a lower resolution regarding sectors and product groups (35 industries, 59 products). Differences to GTAP and other MRIO databases lie primarily in the availability of time series with WIOD data being available for each year between 1995 and 2011. Also the transparency and quality of the underlying data is higher for WIOD compared to GTAP, as official national IO tables were the starting point of the data harmonisation procedures.

With regard to material footprints, a particularly weak point is the limit to only four specific extractive sectors (3 agricultural, 1 mining and quarrying) and eight related products. This also puts a severe constraint to the number of material categories, which can be distinguished in the assessments. In the study for the EU-27, four types of materials were separately analysed (Biomass, Fossil fuels, Metals, Other Minerals). But since the WIOD-model allocates all material types according to exactly the same economic structures to final consumption, the results at this level of detail cannot be considered robust.

As for the GTAP model, Dietzenbacher et al. (2013) also use UN COMTRADE data for the trade linking. In addition, the material flow database used to set up the WIOD is the same as applied by Giljum et al. (forthcoming) – i.e. the SERI Global Material Flow Database (SERI, 2013).

1.6.3 GRAM / OECD (GWS et al.)

Another source for MRIO-based material footprint assessments is the **OECD input-output database** (OECD, 2009). This database was integrated into the Global Resource Accounting Model (GRAM) and used for the calculation of the RMC indicator by Bruckner et al. (2012) and Wiebe et al. (2012). The OECD database is very close to the officially published IO tables, with a transparent documentation of the required steps taken to transform the IO tables into a harmonised format. Therefore, the OECD database is characterised by high transparency and good data quality. Regarding the country and sector break-down, GRAM is comparable to WIOD, with 58 countries and regions, 48 industries and only four aggregated material extractive sectors (Agriculture, hunting, forestry and fishing, Mining and quarrying (energy / non-energy), construction), which significantly limits the potential use of this database for the case of material footprints. Further, OECD MRIO data are so far only available for only three years: 1995, 2000 and 2005.

The trade data used for linking the tables also are taken from OECD. The OECD trade data encompasses data on 64 reporters (i.e. all OECD member countries and 30 non-member economies) and 67 partners (i.e. 34 OECD countries, 30 non-member economies, rest of world, partner unspecified and total world). Trade data exist for the time series 1990-2011 and are updated twice a year: a complete update around the end of the year and a mid-term revision around mid-June. As in the case of the IO data OECD trade data follow high credibility and transparency standards.

The database used to set up the GRAM is the same as used by Giljum et al. (forthcoming) – the SERI Global Material Flow Database (SERI, 2013).

1.6.4 EXIOBASE (TNO et al.)

The **EXIOBASE** system was developed in several European research projects and particularly designed for environment-related applications (Tukker et al., 2013). Therefore, in EXIOBASE, national IO tables were further disaggregated in order to provide a higher industry/product detail in environmentally-sensitive sectors, including agriculture and food industries. The EXIOBASE 2.0 distinguishes 43 countries (representing ~95% of the global GDP) and 5 rest-of-the-world regions and has a total of 169 industrial sectors and almost 200 product groups of which 26 sectors (10 biomass, 4 fossil fuels, 11 mining and quarrying, plus 1 construction) responsible for extraction activities are identified. Especially with regard to this level of detail with regard to overall sector/product disaggregation as well as material sectors EXIOBASE 2.0 is clearly at the research edge when it comes to environmentally-economic analyses. However, EXIOBASE 2.0 data are only available for two years, 2000 and 2007, but time series (1995-2011) are currently being built in the ongoing FP7 project "DESIRE"[2] (EXIOBASE 3.0). The transparency of data manipulation procedures required to disaggregate standard IO tables to the EXIOBASE classification can be improved. Additionally, a larger number of auxiliary data is being used, which cannot always be judged regarding the data quality.

Similar to WIOD, trade data stem from UN COMTRADE, and material flow data from SERI's data base.

1.6.5 EORA (University of Sydney)

The 5th available option for MRIO-based material footprint assessments is the **EORA MRIO** system (Lenzen et al., 2013; Wiedmann et al., 2013). Just recently, EORA has been directly used for the calculations of material footprints (Wiedmann et al., 2013). With 187 countries and country groups, EORA provides the highest spatial resolution of all MRIO systems presented so far. The number of sectors and product groups disaggregated in EORA differs from country to country, depending on the officially available data. This also determines the number and type of material extraction data that can be attached to EORA. In case no official IO table is available, a mathematical optimisation algorithm creates IO tables with 25 industries from national accounts and other economic production data. Also, for all countries an aggregated version of EORA is available in a 25-sector harmonized classification. While the high-resolution heterogeneous classification is clearly an advantage, as the complete detail of the available tables is maintained, the aggregated sector level (25 sectors, of which 3 bio-

[2] See fp7.desire.eu.

mass, 1 mining and quarrying, and 1 construction) is a shortcoming in comparison with other MRIOs such EXIOBASE 2.0. As it is very difficult to verify the applied optimisation algorithms within EORA, transparency and data quality cannot be assured. EORA so far delivers a time series of IO tables from 1990 to 2011.

EORA's monetary trade data stem from the UNCTAD/Eora TiVA Database providing statistics on trade in value added. The data set covers all 187 EORA countries, with 26 to 400 sectors of detail and for a time series of 1990-2011. UNCTAD data ensure high credibility and transparency standards, documentation of methodologies applied for the compilation of the TiVA database is still scarce, also due to ongoing methodological improvements.

The material flow data used in EORA are taken from the CSIRO Global Material Flow Database. The data cover 191 countries and around 250 primary resource categories. Data are available for 1970-2008 for used extraction; no data on unused extraction is provided, neither a documentation regarding planned updates.

1.6.6 Eurostat

The final set of tables analysed was the set of input-output tables published by Eurostat and used for an extensive study for the EEA by Watson et al. (EEA, 2013). Eurostat provides input-output data for all EU Member States, Candidate Countries and Norway, as well as for the EU-27 as a whole with a disaggregation of 60 industries and 64 product groups. Tables have been published every five years (1995, 2000, 2005), but shall be published on a more regular basis now (2008, 2009, 2010), with a delay of about 3 years. Only 3 specific sectors (Agriculture, forestry and fishing, Mining and quarrying, Construction) are relevant for material extraction activities. The tables are compiled by the National Statistical Institutes' Accounts Departments and validated by Eurostat. Hence, a high level of credibility and transparency of the base data as well as their compatibility with the system of environmental and economic accounts (SEEA) is ensured.

The study itself does not integrate the Eurostat tables into an MRIO framework; neither does Eurostat provide such a framework. Watson et al. thus apply a so-called single-region input-output (SRIO) model. This type of models puts one country (or one aggregated region, such as the EU) in the centre of the analysis and integrates only the input-output table for the analysed country or region. While this type of model is technically relatively easy to handle due to limited amounts of data, the key disadvantage is that those models typically work with the assumption that imports are produced with the same technology as products in the domestic economy (i.e. domestic technology assumption) to estimate resource requirements of imports. This assumption can lead to mistakes, as foreign resource intensities are often very different to the domestic ones (Tukker et al., 2013).

Trade data used for the analyses stem from the Eurostat ComExt data base the 7000 products (HS6) of which were aggregated into 59 aggregates. The ComExt data base on international trade in goods statistics collected, compiled and transmitted to Eurostat by Member States in line with the legislation in force. Data are available for 1999-2013 and are updated on a monthly and yearly basis.

Eurostat's material flow data cover data for the EU27, and national data from EU member states, candidate countries plus the EFTA countries of Norway and Switzerland. The most comprehensive data are available for 48 different material categories (at the lowest classification level), and for the years 2000-2011; no unused extraction is reported. Updates are carried out on an annual basis; data collection is carried out by Member States with quality assurance and documentation of the quality being joint responsibility of Eurostat and the Member States.

1.6.7 Résumé input-output approaches

Key advantages

Input-output analysis, in particular in a multi-regional form, brings along a number of key advantages over other methodological approaches (Wiedmann et al., 2011). The main advantage of input-output models is that they allow calculating the footprints for all products and all sectors, also those with very complex supply chains, as the whole economic system is included in the calculation system (Chen and Chen, 2013). Input-output analysis thus avoids so-called "truncation errors" often occurring in coefficient-based approaches, i.e. errors resulting from the fact that the whole complexity of production chains cannot be fully analysed based on Life Cycle Assessment approaches, so certain up-stream chains have to be "cut off".

Input-output analysis thus avoids imprecise definition of system boundaries, which is one key advantage over coefficient approaches (Bruckner et al., 2012). Input-output models also avoid double counting, as different supply-chains are clearly distinguished from each other in the monetary input-output tables. Thus, a specific material input can only be allocated once to final consumption, as the supply and use chains are completely represented (Daniels et al., 2011).

Another advantage of the input-output approach is that the accounting framework is closely linked to standard economic and environmental accounting (United Nations, 2003), which ensures that, at least at the national level, a continuous process of data compilation and quality check takes place.

Key disadvantages

The major disadvantage of input-output analysis is the fact that most input-output models work on the level of economic sectors and product groups, assuming that each sector produces a homogenous product output. This implies that in one sector, a number of different products with potentially very different material intensities are mixed together. This assumption limits the level of disaggregation that can be achieved with that approach and also leads to distortions of results, for example, when very different materials such as industrial minerals and metal ores are aggregated into one sector (Schoer et al., 2012a).

However, a number of recent EU research projects have been devoted to the refinement of input-output tables and multi-regional input-output systems to calculate footprint-type indicators (Dietzenbacher et al., 2013; Tukker and Dietzenbacher, 2013).3 The intention is to create systems with a higher level of disaggregation, in particular in environmentally-sensitive primary sectors (e.g. the mining sectors), thus avoiding mistakes resulting from the high level of aggregation of the input-output tables. Also input-output systems developed outside Europe such as the Eora database (Lenzen et al., 2012) point in the same direction.

