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STATE-OF-PLAY OF NATIONAL CONSUMPTION-BASED INDICATORS

A review and evaluation of available methods and data to calculate footprint-type (consumption-based) indicators for materials, water, land and carbon

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Executive Summary

Background

The “Resource Efficiency Roadmap” presented in 2011 aims at presenting a first set of resource use and resource efficiency indicators and related policy targets by the end of 2013. In this context, it is currently being discussed to what extent indicators reflecting the global environmental pressures related to consumption activities in the EU (“footprint”-type indicators) could be included in this set.

In academia and statistics, a large number of methodologies, data and indicators on various footprint indicators related to the dashboard categories, i.e. material, water, land and carbon footprints, have been presented in recent years. However, so far, no harmonized methodology exists to calculate these indicators in the context of European resource use and resource efficiency. In addition, the data availability and quality to calculate the various footprint indicators varies between the different methodological approaches and the various categories of resource use.

However, despite these observed variations and deficiencies, the general conclusions from the available studies are all pointing to a similar direction: developed regions such as Europe are increasingly outsourcing environmental burden to other world regions via international trade, with footprints being significantly higher than the respective territorial indicators. This fact points to the importance of including both types of indicators, i.e. territorial and footprint-type indicators, in the assessment scheme of the Resource Efficiency Roadmap, in order to avoid misleading policy conclusions on Europe’s actual resource efficiency performance.

Objectives of this report

The present report provides a concise review of the state of the art in the development of footprint-type indicators for materials, water, land and carbon for use on the national level (macro level). Based on a review of a large number of papers and studies published in recent years, the various footprint calculation methodologies along with their key advantages and disadvantages are discussed. In addition, the quality and availability of data to calculate those indicators is assessed and evaluated. In the final chapters, key areas for further improvement of the footprint-type indicators are described, including a first estimation of the required efforts to make them ready for use in the context of EU resource policies.

Main conclusions

1. Methodologies

Significant efforts have been invested in recent years to develop and test various methodological options for calculating footprint-type indicators. Three main methodologies proved to be capable of capturing the global effects of European consumption: input-output analysis (top-down approach), coefficient approaches based on process analyses (bottom-up approach) and hybrid approaches with elements from both basic methods. So far, there is no perfect method available yet. However, hybrid approaches have the highest potential as they allow combining the advantages of the two basic methods: full completeness and consistency of input-output analyses with the high preciseness of process-based coefficients.

2. Data situation
For input-output analyses as well as for all the four main categories of resource use data are already available, although at different levels of disaggregation and quality. Significant improvements have recently been achieved in data sets allowing constructing multi-country input-output models. Regarding environmental data, data on material flows as well as on GHG emissions are already quite robust. In the cases of water and land use there is still a larger potential for improvement regarding accounting standards as well as data coverage, disaggregation and quality.

3. Readiness of existing indicators
The four footprint indicators vary in terms of conceptual and methodological maturity. Carbon footprints and material footprints are relatively advanced concepts, with methodological guidelines being available and ensuring a certain level of comparability. For those types of resource a possible use of one of the indicator options could be envisaged in the short term and various options exist. Before water and land footprint indicators are applied, methodological improvements and harmonisation still need to be achieved.

4. Recommendations
A consistent and robust methodology for calculating the footprint indicators would have one consistent multi-regional input-output data base its is core, with a high sector disaggregation and extensions by bottom-up resource intensity coefficients to cover those products, which are not represented in the input-output framework with sufficient detail. In order to proceed towards this best-suited methodology, further improvement are required in a number of areas, including improving the level of disaggregation in input-output models, the development and testing of hybrid models, the establishment of time-series and the use of synergies between the assessment procedures for different resources.

Europe would be in position to take the stewardship for further developing and aligning footprint indicators. To achieve that long-term commitment to actively establish strong institutional links between statistics, research and policy is required along with adequate funding. The European Commission could establish an international forum for exchange and further development of footprint indicators, including core international research bodies such as the IPCC and the UNEP International Resource Panel, international statistical data providers, such as the UN and OECD, along with a group of stakeholders, who are demanding for footprint-type indicators (policy makers, companies and business associations, civil society organisations).

1. Introduction

1.1. Policy background

The "Resource Efficiency Roadmap" presented in 2011 (European Commission, 2011) set the objective to **agree on a set of resource use and resource efficiency indicators and related policy targets by the end of 2013**. The Communication explicitly mentioned that this set of indicator should also take into account the global environmental pressures related to consumption activities in the EU ("footprint"-type indicators).

Also in the public consultation on 'Options for Resource Efficiency Indicators' (European Commission, 2012), the consideration of consumption-based indicators was called for by various stakeholders. In the public consultation document, the Commission communicated that it is intended to use or further develop the following indicators in the categories of land, water and carbon. Furthermore, for the lead indicator on resource efficiency, the Commission intends to replace the indicator on Domestic Material Consumption (DMC) by the Raw Material Consumption (RMC) indicator in the medium-term. In contrast to DMC, RMC does include the materials embodied in imported and exported products and can therefore monitor indirect effects outside the EU territory caused by European production and consumption activities (see Table 1).

Table 1: Indicators for the dashboard for current use or further development

	Production / territory perspective	**Consumption / footprint perspective**
Material	Domestic Material Consumption (DMC) – available	Raw Material Consumption (RMC) – to be updated and improved Total Material Consumption (TMC) – still under methodological development
Land	Artificial land or built-up area (km²) – available with restrictions in time series	Indirect land use / embodied land for agricultural and forestry products (km²) – to be developed
Water	Water exploitation index (WEI, %) – available with restrictions on completeness of data and regional/temporal resolution (river basin/intra-annual variations)[1]	Water footprint – to be updated and improved or Embodied water – to be developed
Carbon	GHG emissions (t) – available	Carbon footprint – estimates available from scientific sources

Source: adapted from (European Commission, 2012)

In academia and statistics, **a large number of methodologies, data and indicators on various footprint indicators** related to the dashboard categories, i.e. material, water, land and carbon footprints, have been presented in recent years (see the following chapters).