A second major disadvantage is that MRIO-based approaches use the monetary use structures of industries and product groups to allocate material extraction to final demand. These monetary structures in many cases do not well correspond to physical use structures, as price differences between different industries can occur (Schoer et al., 2012b). Therefore, some hybrid approaches (see below for details) aim at replacing parts of the monetary information by physical data (e.g. material units, e.g. tonnes; or energy units, e.g. Joules).

The following table summarises the key advantages and disadvantages of the input-output approaches.

Table 7: Key advantages and disadvantages of the input-output approaches

Input-output approaches	
Key advantages	Key disadvantages
+ Calculating material footprints for all products and all sectors, also those with very complex supply chains – avoidance of "truncation errors"; + precise definition of system boundaries; + avoidance of double counting as supply-chains clearly distinguished from each other; + in the case of multi-regional models: full consideration of different material intensities in a large number of countries + accounting framework closely linked to standard economic and environmental accounting. + Disaggregation of comprehensive material consumption indicators by different categories of final demand (e.g. private consumption, government consumption, investment, etc.), industries or product groups and by material group	- Assumption of a homogenous product output for aggregated economic sectors and product groups, leading to distortions of results, in particular when price to weight ratios are very different for various products aggregated into one sector; - Use of monetary use structures of industries and product groups to allocate material extraction to final demand, which differ from physical use structures, in particular for raw materials - Quality of data for input-output tables of particularly non-OECD countries often difficult to evaluate

1.7 Coefficient approach

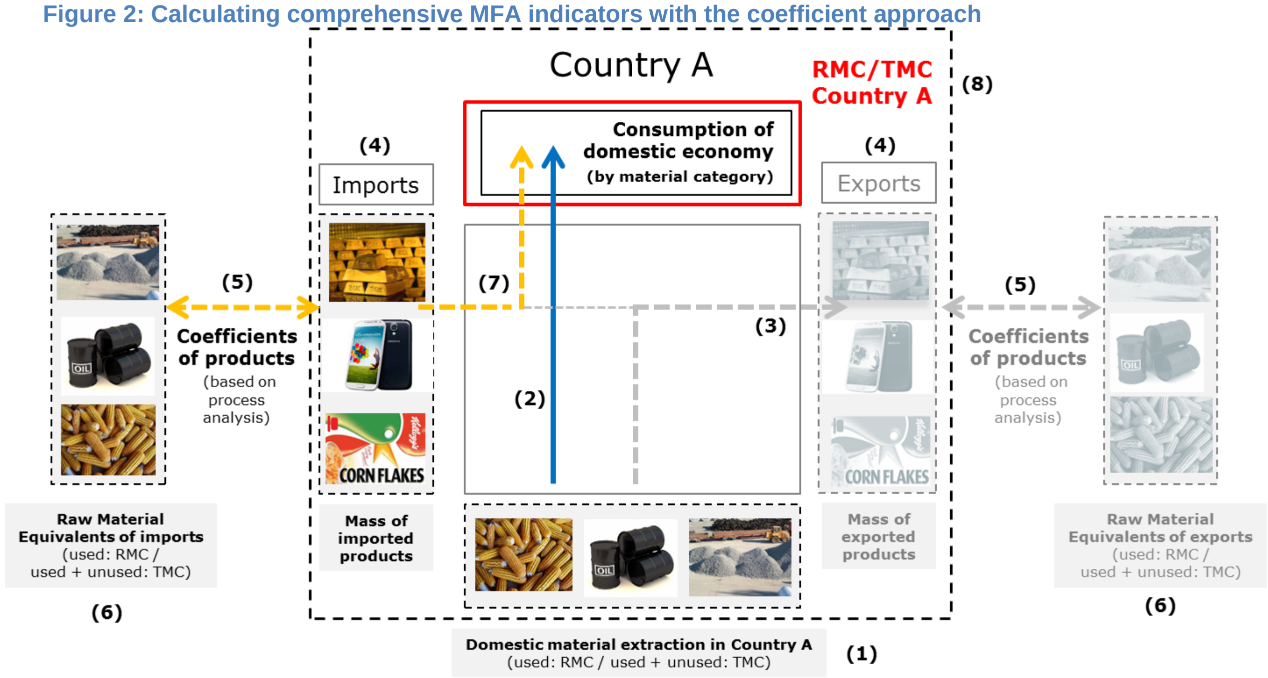
Coefficient approaches calculate the total material use associated with final consumption by accounting for physical in- and out-flows of a country and considering the material intensity of the traded commodities along the whole production chain. The applied material intensity coefficients – or "cradle-to-product" coefficients" – inform about the supply-chain wide (direct and indirect) material requirements for a certain product or activity. These material requirements have also been termed "ecological rucksacks" of products.

[3] Examples include: FP6: EXIOPOL, FORWAST, OPEN-EU. FP7: CREEA, DESIRE, WIOD

Coefficient approaches apply the concept of "apparent consumption", i.e. they cannot specify, whether a certain material extraction was used for intermediate production or consumed by the final consumer. Also, it is not possible to separate e.g. private consumption from government consumption, which is the case with input-output based calculations (see above).

The following Figure 2 provides a schematic representation of the calculations of RMC and TMC according to the coefficient approach.

Figure 2: Calculating comprehensive MFA indicators with the coefficient approach



The calculations with the coefficient approach follow several steps. In a first step, data on domestic material extraction in the observed Country A is compiled (1). If the RMC indicator should be calculated, only data on used material extraction are required. Calculation of the TMC indicator needs quantifying the total material extraction on the domestic territory, i.e. used plus unused extraction.

Parts of the domestic extraction are used for the "apparent consumption", i.e. intermediate and final consumption, in the domestic economy, see dark arrow (2).

Some materials extracted within the territory of Country A serve the production of exported products; see the dotted arrow (3).

Country A also imports various products from other countries and exports products to other countries (4). The direct mass of these imported and exported products, i.e. the mass of a car of a mobile phone, is multiplied with coefficients, which are derived from process analysis on the level of single products (5). These coefficients indicate how many tonnes of raw materials were required along the production chain in other countries, in order to produce the imported product. The coefficients thus transform the mass of imported and exported products into their so-called "Raw Material Equivalents" (RMEs). The exported flows become part of the RMC or TMC indicator of other countries. If the TMC indicator should be calculated, unused material extraction related to the RMEs additionally need to be considered in the coefficient (6).

The RMEs of imports can either serve domestic consumption, or enter the export industries and are thus re-exported from Country A to another country (7).

Conceptually, the RMC indicator of Country A then equals the sum of used domestic material extraction being consumed in Country A plus the RMEs of imports to Country A used for final consumption. Mathematically, the RMC is calculated as domestic extraction plus RMEs of imports minus RMEs of exports. This “indirect” way of calculating RMC is necessary as the coefficient approach does not allow for a mathematical allocation of domestic extraction to domestic final demand. The TMC of Country A additionally includes the domestic and imported unused extraction (8).

Only very few calculations of comprehensive material flow-based indicators on the national level were purely based on a coefficient approach in recent years. In most cases the coefficient approach is used in combination with input-output approaches (see chapter 6 on hybrid approaches below). In the following we will describe the specificities of the methodology developed and applied by the Wuppertal Institute as the most important institution representing this type of approach (Dittrich et al., 2012a; Dittrich et al., 2013; Schütz and Bringezu, 2008).

1.7.1 Wuppertal Institute

Dittrich et al. (2012a) calculate indirect material flows related to international trade by multiplying the physical quantity of each traded product with a coefficient of ecological rucksacks which are caused by the production of that commodity. The direct physical quantities of all traded commodities were taken from the UN Comtrade database. Where physical values were missing, monetary values were divided by average price per kilogram for each commodity group and each year, starting with the most differentiated level. The time series provided covers the years 1962-2005 and all (~170) countries reporting to UN Comtrade. In general, data from UN Comtrade are available for the 5-digt level and more aggregated from 1962 to the most recent year (typically t-1).

The coefficients applied stem from a database compiled by the authors and regularly updated within the so-called “MIPS or MI (material input) database” of Wuppertal Institute as well as with factors of the database on unused material extraction. They encompass up-stream flows of both used and unused material extraction, whereby unused extraction includes soil erosion. However, the final coefficients do not distinguish between used and unused material flows.

Wuppertal's MI database covers more than 200 products (status 2010), with differing level of detail among product groups. Mainly, primary and secondary products are covered. The majority of the coefficients are for one specific (mainly European) country, mainly Germany. In some cases, instead of national coefficients, world averages are provided. Timeliness differs significantly among materials. The data are based on detailed research in industry and scientific literature, estimates and own calculations. Hence, they refer to one point in time (no time series provided); for some commodities of especially high trade volumes (e.g. coal and specific metals) annual factors were estimated. While the data are not part of an official or licensed database, documentation regarding sources is generally scarce.

As holds true for coefficient approaches in general, the coefficients applied by the Wuppertal Institute aim at covering the whole supply chain of a product (see above); however, due to data restrictions there has to be a cut-off at a certain point in indirect chains, e.g. infrastructure, energy or intermediate inputs required to produce a product. Hence, the setting of system boundaries is a potential source of error with regard to underestimation as well as double-counting. The methodology applied is clearly described by the authors - however, the compilation of the coefficients lacks documentation.