However, so far, **no harmonized methodology** exists to calculate these indicators in the context of European resource use and resource efficiency. In addition, the **data availability and quality to calculate the various footprint indicators varies** between the different methodological approaches and the various categories of resource use. This implies that applying different methods and basic data to one single issue can lead to

[1] The WEI indicator has limitations; e.g. it aggregates different water resources, it does not take into account the nature of the water use after abstraction, the commonly used threshold values are under discussion. The Commission is exploring alternatives, which are however not yet fully available. Awaiting improvements, the WEI will continue to be used.

largely diverging results. For example, a study comparing the differences in the total water footprints of countries, when calculated with different methodologies and data sets, revealed that the water footprint can vary up to 48%, with variations being even larger when analysing single economic sectors (Feng et al., 2011). This poses a problem for the use of those indicators in a policy context, where robustness, transparency and replicability of the results are core requirements for data and indicators to be accepted and used by different actors.

At the same time, the general conclusions from the available studies are all pointing to a similar direction, independently of data and methods: footprint-type indicators, which use a life-cycle perspective and take into account global supply chains, reveal **larger and increasingly growing environmental pressures for Europe and other developed countries** compared to territorial indicators focusing only on the environmental situation within their borders (see detailed literature evaluation tables in the Annex). This implies that developed regions such as Europe are increasingly **outsourcing environmental burden to other world regions** via international trade. Applying only territorial indicators reflecting the situation within Europe could therefore lead to distorted conclusions on the actual resource use and resource efficiency performance of the European economy. This fact points to the importance of **including both types of indicators, i.e. territorial and footprint-type indicators**, in the assessment scheme of the Resource Efficiency Roadmap.

Currently, **significant research activities** on the European and international level are devoted to improving and refining the methodologies underlying footprint-type indicators and enlarging the available data bases (for example, Tukker and Dietzenbacher, 2013; Wiedmann et al., 2011). It can therefore be assumed that methodologies and results for footprint-type indicators will converge in the future, thus reducing the diversity of methodological approaches (see recommendations section at the end of this report).

1.2. Objectives of this report

The objective of the present report is to provide **a concise review of the state of the art in the development of footprint-type indicators for materials, water, land and carbon**. The report is oriented towards indicators on the national level (macro level), as it shall provide inputs for the current discussion in the context of the European Resource Efficiency Platform. However, it shall be emphasised that all indicators can also be calculated on the level of products, companies, households and individuals (micro level).

Based on a review of a large number of papers and studies published in the past 5 years (2008 or younger), the various methodologies for calculating footprint-type indicators are summarized and their key advantages and disadvantages discussed. In addition, the quality and availability of data to calculate those indicators will be assessed and evaluated. In the final chapters, key areas for further improvement of the footprint-type indicators are described, including a first estimation of the required efforts to make them ready for use in the context of EU resource policies.

The structure of the report is as following. Chapter 2 provides a clarification of the term “footprint-type indicators” and explains, in which aspects those indicators differ from other resource use indicators. Chapter 3 focuses on the methodological aspects and provides an overview of the three main methodologies in use along with an evaluation of their key properties. Data issues are the focus of Chapter 4, in which we analyse the various data sets required to calculate footprint-type indicators and assess the robustness and availability of those data sets. Chapter 5 draws the conclusions from the review and evaluation and discusses to what extent the available indicators are already fit for use in the EU policy context. Areas for further development along with an estimation of the required efforts by different actors are described in the final chapter 6.

2. Definition of footprint-type indicators

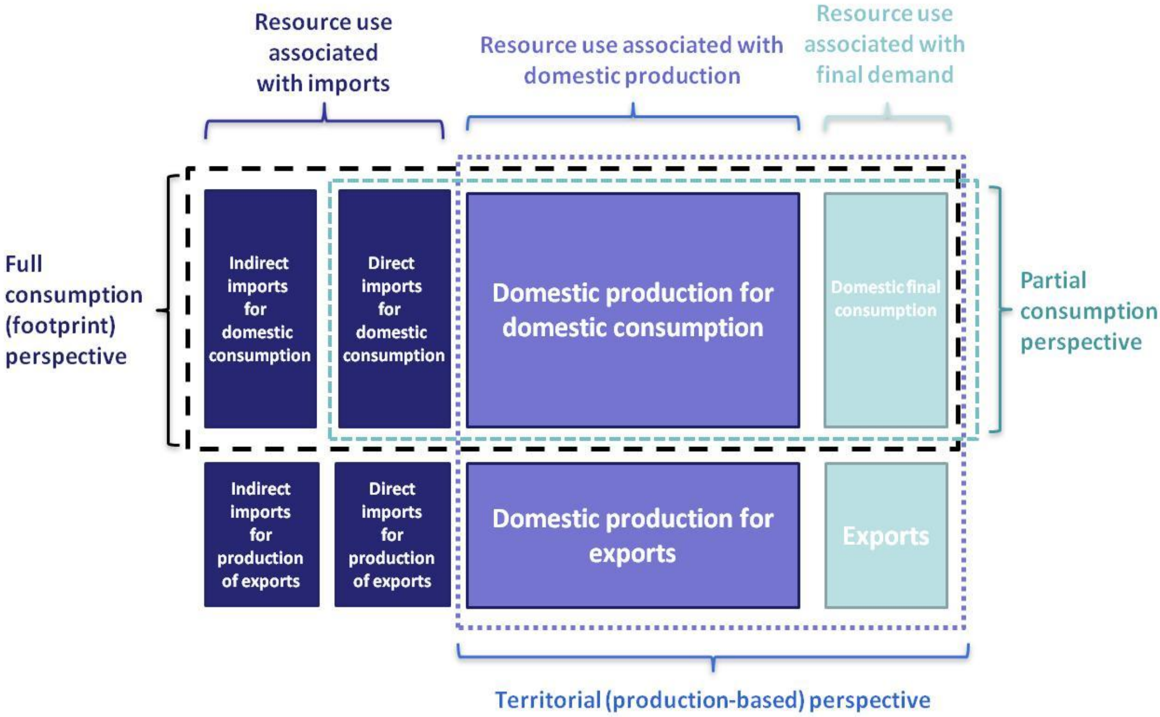
The **term "footprint"** was initially introduced by **Mathis Wackernagel and William Rees in the early** 1990s (Rees and Wackernagel, 1992), when the indicator "Ecological Footprint" was first presented. The Ecological Footprint is an aggregated indicator illustrating the total biologically productive land and water an individual, population or activity requires to produce all the resources it consumes, and to absorb the waste it generates (WWF et al., 2012). Ecological Footprints generally take a consumption-based perspective, i.e. they include all biologically productive areas world-wide to satisfy consumption in a specific country, including those embodied in internationally-traded products.

Following its introduction, the **term "footprint" was rapidly taken up by a large number of other concepts of environmental accounting**. For example, in the area of carbon accounting, several studies in the 1990s quantified the potential magnitude of flows of embodied carbon between countries and suggested this may undermine the effectiveness of global climate policy through 'carbon leakage', whereby a reduction of emissions in one part of the world leads to increased emissions elsewhere (Andrew and Peters, 2013). Those new ways of assessing GHG emissions also initiated a discussion on producer versus consumer responsibility. Under the principle of consumer responsibility, i.e. the carbon footprint perspective, all global emissions are attributed to the final use of a country, whereas the producer responsibility reflects the emissions of a country due to its production. The difference between consumer and producer responsibility is intimately related to the difference between exports and imports of embodied GHG emissions (Tukker and Dietzenbacher, 2013).

More recently, the term "footprint" was then also introduced for consumption-oriented indicators for water, land, materials and overall environmental impacts of products. **In this report, we focus on the resource categories of material, water, land and carbon.** The Ecological Footprint indicator or environmental impact indicators are excluded from the review.

The following illustration (Figure 1) provides a conceptual overview between **three different options for setting the boundaries** to calculate resource use indicators: the territorial (production-oriented) perspective, the partial consumption perspective and the full consumption (footprint) perspective. In this schematic illustration, overall resource use can be observed either to imports (direct and indirect), the domestic production system or final demand (domestic consumption or exports).

Figure 1: The framework for consumption-oriented versus production-oriented accounting of resources



Source: own illustration[2]

The **territorial (production-based) perspective** assesses all resource use taking place within the territory of the assessed country, including resource use required to produce both domestic final consumption and exports. This is e.g. the perspective taken in the accounting of GHG emissions in the Kyoto framework.

The **partial consumption perspective** additionally takes into account direct imports to the domestic economy and subtracts the direct exports. This consumption perspective is thus not providing a full picture of consumption-related resource use of a country, because it lacks indirect resource inputs associated with the production of imported goods and services and includes on the other hand resources that have been used domestically for the production of exports. This approach is e.g. taken in the material flow-based indicator Domestic Material Consumption (DMC).

The **full supply-chain, consumption (footprint) perspective** includes the domestic production for final consumption as well as the total direct and indirect resource use associated with imports serving domestic final consumption. The review undertaken in this report focuses on this third perspective. Consequently, resource use associated with exports is excluded for the analysed country, as the resource use associated with exports (including the domestic production for exports) is allocated to the final consumption of another country. This implies that consumption-oriented indicators can be added up across countries to arrive at the total footprint of a region (such as the EU).

[2] We thank Oliver Zwirner (DG Environment) for providing inputs for this illustration.

It shall be emphasised again that adding consumption-oriented footprint-indicators to an indicator set do not make other indicators obsolete. Increasing the resource efficiency of export production still is a key issue, either for the producing country in the territorial perspective or the consuming country in the footprint perspective.

Based on those definitions of boundaries, the following short definitions can be provided for the four footprint-type indicators. It is important to emphasise that the definitions refer to the general concepts and not specific indicators promoted by various institutions.

Box 1: Short definitions of material, water, land and carbon footprint concepts

The **material footprint** illustrates the global, life-cycle wide material extraction and use related to the final consumption of a country, whether occurring within the country or beyond the countries' borders. Material footprint is therefore a newer term for "**ecological rucksacks**" (Schmidt-Bleek, 1992; Schmidt-Bleek, 2009), which also refer to the life-cycle wide material inputs of products. Material footprints can be focused on used material extraction (resulting in the indicator Raw Material Consumption) or also include unused material extraction (delivering Total Material Consumption). Through underlying guidelines such as those elaborated by EUROSTAT (2011b) or the OECD (2007) the methodological developments of the material footprint indicator are already quite advanced.

The **water footprint** is the total amount of fresh water that is used directly and indirectly to produce the goods and services which satisfy domestic final consumption. For effective water management the water footprint ideally distinguishes between different types of water flows: (1) water withdrawal and water consumption; the first term being the whole amount of water abstracted from the environment, the second being only the amount which is not returned at all (incorporated in the product) or at much later point in time or to another catchment. (2) Blue and green water; the first being water stemming from surface and groundwater, the second stemming from rainwater. Comprehensive water accounts – and the resulting footprint analyses – encompass all these aspects appropriation of water by human society.

The **land footprint** assesses the domestic and foreign land areas, which are directly and indirectly required to satisfy domestic final consumption. It is important to note that land footprint approaches differ from calculations of the ecological footprint, as no weighting of land areas by different bio-productivities is applied. Studies on ecological footprints are excluded from the review in this report. In contrast to the category of materials, no harmonised definition of the land footprint exists so far. Due to data restrictions, land footprint studies have so far often focused on the agricultural and forestry areas. However, important questions still need to be resolved, before land footprint indicators can fully be integrated into a footprint-type indicator set (see chapter 5 for details).

The **carbon footprint** is the footprint indicator addressed by the largest number of studies so far (see next chapter and Annex). The carbon footprint captures the full amount of greenhouse gas emissions that are directly and indirectly caused by an activity or are accumulated over the life stages of products, which are consumed in a country (Wiedmann, 2011). Three standards for carbon footprinting have been already published, including the

PAS 2050 standard (BSI, 2008), the Product Life Cycle Accounting and Reporting Standard by the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD) (WRI & WBCSD, 2011), and the International Organisation for Standardisation developed the ISO 14067 on the Carbon Footprint of Products (ISO, 2012).

3. Methodologies for calculating footprint-type indicators

Chapter 3 contains three parts. In chapter 3.1 we provide an overview over the reviewed literature and the main methodologies applied to calculate footprint-type indicators. Chapter 3.2 presents concise descriptions of the three main methodologies, their basic assumptions and their key properties. In the final chapter 3.3 we conclude with an overview table illustrating the advantages and disadvantages of each method.

3.1. Overview over available methods and literature

Generally, **three types of methodologies** to calculate footprint-type indicators can be specified. Also the literature review allocates the various studies according to those three categories.