1.7.2 Résumé coefficient approaches

Key advantages

The most important advantage of coefficient-based in comparison to economy-based approaches is the high level of detail and transparency, which can be applied in footprint-oriented indicator calculations. The coefficient approach does not face restrictions of the definition of sectors or product groups in input-output analysis and thus allows performing very specific comparisons of footprints down to the level of single products or materials (Dittrich et al., 2012a).

This approach therefore allows for illustrating the composition of material footprints by commodity or product category in a very straightforward and transparent manner, as the overall numbers are summed up from the bottom, which is more difficult to assess with input-output analysis (Mekonnen and Hoekstra, 2011).

Key disadvantages

One key disadvantage of coefficient approaches is the high level of effort to construct solid coefficients for a large number of especially highly processed products. These approaches are therefore often applied to assess the resource requirements of raw materials and basic products, but the availability of coefficients for finished products with highly complex supply chains is often very restricted (Dittrich et al., 2012a).

Coefficient approaches also produce truncation errors, as the indirect material requirements are not traced along the entire industrial supply chains. Inter-sectoral deliveries have to be cut-off at some point due to data availability (Feng et al., 2011). Existing coefficient life-cycle data bases (such as Ecoinvent) also underestimate the total environmental consequences of a national economy, as life-cycle data for services are largely missing (Schmidt and Weidema, 2009). Furthermore, issues such as infrastructure inputs are often neglected in the construction of conversion factors, thus causing an underestimation of the total footprint related to final consumption (Dittrich et al., 2012c). Moreover, coefficient approaches can only trace total imports of a country – in contrast to IO or hybrid approaches which additionally also are able to quantify the volumes of imports only dedicated to final domestic consumption.

In many cases, coefficients are only available for one point in time. Those coefficients thus do not reflect technological improvements and potentially lead to an over-estimation of the resulting environmental pressures, when applying and updated factor to the current situation. The same holds true for limited coverage of geographical specifications, where in many cases national data have to be estimated by global averages. Coefficients are mostly based on selected studies and not on a systematic statistical census, which means that coefficients depict a selected state of technology at a certain time (Schaffartzik et al., 2009).

The following table summarises the key advantages and disadvantages of the coefficient approaches.

Table 8: Key advantages and disadvantages of the coefficient approaches

Coefficient approaches	
Key advantages	Key disadvantages
- very high level of detail, as coefficients can be calculated for a large number of single products - no restrictions of sector or product group definition	- high level of effort to construct solid coefficients for highly processed products, thus availability of coefficients for finished products with highly complex supply chains very restricted - truncation errors, as indirect material requirements not traced along entire industrial supply chains - underestimation of total environmental consequences of national economy, as life-cycle data for services are largely missing and infrastructure inputs are often neglected - double-counting in case products are passing more than one border in one or different process stages - coefficients mostly available only for one point in time and hence do not reflect technological improvements - Limited national differentiation for coefficients regarding countries of origin - No consistent database for material intensity coefficients available so far; coefficients vary with regard to quality and transparency - Only disaggregation by material group, as concept of “apparent consumption” (i.e. intermediate plus final consumption) is applied

1.8 Hybrid approaches

In the past few years, hybrid approaches became increasingly popular for calculations of comprehensive material flow-based indicators. These approaches combine input-output analysis with material intensity coefficients and thus aim at exploiting the advantages from both approaches.

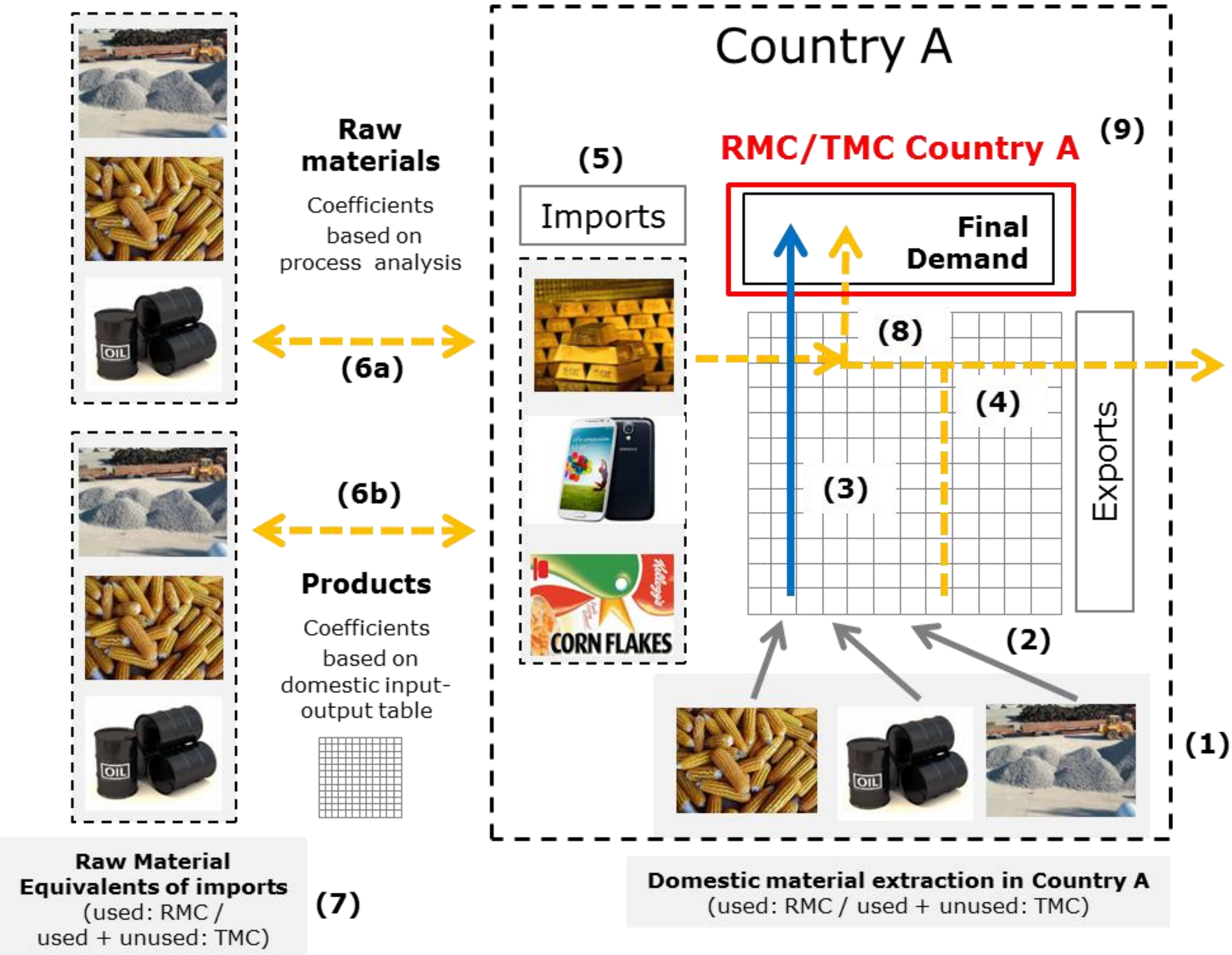
Hybrid approaches apply a differentiated perspective to the calculation of footprint-type indicators for different products and product groups, depending on the processing stage. Typically, hybrid approaches use the input-output table of the analysed country or region for calculating the indirect material requirements of imports, assuming that the technology in other countries equals the domestic one (Domestic Technology Assumption). However, for some imports, this assumption would lead to significant errors. Therefore, the IO-based calculations are complemented by calculations applying material intensity coefficients, in particular for raw materials and products with a low level of processing as well as for products, which are not or differently produced in the analysed country.

Applying material intensity coefficients to selected products and product groups allows reflecting specific aspects with regard to different materials, applied technologies and countries of origin. At the same time, processed commodities and finished goods with more complex production chains are treated with the input-output methodology, which allows considering the full up-stream resource requirements and thus illustrating all indirect effects.

As described for input-output approaches above, also hybrid approaches allow disaggregating the RMC (or TMC) indicator by various categories of final demand (private consumption, government consumption, investment, etc.), as well as by the product groups disaggregated in the input-output table.

The following figure schematically illustrates the calculation procedure of hybrid approaches.

Figure 3: Hybrid approaches for calculating RMC and TMC indicators



The first steps of the calculation procedure in hybrid approaches are very similar to the one explained for input-output analysis above, as a hybrid approach as used so far is, in its core, a single-country input-output model.

Domestic extraction is compiled for Country A (1) and allocated to the corresponding extraction sectors (2).

The monetary (or in some cases mixed unit, see below) input-output table is used to allocate domestic extraction either to domestic final demand (3) or to exports (4).

The monetary imports (5) are transformed into their Raw Material Equivalents (RMEs) with two different approaches. Some RMEs are calculated by process analysis (6a), mainly for raw materials, which are not or differently produced in the domestic economy. For all other products, input-output analysis is applied for calculating RMEs (6b), assuming that imported products are produced with the same technology compared to those domestically produced.

The total RMEs of imports (7) are thus obtained by summing up the RMEs resulting from both types of calculations. The RMEs of imports serve either domestic consumption or are re-exported (8).

The RMC of country A is then calculated as the sum of domestically extracted resources used for final demand plus the RMEs of imports serving domestic demand. If domestic and foreign unused extraction is additionally considered, the indicator TMC can be calculated (9).

Four different hybrid methodologies have been developed by various groups in the past few years (the EUROSTAT approach has been replicated by the Italian Statistical Office ISTAT and is thus not counted twice). All of them have in common that they fully cover the supply chains of the investigated products, either through applying input-output calculations (i.e. the Leontief inverse) or through using material intensity coefficients based on process analysis. However, the details for the modelling of the material coefficients are not always available, which makes it difficult to evaluate, which indirect effects have been considered, how double counting is avoided and where potential cut-offs of indirect process chains took place.