(i) The first group of approaches are based on various forms of economic **input-output analysis**, which integrate physical data on resource use (material, water, land data) or emissions (GHG emissions in the case of carbon footprints). 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 via the input-output tables. 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.

(ii) The second common group of methodologies are **coefficient approaches**, which derive the supply-chain wide resource intensity coefficients from **process analyses** such as Life Cycle Assessment (LCA) or similar methods. This approach is a bottom-up approach, which starts the calculation from the level of single products or product groups.

(iii) **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 and calculate one part based on input-output analysis, and the remaining part with resource intensity coefficients. The literature review revealed that many experts assume that a hybrid approach, which possibly combines the strengths of the two basic methodologies, will be the most important route for future methodological development.

The following literature summary table delivers an overview of the evaluated studies from the past five years (i.e. publication in 2008 or more recent years), ordered by types of approaches and categories of resource use; full references to all reviewed literature can be found in the reference section at the end of this report.

Table 1: Selection of footprint studies published in the past few years

	Input-output analysis	**Coefficient approach**	**Hybrid approach**
Materials	(Arto et al., 2012) (Bruckner et al., 2012) (Duchin and Levine, 2012) (Munoz et al., 2009)	(Dittrich et al., 2012a)	(Buyny et al., 2009) (Schaffartzik et al., 2009) (Schoer et al., 2012a) (Weinzettel and Kovanda, 2009)
Water	(Arto et al., 2012) (Daniels et al., 2011) (Dietzenbacher and Velázquez, 2007) (Feng et al., 2011) (Chen and Chen, 2013)	(Jeswani and Azapagic, 2011) (Ridoutt et al., 2012) (Herath et al., 2013) (Chapagain and Orr, 2009) (Mekonnen and Hoekstra, 2011) (Feng et al., 2011)	
Land	(Arto et al., 2012) (Bruckner, 2012) (Lugschitz et al., 2011) (Wilting and Vringer, 2010)	(Bringezu et al., 2012) (Ermolieva, 2012) (Fader et al., 2011) (Gavrilova et al., 2010) (Kastner et al., 2011b) (Kastner et al., 2011a) (Kissinger and Rees, 2010) (Qiang et al., 2013) (Van Oel et al., 2009) (Von Witzke and Noleppa, 2010)	(Vringer et al., 2010) (Weinzettel et al., 2013)
Carbon	(Arto et al., 2012) (Alcántara and Padilla, 2009) (Bruckner et al., 2010) (EUROSTAT, 2011a) (Hertwich and Peters, 2009) (Li and Hewitt, 2008) (Nakano et al., 2009) (Peters and Hertwich, 2008) (Peters et al., 2011) (Peters et al., 2012) (Wilting, 2012) (Wood and Dey, 2009) (Yunfeng and Laike, 2010)	(Cheng et al., 2011) (Ramachandra, 2012)	(Cranston and Hammond, 2012) (Heinonen and Junnila, 2011)

As the overview table illustrates, a large number of studies have been published particularly in the past few years on various footprint-type indicators, indicating the increasing importance to monitor national environmental and resource efficiency performance in a supply-chain wide (global) context. The **studies available in the literature use all three types of approaches**, but most recent literature refers to input-output models of various forms, in particular in the case of Carbon Footprints. With regard to land, a large number of studies have also applied the coefficient approach, as for land footprint assessments, a high disaggregation level for different products is particularly important. The detailed literature review tables are attached in the Annex document to this report.

3.2. Short description of the main methodologies

In the following, we provide a short description of the three main methodologies and their key properties.

3.2.1. Input-output analysis

Input-output economics was founded by the Russian-American economist Wassily Leontief, who investigated how changes in one economic sector effect other sectors (Leontief, 1936; Leontief, 1986). Leontief introduced "input-output analysis", a quantitative economic technique that represents the **interdependencies between different branches of a national economy** or different regional economies. He also won the Nobel Prize in Economics in 1973 for this new type of economic model.

Input-output models are comprehensive models in terms of integrating economic data for a whole economic system (one country or several countries). 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.

A review by Hoekstra undertaken in 2010, although still only available as a conference paper (Hoekstra, 2010), provides one of the most comprehensive historical analysis in the field of environmental input-output analyses. He tracked close to 360 papers in the refereed literature between 1969 and 2010. Some important conclusions from this meta-review include the following:

- The main scientific production in the EE IO field occurred after 1995; just 50 out of the 360 papers were published before that date.
- Papers published before 1995 focused almost exclusively on energy use, whereas more recent studies take into account a large variety of environmental issues.
- About 90% of the papers focused on single countries.
- Issues related to pollution embodied in trade have been discussed in only a few papers before 1995, whereas the number of papers increased significantly between 2005 and 2010 (20% of the 100 publications).

How to calculate footprint-type indicators with input-output analysis

One of the most important applications of input-output analysis is the calculation of total input requirements for a unit of final demand. By doing so, one can assess not only direct requirements in the production process of the analysed sector, but also all indirect requirements resulting from intermediate product deliveries from other sectors. Thus the total (direct and indirect) input necessary to satisfy final demand (e.g. private consumption or exports) can be determined. If an input-output model includes data on natural resource use (e.g. material inputs, water use, land use) or GHG emissions, the total (direct and indirect) requirements of natural resources or the total emissions to satisfy domestic final demand (in particular: domestic consumption) in each economic sector can be determined.

Different approaches of input-output analysis

Most studies on footprint-type indicators based on input-output analysis use an economic core model, i.e. monetary input-output tables (MIOTs). Input-output tables in monetary units are now available for a large number of countries (see chapter on data availability). This implies that environmental data are allocated to final demand following the monetary flows between the sectors of the economy.[3]

Two basic input-output models can be distinguished:

(a) ***Single-region input-output (SRIO) models***. Those models put one country (or one aggregated region, such as the EU) in the centre of the analysis and integrate only the input-output table for the analysed country or region. The major advantage of this type of model is that it is relatively easy to handle in a technical sense, as the amount of data is limited. The key disadvantage is that those models typically have difficulties to properly assess the resource requirements of imports. They therefore most often work with the assumption that imports are produced with the same technology as products in the domestic economy (i.e. domestic technology assumption). This assumption can lead to mistakes, as foreign resource intensity is often very different to the domestic one (Tukker et al., 2013). This is in particular true for products, which are not (or very differently) produced in the domestic economy, such as metal ores in Europe (for example, Schoer et al., 2012a). However, some authors argue that this assumption illustrates the “resources saved” through importing products instead of producing them domestically (Munoz et al., 2009).