All four investigated approaches could in principle be applied in a modular format, i.e. could be expanded from covering RMI/RMC to TMR/TMC. For the input-output part, this requires applying material extraction data, which cover unused domestic extraction (UDE) and for the coefficients this would imply that unused extraction in the process chains is considered in the calculated material intensities of products. The availability of information on unused extraction is generally still very limited (see Box above) and therefore none of the four reviewed hybrid approaches has so far actually calculated the TMR or TMC indicators.

Being composed of input-output elements and process-based elements, hybrid approaches are only partly compatible with the System of National Accounts. The input-output tables are closely related to the National Accounts, whereas the material coefficients based on process analysis are following other accounting rules and set different system boundaries, i.e. along product chains instead of national borders.

A common feature of all hybrid approaches is also that available results are not up-to-date, i.e. the EUROSTAT approach delivers the most recent data for 2009, and the other hybrid approaches have 2003 to 2010 as their latest year. However, all approaches could potentially be updated on a regular basis, as the required base data are available for more recent years. The input-output tables are the “bottle-neck” in all approaches and are updated at least with a two-year delay (i.e. t-2). Moreover, in all available studies, material intensity coefficients are not available in time series, thus one factor is applied across the whole time period.

Hybrid approaches have so far been applied only for specific European countries or the aggregated EU. On the one hand, this constitutes a certain limitation, as global aspects (such as differences in applied technologies or multi-national supply chains) are not fully taken into account. On the other hand, the level of acceptance and quality of the underlying data is generally high, as national or EU statistics were applied in the case of input-output tables, physical and monetary trade data as well as material extraction data. The material intensity coefficients stem from a variety of LCA databases (including ecoinvent and GEMIS) and many other reports, and it is therefore more difficult to evaluate the quality of the data.

1.8.1 DESTATIS

The German statistical office (DESTATIS) developed a detailed and comprehensive approach for calculating the imports, exports and material consumption for Germany in equivalents of raw materials (“raw material equivalents” - RME; including the indicators RMI and RMC). The DESTATIS methodology consists of three main elements (Statistisches Bundesamt, 2009):

- National input-output tables for Germany (73 x 73 sectors),
- The calculation of selected RME imports to Germany, i.e. raw materials, with the help of LCA-based coefficients,
- And the establishment of specific hybrid input-output tables, i.e. tables that include both monetary and physical units in the technology matrix (A matrix), for each considered raw material (“physical material flow tables”).

The German approach thus addresses several shortcomings of other approaches. First, the use of detailed additional information on the physical flow of certain raw materials allows implementing a deeper level of disaggregation than the standard IO table would enable, which only separates 3 extractive industries and 8 extraction products. Through this additional modelling, a total of 39 abiotic and 16 biotic raw materials can be separately considered in the calculations. For each of the 55 raw materials, detailed supply-use accounts in physical units (i.e. tonnes) were established, in order to model the first stages of each production chain in detail (from extraction via processing to intermediate products). This is done for the first stages of production, because the potential errors originating from allocating several different materials to only one input-output sector are much larger at the first stages of processing than in later stages of the production chain where various materials are incorporated in higher manufactured products and the allocation more closely follows the monetary flows. In order to create these physical supply-use accounts on the level of single materials, detailed German supply-use data (3000 products x 120 production activities) plus additional data (e.g. physical supply-use tables for wood products) are used, partly from non-published information from DESTATIS.

Second, the indirect material flows related to imports are generally calculated applying the modified German input-output tables and applying the Domestic Technology Assumption, i.e. assuming that imports from other countries were produced with the same input factors as applicable in Germany. In order to avoid mistakes for a range of imports, which are not or differently produced in Germany, an exemption to this general procedure are all raw materials, which are separately modelled applying LCA-based factors. The factors have been compiled from various literature sources and also partly modelled with the LCA software "Umberto". A detailed technical report informing about the approach and results concerning the material intensity coefficients is available (Lansche et al., 2007). For some material imports, e.g. coal, material coefficients were specified for the main countries exporting coal to Germany.

The results for the German hybrid model published so far cover the time period from 2000 to 2005 (Statistisches Bundesamt, 2009) and 2000 to 2009 (Destatis, 2012); however, longer time series could be calculated, as German supply-use tables are currently available for 1995-2010.

1.8.2 EUROSTAT

In a series of projects, carried out by external consultants, Eurostat developed a methodology for assessing the indirect material flows related to European imports and exports and calculate the RMI and RMC indicators. Results have so far been presented for the aggregated EU-27 in a time series of 2000-2011. For the Eurostat methodology, a number of publications and detailed technical reports (Schoer et al., 2012a; Schoer et al., 2012b) as well as a range of online material and data sets are available, making this methodology one of the most transparent among all hybrid approaches.

As the German calculation approach, imports into the EU-27 are generally calculated using an aggregated EU-27 input-output table under the "Domestic Technology Assumption". An exception are 62 selected products and product groups, mainly metal ores and energy carriers, for which specific material intensity coefficients of imports were calculated (so-called "LCA products"). The main data source for these coefficients was the ecoinvent 2.0 database (see www.ecoinvent.org). However, as the authors state, eco-invent is not very reliable regarding metal ores, therefore additional research was undertaken using data from USGS and mining reports to derive appropriate ore grades for metal imports into the EU-27. Although metal ore grades significantly differ between countries of origin, it was decided to apply global average ore grades, because huge variations in ore grades between years and countries were observed, with a potentially distorting effect on the overall results.

As with the German approach, the original IO table for the aggregated EU-27 was significantly modified, in order to adapt it to the requirements of assessing embodied material flows. While the German model kept to original sector structure (73 x 73 sectors) and provided additional detail through implementing physical input-output structures on the level of single raw materials (see above), the Eurostat model disaggregated the whole input-output table. Starting from the original 60x60 products tables from Eurostat, the IO table was expanded to a 166x166 products table by using additional information, such as total output of more detailed product groups and detailed German supply and use structures, which are not publicly available (the same detailed tables were also used in the German approach). The result is that more than 50 product categories, 48 different material extraction sectors (15 biomass, 10 fossil fuels, 18 metal ores, 5 minerals), and ten categories of final demand can be specified.

In addition to detailing the sectors, in order to allow separating a larger number of single materials, a hybrid input-output table was created by replacing the monetary information for some sectors in the IO table are with data in physical units. This was done, e.g., for biomass products, for sectors containing abiotic raw materials and basic metals as well as for energy carriers. The rationale was that for these products, physical use structures are more appropriate for depicting the flows of materials through an economy compared to monetary structures, because in reality, different users of e.g. a raw material or energy carriers, pay different prices for the same product (Schoer et al., 2012a) and thus monetary use structures are not simply a unit conversion from underlying physical structure (see also Hubacek and Giljum, 2003).

The Eurostat model can thus be described as very advanced approach, applying a highly detailed, mixed-unit input-output model, where a number of imported products are calculated with specific material coefficients. Experiences from recent applications by EU Member States show that it is easy to use and allows for a comparison in time and among EU countries. Further, comparisons with other approaches show the robustness of the method. Its major drawback is that, so far, the model only exists for the aggregated EU-27 and that detailed data only for Germany and partly unpublished information was required to set up the model. This limits the potential replicability for other countries and regions. Further, improvements are needed e.g. with regard to material-intensive flows as well as flows of materials with very small flows and not very robust data, but high impact on the RME (e.g. rare earths).

1.8.3 ISTAT

Marra Campanale and Femia (2013) calculate indirect material resource use associated with imports, exports and final domestic uses (and resulting EW-MFA indicators in RME), on the basis of the Eurostat model as described above. For their study, the average EU coefficients provided were used to calculate the imports in RME. The RMEs of the Italian extra-EU trade were estimated with the EU level import coefficients, while the Italian intra-EU trade were calculated with the EU level export coefficients. An additional hybrid input-output model based on Italian I-O tables (59 × 59 product groups) was used to calculate the RMEs of Italian exports and other final uses.

1.8.4 CUEC

Researchers at the Charles University Environment Center (CUEC) developed a hybrid methodology to calculate raw material equivalents related to Czech imports and exports as well as the Raw Material Consumption (RMC) indicator (Kovanda, 2013; Kovanda and Weinzettel, 2013; Weinzettel and Kovanda, 2008, 2009). The latest available calculations have been presented for the period of 1995 to 2010.

The Czech approach is less sophisticated compared to the DESTATIS and EUROSTAT methodologies, as it does not adapt the Czech input-output table from its original 60 x 60 sector format. The CUEC approach thus has a lower accuracy of tracing domestic material flows, as the sector aggregation is relatively high, i.e. only 8 material extraction sectors can be separated. Furthermore, no monetary data are replaced by physical data in the input-output table and thus material inputs are allocated to final demand using only the monetary structures.

However, as a hybrid approach, the CUEC methodology calculates selected imports not applying the Czech input-output table, but calculating specific material intensity coefficients for crude oil, natural gas, and metal ores. As a data source for extracting the coefficients, also ecoinvent is applied.

Although several academic papers have been published, a detailed technical documentation of the Czech approach is missing. Therefore, it is difficult to judge the quality e.g. of the material coefficients taken from the ecoinvent database.

1.8.5 SEC/IFF

A very similar approach to the one applied for the Czech Republic was developed at the Institute of Social Ecology in Vienna for the case of materials embodied in Austrian external trade and consumption (Schaffartzik et al., 2013, in press; Schaffartzik et al., 2009). Data in 2013 publication refer to the time period of 1995-2007, and updates for the years 2008 and 2009 are currently ongoing.