(b) ***Multi-region input output (MRIO) models***: those models link the input-output tables of several countries or regions with bilateral trade data.[4] The major advantage compared to type (a) models is that they trace not only domestic supply chains, but supply chains on the international level (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 become very large and require specific mathematical skills to programme and calculate footprint-type indicators.

Key advantages of input-output analysis

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 resource input can only be

[3] Input-output tables can in principle also be produced based on physical units, such as mass or energy flows (Physical Input-Output Tables, PIOTs). However, PIOTs are not yet available for a larger number of countries and differ widely in their levels of sectoral aggregation and the definition of system boundaries (Giljum and Hubacek, 2009).

[4] There also exist variations within MRIO models. Some just include bilateral trade with main trading partners to estimate resources or pollution embedded in this bilateral trade (unilateral trade models), others reflect bilateral trade between all countries covered in the data set (multilateral trade models) (Wiedmann, 2009).

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 of input-output analysis

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 resource 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.

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).[5] The **intention is to create systems with a higher level of disaggregation**, in particular in environmentally-sensitive primary sectors, thus avoiding mistakes resulting from the high level of aggregation of the IO tables. Also input-output systems developed outside Europe (such as the Eora database) (Lenzen et al., 2012) point in the same direction.

Other disadvantages that are emphasised in the literature related to footprint-type calculations based on input-output analysis are

- the **large time-lag** for the publication of input-output tables, in particular those harmonised for MRIO models and those tables with a high level of disaggregation: input-output tables are often published with a delay of several years, sometimes even a delay of 6-10 years.
- the high sensitivity of input-output models to **relatively small errors in the trade data**, in cases where imports and exports of a country are large relative to its domestic production. Relatively small errors in the estimates of imports and exports can then suddenly translate into relatively large errors in the footprint estimate (Mekonnen and Hoekstra, 2011).
- the **assumption of proportionality** when allocating resource flows to monetary structures, which implies that trade of western countries with high value-to-weight ratios is underestimated in terms of actual resource requirements related to trade and consumption compared to non-western countries which in reality have higher value-to-weight ratios (Bruckner et al., 2012).
- the high sensitivity of results depending on the way **resource use data are allocated to sectors.** E.g. allocating construction minerals either to the extraction sector or the construction sector as the main user of the minerals can result in different further distribution of these materials throughout the domestic economy and the trade chains due to the

[5] Examples include: FP6: EXIOPOL (www.feem-project.net/exiopol), FORWAST (forwast.brgm.fr), OPEN-EU (www.oneplaneteconomynetwork.org). FP7: CREEA (www.creea.eu), DESIRE, WIOD (www.wiod.org)

different trade partners of the extraction and construction sector, respectively (Bruckner et al., 2012).

3.2.2. Coefficient approaches based on process analyses

Coefficient approaches are applied in various methodologies of environmental assessments. Most prominently, current estimations of domestic GHG emissions in the context of the UN Convention on Climate Change follow a coefficient approach, where activity data (e.g. the production of certain amount of metal or agricultural product) is multiplied with a GHG intensity emission factor (UNFCCC, 2006).

How to calculate footprint-type indicators with coefficient approaches

Coefficient approaches calculate the total resource use (or GHG emissions) associated with final consumption by multiplying the direct physical quantity consumed of each product with a factor which illustrates the “cradle-to-product” resource intensity. Thereby, the factors inform about the supply-chain wide (indirect) resource inputs for a certain product or activity (for the case of material intensity coefficients, see Dittrich et al., 2012a).

Key advantages of coefficient approaches

The most important advantage of coefficient approaches in comparison to input-output approaches is the **high level of detail and transparency**, which can be applied in footprint-oriented indicator calculations. Coefficient approaches do not face restrictions of the definition of sectors or product groups in the input-output models and thus allow 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 footprints by commodity or product categor**y in a very straightforward and transparent manner, as the overall numbers are summed up from the bottom, which is more difficult to assess in the top-down approach of input-output analysis (Mekonnen and Hoekstra, 2011). Coefficients can also be a pragmatic alternative to estimate the total resource use of products in case input-output calculations are not available (Dittrich et al., 2012a).

Key disadvantages of coefficient approaches

One key disadvantage of coefficient approaches is the **high level of effort** to construct solid coefficients for a large number of products. Coefficient 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 so-called “**truncation errors**”, as the indirect resource requirements are not traced along the entire industrial supply chains. Inter-sectoral deliveries have to be cut-off at some point due to an overproportional effort to consider all indirect effects (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 coefficient approaches, thus causing an underestimation of the total footprint related to final consumption (Dittrich et al., 2012b).

In many cases, resource intensity 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 applied 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).

However, also regarding the coefficient approach, significant efforts are being invested into constantly **improving and enlarging the data situation**. The Wuppertal Institute's data base for material intensity coefficients comprises more than 2000 specific factors (Dittrich et al., 2012a). Also in the context of the Eurostat project to estimate materials embodied in European imports and exports, specific coefficients to supplement input-output based calculations were derived for a number of products comprising crude oil, natural gas, primary metal ores, and all basic metals (Schoer et al., 2012b). Also the coefficients underlying the water footprint calculations are constantly expanded and improved (Mekonnen and Hoekstra, 2011).

3.2.3. Hybrid approaches

In the past few years, hybrid approaches became increasingly popular in footprint-type calculations. These approaches combine elements from input-output analysis with coefficients and aim at exploiting the advantages from both approaches.

How to calculate footprint-type indicators with hybrid 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 coefficients for raw materials and products with a low level of processing, as the coefficients allow taking into account specific aspects with regard to different materials, applied technologies and countries of origin. 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 (Buyny et al., 2009; Schoer et al., 2012a).

Key advantages of hybrid approaches

The key advantage of the hybrid approach is that applied coefficients allow **compensating the disadvantages** normally faced with input-output analysis, which is particularly relevant for the assessment of products with a low level of manufacturing (Schaffartzik et al., 2009; Schoer et al., 2012b; Wiedmann, 2011). At the same time, the above mentioned advantages of input-output analysis in particular regarding the full reflection of all supply-chains are kept for products with a higher level of manufacturing.

Many authors thus regard hybrid approaches as the most promising way forward for further developing methodologies for footprint-type indicators in the future (see also recommendation section below).

Key disadvantages of hybrid approaches

So far, **no harmonised methodology** exists how to best apply the hybrid approach. Each study thus selects its own set of products, which are calculated based on the coefficients versus the input-output methodology. Results from different studies can thus not be directly compared.

Furthermore, some of the **disadvantages described for the two basic approaches** are also relevant in this case, including the limited number of temporary or spatial explicit resource intensity coefficients and the lack in timeliness of available input-output data.

3.3 Conclusions

After the description of the main properties of each of the three main methods, we now provide a summary on the key advantages and disadvantages of each method. We use a simple, three-step evaluation scheme to highlight the main strengths and weaknesses of each method: light grey implies a criterion is fully fulfilled, mid grey means medium fulfilment, dark grey indicates that a criterion is not fulfilled.

Table 2: Key advantages and disadvantages of the three basic methods

	Input-output analysis	Coefficient approaches	Hybrid approaches
Inclusion of the full supply-chains	Single-country models: inappropriate representation of supply-chains of imports due to domestic technology assumption Multi-regional models: full representation of all international supply chains	Incomplete representation of full supply-chains, in particular for higher-manufactured products, due to high efforts of bottom-up assessments of all indirect effects. Practice of "truncation", i.e. cutting off supply-chains at a certain level	Full representation of supply-chains, as the more complex chains are modeled with input-output analysis and coefficients are only applied for raw materials and basic products
Geographical specification	Single-country models: no geographical specification due to domestic technology assumption Multi-regional models: full reflection of different resource intensities in different countries	Factors often do not represent country specific situation, but are represented by averages	As elements from both approaches are applied, the advantages of MRIO specifications along with available country-specific coefficients can be used
Sector and product detail	Limited detail of environmentally-sensitive sectors and products groups traditionally one key disadvantage of input-output models. However, recent efforts in particular on disaggregation of sectors in MRIO data bases	One key advantage of coefficient approaches, as assessments can be undertaken down to the level of single products and raw materials	Apply the coefficient approach where necessary to ensure sufficient resolution of product detail, which is particularly important for raw materials.
Double counting	Double counting in footprint calculations completely avoided, as inputs are specifically allocated to final demand in only one country.	Danger of double-counting, as bottom-up supply chains may overlap, in particular for higher manufactured products.	Double counting mostly avoided, as higher manufactured products are calculated based on input-output approach.
Timeliness	Input-output tables for single countries often produced with long time lags. Even more problematic for multi-regional models. Only recent efforts in modelling more timely input-output tables.	Activity data often available for very recent years, but applied coefficients often outdated and not reflecting the current situation.	As elements from both basic approaches are applied, also hybrid approaches face the same limitations.
Transparency	Transparency is often limited due to the huge amounts of data and the complexity of supply chains depicted in the Leontief inverse. As a consequence, it is a highly sophisticated task to interpret and comprehend results in detail.	Coefficient approaches more clearly depict the major resource flows based on production and trade data. This reduces the completeness of the analysis but increases its transparency.	Hybrid approaches include elements from both approaches and thus face similar issues regarding transparency.

As the above table illustrates there is **no perfect method available yet** for calculating footprint-type indicators for the EU, as each of the approaches has its advantages but also disadvantages. However, **hybrid approaches have a very high potential** as they combine the advantages of the two basic methods. The method is already far advanced, and as this report is written various research projects push forward the research frontier. Especially appealing is the fact that such a hybrid input-output approach allows for calculating footprints for the four main resource categories on the basis of the same economic-environmental dataset and using the same basic calculation procedures. This guarantees consistency, comparability and soundness of results. Having said this, methodologically especially in the case of water and land methodological developments are still required, in order to ensure comparable and meaningful results.

4. Data availability for footprint-type indicators

After having reviewed the various methodologies along with their key advantages and disadvantages, we now turn to the issue of data availability and quality.

Input-output models require two distinct sets of data: monetary data (input-output tables and bilateral trade data, the latter only required for multi-regional models) and data on resource use to be attached to the input-output tables. We will therefore provide an overview over available data sets for both types of data.

Coefficient approaches are based on two data parts: activity data (e.g. production, consumption and trade data, which is normally easily available from national and international statistics and therefore not reviewed in this report) and resource intensity coefficients (from Life Cycle Assessment or similar approaches). We will provide a short description of the main available data sources for coefficients.

4.1 Main criteria for data evaluation

Several criteria are important, when evaluating the various data sets.

Acceptance of the institution providing the data (preference for official statistical data): Data reliability is essential when it comes to calculating meaningful indicators on the basis of which efficient policies shall be designed. As a consequence, the reputation of an institution because of the provision of good quality data is of great relevance to ensure acceptance by people manipulating the data as well as transforming the results into policies. We therefore suggest focusing on official and renowned data sources. In this context also the following arguments have to be understood, as in the majority of the cases such data sources will ensure the coverage of the other data issues explained.

Standardisation and transparency of data generation procedures: To ensure comparability as well as comprehensibility of calculation results, it is of great importance to use a standardised procedure for data generation and make this methodology as transparent as possible. This also allows for identifying the reasons for possible differences between calculation results.

Quality checks of data before being published: In the context of quality assurance various types of data checks have to be carried out. A solid data set/source will have run through such checks to avoid calculation mistakes and hence misleading interpretations.

Geographical scope of data (national, European, global): When seeking to take into account the global environmental pressures related to consumption activities in the EU it is necessary to have data available not only for the individual Member States but also for as many other countries of the world as possible. In fact, this criterion is often a limiting factor as data availability and quality are often decreasing the larger the number of countries covered.

Level of available disaggregation of data: In order to allow identifying so-called “hot spots” where high levels of resource use or low levels of resource efficiency are identified and actions should be taken first, it is of high relevance that data in use can be disaggregated to a high level of disaggregation; with regard to sectoral as well as resource type or national/regional detail.

Availability of time series: It is of high value to know about the level of human appropriation of natural resources at a certain point in time. However, for the analysis of trends and for integration of data in scenario modelling of future options the availability of time series of resource use is essential. The shorter the gap to the current year, the easier to do so-called “now-casting”.