Also in this hybrid approach, the Austrian national supply and use tables form the core of the model. The symmetric tables have the format of 57 times 57 industries/commodities and contain 7 sectors, which refer to primary material extraction, i.e. 3 biomass extraction sectors and 4 mining sectors. Material flow data in a resolution of 16 material categories are taken from the official Austrian MFA accounts.

The LCA database “GEMIS” maintained by the International Institute for Sustainability Analyses and Strategy in Germany (see http://www.iinas.org/gemis-database-en.html) is the main data source for the LCA factors, which are applied to a number of imported products. i.e. products from the extraction and first processing of metals (iron, copper, and aluminium), the processing of raw materials for fertilizer production and petroleum and gas extraction. Coefficients were not specified according to the origin of certain raw materials.

1.8.6 Résumé hybrid approaches

Key advantages

Hybrid approaches have the key advantage of exploiting the complementary strengths of the two main underlying methods, i.e. the coverage of all indirect effects and all supply chains of input-output analysis with the high resolution for key products, in particular imports of raw materials, through the application of material intensity coefficients. This type of approach can thus ensure comprehensiveness and accuracy at the same time.

Interesting modifications of input-output tables in hybrid approaches consist particularly in replacing some of the monetary use structures by physical data, which better reflect the flows of materials through an economic system. The creation of mixed-unit input-output tables will be an interesting field for further development.

Hybrid approaches as presented so far focus on one country or region. This narrow perspective allows for using a large number of official data from national statistical sources, including material flow, trade and input-output data. National users thus have a good control over the basic data, which increases the acceptability of this approach with certain stakeholders, in particular national statistical offices.

Key disadvantages

So far, hybrid methodologies were only applied for a limited number of countries and the aggregated EU. All reviewed approaches used different methodological assumptions and data sources. The comparability between the existing hybrid approaches is therefore very limited, and data are missing for a large number of countries.

The sophisticated hybrid approaches which modify the underlying input-output tables by using mixed-units as presented by Destatis and Eurostat rely on detailed supply-use data from the Germany Statistical Office, which is not publicly available. Therefore, it is questionable, whether these detailed approaches can be replicated by other countries.

So far, all hybrid approaches applied the “Domestic Technology Assumption” for calculating a large number of imports assuming that imports are produced with the same technologies as in the domestic economy under observation. Hybrid approaches have so far not been applied in the context of multi-regional input-output approaches, which could eliminate the errors due to this assumption. However, such a global approach is highly data intensive

All hybrid approaches rely on using material intensity coefficients for a selected number of imported products. So far, no single and quality-proofed database exists for the case of material flows, thus the reviewed studies extract these factors from various sources and data bases, with different standards of quality control and varying transparency of documentation.

The following table summarises the key advantages and disadvantages of the hybrid approaches.

Table 9: Key advantages and disadvantages of the hybrid approaches

Hybrid approaches	
Key advantages	Key disadvantages
+ Exploiting the complementary strengths of input-output analysis (coverage of supply chains) and coefficient approaches (high resolution for key products), thus producing very accurate results in terms of comprehensiveness and preciseness; + In some hybrid approaches: Better reflection of flows of materials through an economic	- Approaches only applied for a small number of countries and aggregated EU with very limited comparability; even pilot data are missing for many countries. - Approaches which developed mixed-unit input-output tables used detailed and unpublished data from the German statistical

system through creation of mixed-unit tables through integration of physical use data; + Large control over input data, as material flow data as well as trade and input-output data can be taken from official national statistics + High acceptance especially among European statistical institutions. + Disaggregation of comprehensive material consumption indicators by different categories of final demand (e.g. private consumption, government consumption, investment, etc.), industries or product groups and by material group	office, limiting the replicability. - All hybrid approaches so far apply the "Domestic Technology Assumption" for a large number of imports, thus creating mistakes. No MRIO hybrid approaches tested so far. - No consistent database for material intensity coefficients available so far; coefficients vary with regard to quality and transparency

1.9 Evaluation results: key messages

The analysis so far shows that each of the presented approaches has its advantages but also draw backs; hence, no "ideal" approach can be identified. One of the aims of the evaluation is to analyse which approach is most promising for calculating comprehensive material input and productivity indicators, if the identified disadvantages can be eliminated and by what means. In this context, it is especially interesting to check if advantages of one approach could be used to improve the other.

In our analysis we aimed at evaluating the three main approaches for calculating comprehensive material input and productivity indicators: input-output models, coefficient-based approaches, and hybrid approaches. The analysis showed that especially "pure" input-output approaches as well as hybrid approaches are constantly further developed, while approaches fully relying on coefficients are scarce. As explained above, this is due to the fact that input-output models allow calculating the "material footprints" for all products and all sectors, also those with very complex supply chains, "truncation errors" are avoided and double counting is prevented. Both of these aspects do not hold true for coefficient approaches. On the other hand, by expanding input-output approaches with specific coefficients in hybrid approaches the lack of product or sector detail faced in many input-output tables can be overcome. In the following, we will hence focus our conclusions from the evaluation mainly on the input-output and hybrid approaches.

Considerable work is currently being invested into the further detailing of multi-regional **input-output models** with regard to their country and sectoral coverage. This is especially important for sufficiently detailed analyses of "hot spots" in direct and indirect material use. While, for instance, the EORA model is pioneer in providing IO-tables for almost all countries in the world (however, with the drawback that IO tables for many countries need to be estimated based on macro-economic data), EXIOBASE is the only model with coverage of up to 200 sectors/products for 42 countries plus 4 regions covering the rest of the world. High country and sector detail is needed to allocate material extraction as precisely as possible to the responsible sector and country. Hence, a low number of extractive sectors or "cluster regions" such as a big "rest of the world" group, mix together smaller resource users with larger ones, which results in a loss of necessary detail. It is clear that further disaggregation implies increasing data work load and the necessity for applying valid assumptions where real data (or IO tables) are missing.

Another important aspect where ongoing research is focussing on is the timeliness of the IO-tables used as well as the provision of time series. To evaluate developments in resource throughput of specific sectors, the availability of time series is essential. In recent years, efforts have been intensified on filling the gaps between officially provided IO-tables. While methodologies are improving in this regard, additional emphasis is also put on what is called “now-casting” or even “forecasting”. Interpolation and projection techniques are developed to allow for a more up-to-data analysis, and even an evaluation of possible effects of specific measures in the future.

With regard to the monetary trade data used to link the IO-tables, the analysis carried out shows a very positive picture: for European countries, comprehensive and credible trade data are available from national statistical offices as well as from Eurostat on a very detailed level and for long time series (generally up to the current year). Also on the international level very comprehensive and credible data are provided from databases such as UN Comtrade, UNCTAD and OECD.

Another key aspect for further development is the harmonisation of available international data bases for input-output tables and bilateral trade data. So far, different approaches used different economic databases for their calculations, which lead to significantly different results e.g. for the RMC indicator, even if the material input data were the same. This is the case because the economic information in input-output tables is not consistent across various sources. It would therefore be important that input-output tables and trade data are being reviewed and harmonised by international organisations, such as the OECD and the UN, in order to reduce the variance of results and thus contribute to the acceptance of comprehensive MFA-based indicators in policy making.

For the calculation of material-related indicators it is also a prerequisite to have a detailed data set on material extraction available which can be aggregated to the sector detail needed. At the same time, material extraction data can be used to further disaggregate monetary data in input-output tables, which is only available only on lower level of detail. Official sources such as Eurostat only just recently started to make material accounting obligatory, resulting in more comprehensive datasets provided by Member States. However, these new developments are reflected in the fact that time series exist for recent years only (2000-2011, in the case of Eurostat’s material accounts) and the level of detail is limited. Hence developers of multi-regional IO-models often resort to “semi-official” sources providing more extensive global databases using official data sources and MFA handbooks for their compilation. Examples are the SERI/WU Global Material Flow Database (www.materialflows.net) (SERI and WU Vienna, 2014) or the database developed by SEC (Warr et al., 2010) or CSRIO (for instance, UNEP, 2011a, b). Recent developments in this field show a common effort of these providers to further harmonize data and come up with one consistent worldwide dataset in the medium term. An important aspect in this regard will be the coverage of not only used but also unused extraction – a prerequisite to calculate indicators such as TMR or TMC. In this regard, only the SERI/WU database fulfils this requirement.

Hybrid approaches, in comparison, aim to achieve a balance between accuracy and effort. They use domestic input-output tables to calculate materials embodied in imports for a large number of products, but apply material intensity coefficients for those products, which are not or differently produced in the analysed countries (which is the case in particular for raw materials). Hybrid approaches also apply data on physical trade of materials and products as well as material intensity coefficients stemming from specific databases such as the one provided by the Wuppertal Institute (2013), adapted from LCA databases, such as ecoinvent or GEMIS or estimated from data in the literature. Further, improvements are needed e.g. with regard to material-intensive flows as well as flows of materials with very small flows and not very robust data, but high impact on the RME (e.g. rare earths).

Regarding physical trade data, the data situation seems to be considerably satisfying for the national EU level, as national statistical institutions as well as Eurostat with its COMEXT database provide detailed up-to-date data even in time series starting in the 80ies or 90ies of the last century. When it comes to the international level, the data situation changes. Dittrich et al (2012a) use the UN COMTRADE database with time series since 1962 up to the most recent year applying high credibility and transparency standards. However, data are incomplete and missing data have to be estimated via average prices. Hence, for a global application of hybrid approaches improving the data situation as well as further research on the completion of patchy data is required.