Periodicity of data updates: In context of the criterion above on time series it is obvious that a good dataset is updated on a regular basis and with as little delay as possible. Especially with regard to material resources the gap should not be bigger than t – 3; in many cases it should be even smaller. Having said this, in the case of water use often data are only provided for time intervals of various years.

4.2. Evaluation of datasets

The following tables show the evaluation of the different data sets. We start with a table on monetary data (input-output tables and trade data) and then move on to data on the different resource categories. The final table illustrates the state of the art with regard to coefficients.

The different columns encompass the specific evaluation criteria as identified and described in chapter 4.1, some of them aggregated to one group criterion. Particularly positive features of the respective data sets are marked in colour. A discussion on the various tables is provided after the tables.

Table 3: Monetary data: Input-output tables and bilateral trade data for multi-regional input-output models

Name of dataset	Acceptance of data source	Level of standardisation and quality insurance	Level of geographical detail	Level of disaggregation	Availability of time series	Periodicity of data updates	Examples for reviewed studies
EORA	Only unmanipulated data from official statistical sources	Data base only recently presented	187 countries	Disaggregation of sectors differs between countries	1990-2010		Lenzen et al. 2013
Eurostat Supply, Use and Input-Output Tables (SUIOTs)	Official statistical data	Full standardisation across EU countries	27 single EU Member States, Norway, candidate countries, and aggregates for EU27 and the Euro area	60 industries/products	Various years (depending on EU country)	supply and use tables annual, IO every five years	Schoer et al., 2012; Aichele and Felbermayr, 2012; Mekonnen and Hoekstra, 2011; Aichele and Felbermayr, 2012; Peters et al., 2004
EXIOBASE/CREEA	No official statistic; renown in research community	Documentation of data and their generation process available	43 countries and 5 regions of the rest of the world	169 sectors	2000 (2007)		Tukker et al., 2013
GTAP IO-Tables	No official statistic	Not sufficiently transparent.	Up to 129 countries and regions	57 sectors	1997, 2001, 2004, 2007	3 years with a time lag of 5 years	Weinzettel et al. 2013; Lugschitz et al. 2011; Bruckner et al. 2012a; Bednar-Friedl et al. 2010; Chen and Chen, 2013; Peters et al., 2011, 2012
WIOD - World Input-Output Database	No official statistic; renown in research community		27 EU countries and 13 other major countries in the world, as well as rest of the world	59 products and 35 industries with special focus on economy-environment relationships	1995-2010	No announcements for updating after May 2012	Arto et al., 2012
GRAM (OECD data)	Official OECD IOT and bilateral trade data	high level of transparency and reliability of the data and its generation process	29 OECD countries, plus 11 non-OECD countries	48 sectors	years 1995, 2000 and 2005		Bruckner et al., 2012b; Bruckner et al, 2010; Nakano et al., 2009

Table 4: Environmental Data – Materials							
Name of dataset	**Acceptance of data source**	**Level of standardisation and quality insurance**	**Level of geographical detail**	**Level of disaggregation**	**Availability of time series**	**Periodicity of data updates**	**Examples for reviewed studies**
Eurostat EW MFA	Official statistics	EW-MFA Compilation Guide 2012	EU 27, Norway and Switzerland	Physical accounts (measured in metric tonnes) of all material inputs (excluding water and air) into national economies	1990-(t-3)	Annually	EW-MFA Compilation Guide 2012
FAOSTAT	Official statistics	All data following the same compilation standards; however, quality varies among countries	Worldwide and country groups	Domains related to materials are: ResourcesSTAT, FishSTAT, and ForesSTAT.	depends on the country, most recent are 2012 data	depends on the database	Feng et al., 2011; Chapagain and Hoekstra, 2004; Ermolieva et al. 2012; Würtenberger et al. 2006
USGS Minerals Yearbook	Official statistics	Standardisation and quality measures provided	Worldwide	Includes approximately 90 commodities	1990-(t-2) downloadable, 1963- pdf	Annually	Schaffartzik et al., 2009;
BGS World Mineral Production	Official statistics	Standardisation and quality measures provided	Worldwide	Includes 70 economically important minerals, metals and mineral-based materials.	1913- book, 1986-(t-2)	Annually	BGS 2012
World Mining Data	Official statistics	Standardisation and quality measures provided	Worldwide	Includes around 61 commodities	1984- (t-3)	Annually	Weber et al., 2012
SERI - Global Material Flows Database	Based on official statistics	Standardisation and quality measures provided	Worldwide	Includes 320 comodities	1980-(t-3)	Annually	(SERI, 2013)
Raw Material Group - Raw Material Data	No official statistics	Standardisation and quality measures provided	Worldwide mine-specific data	More than 20.000 entities on ore grades, capacity, ore production, reserves, resources, present and past metal production, cash costs for gold mines and more.	Metal production 1984-(t-4), coal production 2000-(t-4)	Monthly	
Institute for Social Ecology – Global Material Extraction Data	No official statistics	Standardisation and quality measures provided	Aggregated global data	4 aggregated material groups	1900-2009		(Krausmann et al., 2009)

Table 5: Environmental Data – Water

Name of dataset	Acceptance of data source	Level of standardisation and quality insurance	Level of geographical detail	Level of disaggregation	Availability of time series	Periodicity of data updates	Examples for reviewed studies
Eurostat Water statistics	Official statistics	Data collected via Eurostat-OECD Joint Questionnaire	European Union, Bulgaria, Romania, Turkey, Iceland, Norway, Switzerland, Croatia and Macedonia.	Data on use, supply, pollution, treatment, resources, etc	since 1970/1980 to (t-3)	every second year	Eurostat and OECD 2012
FAO AquaSTAT	Official statistics	Data standardised, but quality varying	Worldwide (150 countries and five regions)	Contains country level data on water resources and agricultural water management.	depends on the country, most recent are 2012 data	constantly	Feng et al., 2012; Chapagain and Hoekstra, 2004; Mekonnen and Hoekstra, 2011
UN Water Statistics	Official statistics	Data standardised, but low coverage	Between 50 and 100 countries	Contains data on inland water resources divided into 13 categories	1990 and 1995 to (t-3)	next update: July 2013	Mekonnen and Hoekstra, 2011
OECD Water Statistics	Official statistics	See Eurostat	36 countries	Contains three major data sets [freshwater abstractions (million m³), freshwater resources (long term annual average, billion m³), wastewater treatment (% population connected)]	1980-(t-3)	constantly	