Perhaps the area where most scientific work will be needed is the compilation of a comprehensive, credible and up-to-date database on material input or “raw material equivalent” coefficients. The task is challenging though. Material inputs differ significantly among materials and products, countries and over time. Metal ore grades change between deposits and over time; and so do production technologies applied in different countries and changed over the years due to technological advances. However, for a meaningful analysis of material requirements related to final consumption this level of detail seems to be imperative. Existing datasets such the above mentioned Wuppertal Material Input dataset (Wuppertal Institute, 2013), as well as coefficients produced with hybrid approaches and the existing expertise behind its compilation can serve as a valuable basis for the compilation of a more comprehensive data basis.

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2 AP 1.2 – Interview-Synthesis

2.1 Introduction

In the first phase of the project (Task 1.1) the project team at WU Wien carried out a desk study analysing the main existing approaches for calculating comprehensive material use and productivity indicators and identifying the main areas of improvements and needs for harmonisation (AP1.1).

Before discussing the results with different stakeholders on the international and national level by means of several workshops (Task 2.1 and 2.2), the review was complemented in AP1.2 with expert inputs of relevant actors in the field of material use and productivity by means of conducting telephone interviews. Thereby, the different points of view of various groups of stakeholders should be integrated: statistics, policy makers, academia, civil society, and international organisations. By that means a comprehensive picture of current challenges and potential next steps was drawn, in order to contribute to/foster a valuable and fruitful discourse throughout the different workshops.

The following list shows the interviewed persons by stakeholder group:

Group	Institution	Land / Region
Statistical offices	DESTATIS (Sven Kaumanns)	DE
	EUROSTAT	EU
	ISTAT	IT
	Centraal Bureau voor de Statistiek	NL
Research organisations	Wuppertal Institut	DE
	Dr. Karl Schör	DE
	Ifeu	DE
	CSIRO	AU
Policy makers	European Environment Agency (EEA)	EU
	European Commission, DG Environment	EU
	Ministry of Life (Caroline Vogl-Lang)	AT
International organisations	UNEP International Resource Panel Secretariat (Thomas Marques)	INT
	OECD Environmental Assessment Unit	INT
	UNIDO Environmental Management Unit	INT
Civil society	Naturschutzbund (NABU) (Benjamin Bongardt)	DE
	Friends of the Earth Europe (Michael Warhurst)	BE & UK

The inputs from the relevant actors mentioned above were obtained by means of structured telephone interviews. The interviews were based on questionnaires, which were sent out to the participants beforehand (Annex 1). Interviews were documented in protocols and checked back with the respective interviewees for approval for further use.

In the following two sections, we provide

1. a synthesis of the interview findings relating to the approaches used for indicator calculation, i.e. input-output, coefficient and hybrid (section 2.2. Synthesis on methodology-specific findings)

2. a synthesis of the interview findings relating to the three indicator pairs used and discussed for material flows and resource efficiency, i.e. DMI/DMC, RMI/RMC, TMR/TMC (section 2.3. Synthesis on indicator-specific findings).

2.2 Synthesis on methodology-specific findings

In the following the arguments are organised according to stakeholder group and aspects tackled (methodological issues, data issues and strategic political issues).

Overall, interviewees from the stakeholder groups policy making, international organisations and civil society exclusively discussed and mentioned issues in relation to specific indicators, but did not provide feedback on the approaches. Therefore, after the methodological comments there follows a section on preferred indicators.

Input-Output-tables are oriented towards economic analyses. However, more detail in resource flow relevant sectors would be needed and data sources available for and used in input-output approaches were considered of low quality in some cases. Furthermore, the data sources used in different countries are seldom comparable across countries. Therefore, interviewees from statistical offices called for further work being needed to collect high quality trade data and compile further disaggregated input-output tables.

Furthermore, some interviewees saw policy makers needs in knowing how much we get out of the resources used; how bio-based the economy is; the relation between primary and secondary material inputs; the ratio between products and waste; the ratio of consumption vs. waste produced; how much resources are needed to make a product; and the use of critical materials. More than others multi-regional input-output approaches (MRIO, physical supply and use tables) can also answer these questions, but the data has to be sufficiently disaggregated to allow for such statement. Hence, it might be difficult to select and design policies on the basis of MRIO-based data/results because they might deviate from national data, lag behind in time or are not available for a longer period.

The revision of national accounts might have a negative influence on the use of IO tables in the calculation method. Due to newly introduced Systems of National Accounts (SNA)-concepts like ‘production abroad” and “goods sent for processing” the ownership of the products becomes more important than the physical flows itself.

According to interviewee feedback from statistical offices and research institutions, the most promising approach would be a hybrid model that combines coefficient-based and an input-output approach with a high level of detail in the relevant sectors. So far, the EUROSTAT methodology was considered a fair compromise between representing reality and adopting a full Domestic Technology Assumption (DTA). In addition, the main advantages of the approach developed by Eurostat was believed to be its sector and material detail, its modular structure, the official and reliable data sources, the high level of harmonisation among MS and the acceptance by statistical offices, policy makers and the economy.

On the flipside, although results of Eurostat's approach show a good picture of the dimension of material use, material-specific results are often less precise. Furthermore, the robustness of the hybrid results is difficult to evaluate and hybrid approaches on the country level are very resource-intensive – so far, they are only available for single countries or country groups (e.g. the EU).

Interviewees from statistical offices highlighted that coefficients used in hybrid approaches are often derived from literature and might refer to the situation in one country only – this is done for instance in Germany.

In order to promote and further develop hybrid approaches, some interviewees recommended that rather than having statistical institutions it might be good that research institutions or public institutions working more in research get attributed the responsibility.

A precondition for broad application is to converge towards a limited number of methods. Pooling of efforts is required to define missing conventions. In order to reach agreement on methodological soundness of approaches and to attempt to achieve concerted actions towards indicator calculation, interviewees from statistical offices stressed that is inevitable that some issues are resolved by convention (e.g. United Nations Systems of National Accounts, SNA). Conventions are an essential part for setting up sound methodologies for the users on the international level. Experts need to converge towards a few (or even a single) alternative method for estimating specific items. This must be doable for all countries, with availability of time series and up-to-date data.

This could be supported by establishing routine international audits of how countries do the environmental accounts. This could build on the experiences from UNFCCC process, where some quality review is done by the UN, ensuring a constantly ongoing process for improvement.

2.3 Synthesis on indicator-specific findings

2.3.1 Indicators used and familiarity with indicators

Statistical experts were deeply familiar with the three indicators DMI/DMC, RMI/RMC and TMR/TMC, while the policy experts also know all of them but with varying knowledge of their methodological details.

At the policy level the focus is more on the available indicators than their underlying methodologies. The goal is to answer questions related to the composition and efficiency of the economy, dependency on foreign-sourced resources, and the environmental impacts associated with natural resource use. Several interviewees from different stakeholder groups (statistical offices, policy making, civil society) indicated that the political use of indicators and underlying approaches depends on the questions they seek to answer and the targets they set – or in the case of resource policy rather not set. The policy area of resource use/efficiency was considered to still lack concreteness. Policies should target specific material categories; however, aggregated indicators often only reflect the current status of specific sectors. In addition, there are perceptions and strategic considerations regarding the strengths and weaknesses of various approaches and indicators that influence the selection.

According to interview feedback from OECD experts, material intensity and material use indicators are routinely used to alert policy-makers to important developments that require decision-making, but they are less important in the decision-making process itself due to the indicators weaknesses (see below). While OECD uses these indicators – specifically the resource and material flow indicators – in its environmental and economic country reviews, they are currently not yet used in the economic reviews. Nonetheless, these indicators have been identified as important metrics for the Green Growth work being undertaken by the OECD.

At UNEP, as an interview partner stated, while such indicators may not be used frequently and directly in decision-making, they contribute to the better understanding of how to achieve a decoupling of economic growth from escalating resource use and environmental degradation. They are used for example in relevant scientific assessment reports of UNEP International Resource Panel, which aims at the provision of independent, coherent and authoritative scientific assessment on the sustainable use of natural resources and the environmental impacts of resource use over the full life cycle on the other.

The following Box 1 summarizes what policy-makers generally expect and need from material and resource use indicators.

The information demand from indicators with respect to resource policy decisions is substantial and includes (i) how efficiently an economy is using its resources, (ii) status and trends in supply security, (iii) signalling of looming resource scarcities, (iv) identifying areas and sectors suffering from wasteful resource use, and (v) measuring progress towards a more circular economy. Thus, *useful* indicators provide a more *complete* and *timely* picture of direct and indirect material and resource use in a country, they are accurate and unbiased. For global outreach and intergovernmental organizations, such as UNEP, useful indicators are those that allow getting robust, comparable results across countries. A formalized assessment of the requirements for a useful indicator are given by OECD's five criteria of (i) policy relevance, (ii) soundness and validity, (iii) responsiveness to relevant changes while being robust to noise, (iv) being usable for international comparisons and (v) being interpretable.

Box 1: Characteristics of indicators that are useful for policy-making.

2.3.2 Strengths and Weaknesses of the Indicators

Strengths

According to interviewee feedback, material flow based indicators are especially apt to describe the pathway of materials from source to sink. However, to describe specific aspects of resource use, it is necessary to prepare the data in a way that is adequate for the question at hand. The "Four Footprints" advocated by Friends of the Earth Europe (land, water, carbon and material footprints)[4] are all based on Material flows, but have been elaborated further to address specific issues related to land, carbon, water and material use.

Across the interview partners, DMI and DMC were considered the most established and statistically most advanced indicators in terms of data availability and harmonization. Long time series are available for all EU member countries and for many other nations. Notwithstanding the limitations of MFA-derived indicators, there is therefore no real alternative to using MFA indicators, with the exception of specific sector or impact indicators such as embedded carbon, land or water footprint indicators[5] – all of which incidentally are not covered by the MFA-based indicators.

Furthermore, interviewees perceived the existing material use indicators DMI/DMC and RMI/RMC robust and detailed enough to help answer broad questions related to domestic and raw material use for economic and other policy fields. This is true to a much lesser degree for TMR/TMC. The available data are robust enough to identify trends over time (even if biased up- or downward due to data issues or exclusion of some resources), but require caution if structural shifts in the economic composition have taken place that may have shifted resource use to foreign countries or sectors not included in the analysis, e.g., the outsourcing of resource-intensive industries. In addition, detailed material flow data are only available for some resources, e.g., iron and copper, but are still lacking for many others.

In contrast, the strength of TMR/TMC and RMI/RMC was seen by some interviewees in that these indicators attempt to account global pressures exerted by national resource needs, by virtue of accounting for unused extraction and the associated ecological rucksacks arising abroad. This gives a more complete picture of the total material impact associated with a country's domestic consumption and can help avoid misleading resource use conclusions that so often plague specifically the DMI/DMC indicators. For example, if domestically produced coal, which has a level of material extraction, were replaced with imports, then the national MFA accounts and associated resource efficiency indicators would improve but at a global level the pressures would remain and could in fact be higher due to additional resource use for transport and possibly higher resource extraction inefficiency abroad. In addition, from a resource supply security standpoint this shift could be undesirable.

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[4] See http://www.foeeurope.org/resources, accessed 25 March, 2014.

[5] These footprint indicators build on the concept of the Ecological Footprint, which despite its methodological shortcoming and heavy reliance on generalization and estimation, has a compelling and intuitive idea, which makes communicating them much easier than MFA-based indicators.

Furthermore, some interview partners highlighted that putting MFA-based indicators on total domestic and raw material consumption in relation to imports of raw materials (e.g., import of oil, coal or natural gas) provides useful information for economic and security policy. It identifies resource dependencies that may lead to economic as well as foreign policy changes such as in areas of rare earths, energy, and other minerals.

Another strength of the indicators, according to interview feedback, is the possibility to relate them to measures of economic output, especially GDP and related indicators. By doing so, the indicator becomes a proxy for resource efficiency. Indeed, a major role of MFA-based indicators is in monitoring trends in how much and how efficiently an economy uses natural resources. This ratio can be further supported by a measure of resource use per capita. Both metrics combined tell a story of how well and effectively resources are used.

However, interviewees from statistical offices cautioned that comparing DMC as a resource use indicator to GDP is problematic, unless the trade balance is in full monetary equilibrium. Thus GDP plus value of imports minus value of exports would be the correct monetary value.

Despite its shortcomings, the lead indicator resource productivity (GDP/DMI) is perceived to be helpful for resource policy because it has a robust data basis and long time-series and because it has been elevated in several resource policy initiatives such as the German national sustainability strategy (in this context calculated as GDP/DMI_{abiot}). In the context of the German Energiewende, applying the lead indicator despite its shortcomings could send out a strong message to policy makers because it shows that by reducing the consumption of domestic lignite and increasing consumption of renewable energy carriers through the Energiewende the indicator GDP/DMI_{abiot} could show improved resource productivity perfomance (because of reduced quantities of lignite used) without shifting ecological burden to other countries by importing coal, e.g. from China with respective upstream burden.

Any resource efficiency assessment needs to put resource use in relation to economic output and per capita use because only the two combined tell a story of how well and effectively we are using materials. Despite known methodological biases, such as lead indicator allows setting goals and standards at political and corporate levels and hence allows measuring progress over time. The key question then becomes what goal or target should be set.

Weaknesses

Among the key issues requiring attention is (i) interpretation of the indicators and (ii) data availability, in particular for TMR/TMC.

Several interview partners stressed that none of the indicators discussed provide sufficient information on the environmental and/or social impacts associated with resource use or efficiency. For example, there is no differential treatment for using a ton of sand than there is for using a ton of mercury. MFA indicators expressed in physical units without adjusting for environmental impacts are, therefore, meaningless in the context of measuring environmental harm or creation of social wellbeing. In addition, from an environmental management perspective, the amount of resources used is not sufficient, because moving to a sustainable resource use policy means absolute decoupling of resource use from economic growth. However, the link between the amounts of resources used and their impacts are presently not robustly measurable and no benchmarked policy actions are usually taken before indicators with quantifiable progress and targets are developed.

Another critical weakness was seen to be data availability and quality. They are both still lacking in many countries, which impacts their ability to calculate the indicators as well as the calculation of TMR/TMC in the European countries. Data availability and harmonization are relevant for international and regional organizations, such as UNEP, OECD and Eurostat that conduct comparative analyses or have ongoing cooperation programmes with statistical offices and experts. Improving international trade data, further refinement of product tables and intensify coefficients is, therefore, very important to improve the completeness and accuracy of the indicators.

Methodologically, interviewee feedback made it clear that all three indicators have limitations that are well-known in the resource use and efficiency community but that might not be so apparent to less-experienced audiences. For instance, statisticians may not support the use of TMR/TMC precisely for these methodological reasons, the main argument being that much estimation (and guesswork) is involved in compiling TMR/TMC. Unused extraction (TMR/TMC) is far from being implemented in official statistics due to lack and/or poor quality of data. Non-expert audiences, on the other hand, may take explicit values for TMR or another of the indicators at face value without questioning or knowing the methodological and data limitations that make the value a best estimate as opposed to an accurate figure.

As regards the use of GDP as a denominator to estimate resource productivity, some interviewees pointed out that often no further contextual detail is provided. GDP as a denominator does not say anything about quality of life or the need to have absolute limits on resource use. That is because as long as GDP growth outpaces DMC growth resource productivity increases, which may be entirely misleading with respect to the environmental and/or social harm generated. Users of resource productivity indicators should also be aware that resource productivity does not always correlate with resource use in physical terms due to fluctuating market prices.

Another limitation, according to interview partner feedback, is that aggregate indicators do not provide information on sector-specific, product-specific or regional trends. In fact, positive resource use developments in one sector/product/region can be balanced out by negative trends in another. Aggregated results need to be treated with much more caution, because the economic structure of a country has implications on how to interpret the aggregated indicator: material-intensive sectors may co-exist with less material-intensive sectors such that the aggregated indicator does not tell much about where most material use occurs. Thus, when using production-based indicators, disaggregated indicators covering different sectors, product groups and, if available, regions should be considered to the extent possible.

With respect to geographical detail, the indicators discussed here are often not disaggregated due to lack of geographically differentiated data. Material flow indicators do not provide information on where the extraction of the materials is happening and global averages for material inputs are used.

2.4 Need for further methodological development of indicators

To be useful for monitoring and evaluating policy decisions it is critical that the time lag of the indicators is reduced from currently 4 or more years to 1-2 years. Eurostat is working towards this goal but it requires the combination of high-level commitment and changes in the national and international statistical systems. While methodologies and data are converging within the EU, that is not yet the case at the broader international level. In addition, greater acceptance of the indicators needs to be fostered, in part through their official adoption at high levels and in major resource policy initiatives. In the case of the OECD Green Growth Strategy, there is a strong top-down demand. The same holds for the EU's Resource Efficiency Roadmap. Both can be used to argue for the need to monitor progress and further investments in the development of the indicators. They also serve as test beds for the indicators utility. It is even better, if the indicators are linked to other policy areas such as competitiveness, because it increases their justification and use. However, setting resource related targets for resource efficiency is (mostly) politically difficult for the European or global level, and even more so to break these down to the country level. Therefore, policy makers should collaborate with academia to define needed goals.

Improvements should also be made with respect to regionally disaggregated data such that it becomes possible to identify the geographical source of raw materials. Various ongoing project efforts (e.g. WIOD-database projects, e.g. CREEA, EXIOBASE, OECD Gram, etc.) combine MFA-data with Input Output analysis aiming to show where resource use occurs and how efficient it is. It allows the policy-maker to identify the biggest users of specific materials. More detailed disaggregation by material/material category and sector would also be beneficial for identifying the most resource-intensive processes and for linking the indicators to evaluations of environmental impacts. MFA data is currently available for construction minerals, fossil fuels, biomass and metals, but the underlying data is reported for more than 50 categories. The official IO-table of Germany, based on external trade statistics covers 73 x 73 production areas – having greather detail would be better. If feasible, imputation methods should be considered, but clearly marked, so as to complete the available data basis.

A combination of LCA and IO approaches is generally considered to require a major, coordinated effort, while building on and improving intensity coefficients and external trade data would be a lot easier. However, this requires a greater extent of harmonization across Europe and internationally. Linking MFA-based indicators with existing indicator frameworks such as the DPSIR or the environmental impact indicators developed by the JRC would be useful because it then provides enhanced opportunities to assess the overall sustainability of an economy.

Lastly, among the most important aspects for improvement is to clarify the definition of productivity indicators. More clarity is needed on what will be measured in relation to which economic indicator. This ties into the need for better documentation, including the documentation of uncertainties in the indicators and strategies to deal with them.

In any such joint process for improvement of indicators, interviewees from statistical offices considered it essential that research institutions should try not to duplicate work and develop rival models only when the differences in the approaches pursued are too big. Focus should be on joining forces and cooperating as much as possible in order to a) fill the information gaps by collecting basic information rather than making use always of the same data; b) develop a very limited number of sophisticated calculation models for RMEs and TMRs, and explain to policy and public what this all is about.

2.5 Conditions conducive for further development

A key precondition for improving the indicators is high-level political support in terms of making the necessary resources available, but also with respect to the commitment to use the indicators in policy-decisions (policy demand). The Resource Efficiency Roadmap calls for accompanying the lead indicator by a dashboard of indicators and while the lead indicator has been adopted (with reservations), the dashboard is not yet broadly agreed and the same is the case for third-level detailed indicators. Thus, there is a need to focus policy demand on defining the issues that should be measured and translate them into suitable indicators coupled with adopting measurable targets for resource efficiency. It might be helpful to identify an organization or agency that can take on a leadership role in the process of data creation and methodological development (e.g., Eurostat or OECD). Such a leadership role should also include identifying (pro)active countries working on such issues and facilitating exchange between their statistical offices in order to build a critical mass of experienced experts able to inform and encourage other countries not so advanced yet.

Political support should also involve ensuring that the statistical offices have the staff to competently and effectively implement the program for calculating, monitoring and reporting on the indicators. Availability of case studies, i.e., countries that have successfully experimented and implemented the indicators (e.g., Netherlands) in policy processes provides added credibility for policy-makers to initiate a program in their own countries.

Concerning the names given to the indicators, it has become apparent that the current names do not mean much to policy-makers and civil society and even experts in different disciplines (economists vs. MFA experts) have varying definitions of some terms (e.g., material). It is therefore worth considering re-thinking the names given to the indicators.

The Indicators should be disseminated and regularly updated as much as possible, which will positively affect their visibility and long-term acceptance. Interviewees from statistical offices saw rather of problem of awareness than of acceptance regarding the meaning and usefulness of more comprehensive indicators. If you do not know such indicators exist and what they mean, you cannot accept them. Hence, awareness raising efforts are needed in order to create and foster acceptance.

For policymakers it is important to know why and how to relate the indicators to other pressing policy concerns (e.g., employment, growth, competitiveness, economic crisis) that they are working, because then it is easier to build up support for the indicators. This also concerns the indicators' ability to 'tell a story' that resonates with the policy-makers' constituents and also informs them about the trade-offs that resource efficiency entails in these other policy areas.

Another need of the policymaker community is getting the scientific community to better translate the nuances and technical details of the indicators into short, communicable pieces. For policymakers it is important to be able to explain to their constituents what the indicators are signaling, because people need to be able to relate to them. Otherwise uptake will be limited.

The material/resource use indicators discussed here are all highly aggregated metrics, which leads to the question of how they can be used in actual policy decisions without the disadvantages that are a typical consequence of aggregation.

Additional needs are:

- setting the targets for the economy,
- impact assessment of policy actions in relation with the economy and other policy areas of concern,
- assisting companies and governments in becoming more resource efficient,
- providing guidance to identify hotspots of policy action need (temporal and geographical)
- fostering joint and concerted, harmonious action in the indicator community and thus preventing or mitigating fights between different camps

Overall, there is a significant effort on statistical and research projects working towards combining environmental and economic accounts, IO using MFA data (WIODs, CREEA, EEA work). This in principle allows examining trends from a domestic and from global perspectives, to explore the driving forces and policy intervention points, and to monitor and compare resource productivity across countries or sectors and over time. However, when looking for specific policy application of such combined indicators, there is less evidence on where they are actually being used. Therefore, there seems to be a gap between the growth in available data and analyses on the one hand and their use in informing policymaking on the other. This disconnect needs to be repaired through closer communication between the end-users and the developers.

In addition, ensuring a level playing field by obliging all companies (within selected sectors) to monitor and publish monitoring reports would help indicator based communication and also the improvement of indicator data availability

3 AP 1.3 – Synthesis of background study and expert interviews

In the project on further development of raw material input indicators for the German UBA work package AP 1 performed a comprehensive review of existing approaches for the calculation of comprehensive indicators, such as Raw Material Consumption (RMC) or Total Material Consumption (TMC). This review was complemented by means of expert interviews, whereby a large number of representatives of different stakeholder groups such as policy makers or statisticians discussed and commented the current status quo of methodology development, indicator application and the needs for further improvements and harmonisation. In the following, we aim to provide a synthesis of the findings of these two work steps (AP1.1 and AP1.2 respectively) and to specify the main areas for future methodological improvements, indicator application and necessary next (political) steps.

Area	Issue	Argument	Suggested next steps
Methodology	Regional and sector coverage	Improvements should be made with respect to regionally disaggregated data to allow identifying the geographical source of raw materials and thus consider the different material intensities in various countries of origin. More detailed disaggregation by material category and sector would also be beneficial for identifying the most resource-intensive processes and for linking the indicators to assessments of environmental impacts.	Efforts have to be put on further disaggregation of both input-output tables as well as material intensity coefficients derived from process analysis – by means of research projects as well as further work within statistical offices. If feasible, modelled data should be considered, but clearly marked, to complete the available data basis.
	Economic focus of IO-tables	Input-Output-tables are oriented towards economic analyses. However, the economic structures (i.e. sectors of main monetary flows) do often not match with the resource flow relevant sectors. I.e. a high detail is provided for manufacturing and service sectors, but material extraction and processing sectors are often highly aggregated.	Further detailing and disaggregation of resource flow relevant sectors in national input-output tables is needed, in order to improve their suitability for assessment of material flows.
	Source, credibility and transparency of data	Procedures for manipulating IO tables, e.g. for disaggregating existing tables or harmonizing IO tables from different national sources, are often not well documented. Used accounting frameworks and data need to be closely linked to standard economic and environmental accounting, as this also increases acceptance by statisticians and policy makers.	Improve the applied methodology's linkage to official accounting frameworks as well as the scope and detail of methodological documentations.

Area	Issue	Argument	Suggested next steps
	Data availability / quality	Quality of data for input-output tables of particularly non-OECD countries is often difficult to evaluate. Coefficients are mostly available only for one point in time and hence do not reflect technological improvements. Approaches which developed disaggregated mixed-unit input-output tables (e.g. the Eurostat approach) used detailed and un-published data from the German statistical office, limiting the replicability.	Harmonisation of available international data bases for input-output tables and bilateral trade data is urgently required. It would therefore be important that input-output tables and trade data are being reviewed, quality-checked and harmonised by international organisations, such as the OECD and the UN. The compilation of a comprehensive, quality-checked and up-to-date database on material inputs or "raw material equivalent" coef-ficients is another key step.
	Future methodology	Focus should be on joining forces and cooperating as much as possible in order to a) fill the information gaps by collecting basic information rather than making use always of the same data; b) develop a very limited number of sophisticated calculation models for RMEs and related unused extraction (for calculating TMR and TMC), and explain to policy and public the potentials of compre-hensive material flow indicators.	The most promising approach would be a hybrid model that com-bines detailed RME coefficients for imported raw materials with a multi-regional input-output approach with a high level of detail in the relevant sectors. Rather than statistical institutions, which have a limited mandate on the international level, it might be advisable that research or other public institutions promote and further develop hybrid ap-proaches.
	Methodology improvement	Improvements of methodologies to be applied are resource inten-sive and costly; so is the actual application and related data collec-tion. Adding this burden to the current work load of statistical offic-ers will not allow for a satisfying result, i.e. regular, up to date and high quality data collection. So far, there are various initiatives which aim at improving meth-odologies and collect data – often with a lack of coordination which leads to parallel processes and lack of funds due to fragmentation.	Political support should ensure that statistical offices have the required staff to competently and effectively implement the pro-gram for calculating, monitoring and reporting on comprehensive material flow indicators. Availability of case studies, i.e., countries that have successfully experimented and implemented the indica-tors in policy processes (e.g., Netherlands) provides credibility for policy-makers to initiate a program in their own countries. Identify an organization or agency that can take a leadership role in the process of data creation and methodological development (e.g., Eurostat or OECD). Such a leadership role should also in-clude identifying (pro)active countries working on such issues and facilitating exchange between their statistical offices in order to build a critical mass of experienced experts able to inform and encourage other countries not so advanced yet.

Area	Issue	Argument	Suggested next steps
Indicator	Time lag in indicator cal-culation	To be useful for monitoring and evaluating policy decisions it is critical that the time lag of the produced indicators in use is re-duced from currently 4 or more years to 1-2 years. Eurostat is working towards this goal but it requires the combination of high-level commitment and changes in the national/international statis-tical systems.	In the OECD Green Growth Strategy, there is a strong top-down demand for comprehensive material flow-based indicators. The same holds for the EU's Resource Efficiency Roadmap. Both can be used to argue for the need to monitor progress and further in-vestments in the development of these indicators.
	Indicator acceptance	For policymakers it is important to know why and how to relate the indicators to other pressing policy concerns (e.g., employment, growth, etc.). This also concerns the indicators' ability to 'tell a story' that informs them about the trade-offs that resource efficien-cy entails in these other policy areas.	Acceptance can be increased through increased awareness of what comprehensive material use indicator can tell, as well as through their official adoption at high levels and in major resource policy initiatives.
	Targets	For effective resource use management it is essential not only to be able to quantify past, current and expected future resource use, but also to set specific targets towards which to thrive for.	There is a need to focus policy demand on defining the issues that should be measured and translate them into suitable indicators coupled with adopting measurable targets for resource efficiency.
	Linkage to other indicator frameworks	Linking MFA-based indicators with existing indicator frameworks such as the DPSIR or the environmental impact indicators devel-oped by the JRC would be useful because it then provides en-hanced opportunities to assess the overall sustainability of an economy.	
	Defining productivity	More clarity is needed on what will be measured in relation to which economic indicator? When setting economic performance into relation with environmental pressures, it is essential to do so at comparable (regional, sectoral, etc) levels to ensure meaningful results.	Agreement on productivity indicators to be applied on MS, EU and international level.
	Indicator na-ming	Concerning the names given to the indicators, it became apparent that the current names do not mean much to policy-makers and civil society and even experts in different disciplines (economists vs. MFA experts) have varying definitions of some terms (e.g., material).	It is worth considering re-thinking the names given to the compre-hensive material flow-based indicators.