Table 6: Environmental Data – Land							
Name of dataset	**Acceptance of data source**	**Level of standardisation and quality insurance**	**Level of geographical detail**	**Level of disaggregation**	**Availability of time series**	**Periodicity of data updates**	**Examples for reviewed studies**
Eurostat – LUCAS	Official statistics	Standardisation provided	European Union (with gaps)	It provides coherent and harmonized statistics on land use and land cover	2009, 2012 (soon)	constantly	
CORINE/LEAC	Official statistics	Standardisation provided	CORINE: EU-27, single countries; LEAC: EU-27, on several levels: NUTS 0, NUTS 1, NUTS 2 , NUTS 3	Provides detailed maps and land coverage data in hectares by country by five different land use categories, which are additionally subdivided into 44 land cover classes	Single years 1990, 2000 and 2006		
FAOSTAT – Land use data	Official statistics	Standardisation provided	Worldwide	Contains data on agricultural areas and yields for around 200 agricultural commodities	1961-(t-2)	annually	Lugschitz et al. 2011; Kastner et al. 2011a,b;Wilting and Vringer 2009; Bruckner et al. 2012b; Prieler, 2005;; Ermolieva et al., 2012; Fader et al., 2011; Weinzettel et al., 2013
UNECE Committee on housing and land management	No official statistics		39 countries	Contains information on housing, urban development and land administration policies.			Ermolieva et al. 2012
Institute for Social Ecology: Global land use data	No official statistics		Global in 5min resolution (grid cells)	5 layers on land use (infrastructure area, cropland, forestry, grazing land, and untouched areas) and one layer on grazing suitability	2000		(Erb et al., 2007)
IIASA-GAEZ Database	No official statistics						Ermolieva et al. 2012

Table 7: Environmental Data – Emissions/Carbon							
Name of dataset	**Acceptance of data source**	**Level of standardisation and quality insurance**	**Level of geographical detail**	**Level of disaggregation**	**Availability of time series**	**Periodicity of data updates**	**Examples for reviewed studies**
United Nations Framework Convention on Climate Change (UNFCCC)	Official country data reported to the UNFCC	Standardised compilation guides available	All parties, some groups	Provides official submissions of GHG national data by countries that are Parties to the Climate Change Convention (nearly all countries of the world)	1990-(t-1) (depends on the category)	annually	Peters et al., 2012
Eurostat - Air Emissions Accounts	Official statistics	Standardised compilation guides available	EU member states	Contains emission data of 12 different substances such as SOx, NOx, NH3, CO, NMVOC, CH4, N2O, CO2, HFC, PFC, PM10 and SF6.	1995-(t-4)	constantly	EUROSTAT, 2011
European Pollutant Release and Transfer Register (E-PRTR)	Official statistics		EU member states and in Iceland, Liechtenstein, Norway, Serbia and Switzerland	Provides data on emissions into air, water and land as well as off-site transfers of waste and of pollutants in waste water for selected industrial sites	year 2007, 2008 and (t-3)	3 years	
Electronic Data Gathering, Analysis and Retrieval system (EDGAR)	Project run by EU JRC and Netherlands Assessment Agency		Worldwide	Provides global past and present anthropogenic emissions of greenhouse gases and air pollutants	1970-(t-3)	constantly	Wilting and Vringer, 2010; Peters et al., 2012; Wilting 2012
EEA emission data	Official statistics		32 member countries (27 EU member states and Iceland, Liechtenstein, Norway, Switzerland and Turkey)	Contains estimates of the amount of air pollutants and greenhouse gases emitted into the atmosphere from different anthropogenic sources.		constantly	

Table 8: Environmental Data – Data bases for resource efficiency coefficients							
Name of dataset	**Acceptance of data source**	**Level of standardisation and quality insurance**	**Level of geographical detail**	**Level of disaggregation**	**Availability of time series**	**Periodicity of data updates**	**Examples for reviewed studies**
Ecoinvent	Most widely use LCA database, non-official	Good documentation available	Often only global factors available		Often no time series of factors available	Regularly	Weinzettel and Kovanda, 2009
GEMIS	Non-official database maintained by the “Öko-Institut” in Germany	High level of transparency	EU-27 plus a selection of other OECD and some developing countries			Regularly	Schaffartzik et al. 2009;
Database of the Research Group Material Flows and Resource Management (Wuppertal Institute)	Data base widely used by various national and international studies	Detailed documentation often missing	Geographical specification for some product groups		Time series of coefficients largely missing	Regularly	Dittrich et al., 2012; Buyny et al. 2009

In terms of **monetary data sets for input-output tables and bilateral trade data**, a number of options have been developed and presented in the past few years. As illustrated in the table above, the different data sets have complementary strengths. The EUROSTAT data set is the most official data set available for Europe, but has its deficits in particular in terms of sectoral disaggregation and does not include data for non-EU countries. The largest number of countries and a long time series is provided by the EORA system, but the data set has only been recently introduced and not yet sufficiently quality-checked. EXIOBASE has its main advantage in providing a high sectoral detail, but is so far only available for the year 2000.

There are various data sources for **material flow data** of good to very good quality with regard to used materials. For European countries the EUROSTAT economy-wide material flow accounts (EW-MFA) are currently the most reliable and very comprehensive data source, but they only cover material flows within Europe and direct imports and exports. For the global level, SERI's Global Material Flow database on material extraction provides a high level of disaggregation following the MFA standards. Also a number of other official sources are available for global material flow data, focusing mainly on different aspects of metals and minerals. FAO is the most widely-applied source for biomass. It shall be emphasised that data on unused material extraction are still incomplete and of insufficient quality. Efforts to improve this part of material flow analysis would be very important.

Availability and quality of data on **water use** by humanity is critical. As the topic is gaining awareness, also the attempts to ensure the collection and compilation of good-quality water data increase. However, for the time being indicator calculations as well as interpretations will have to remain on a more aggregated level. The data collected by Eurostat are definitively the best option. Significant efforts are currently being made to improve compilation standards and at the same time ensure better data coverage. The Eurostat data as well as AquaSTAT and modelled data allow for first analyses on global water appropriation which are crucial to allow for meaningful water management. Current efforts will ensure that in the short to mid-term the data situation will be improved, allowing for increasingly meaningful analyses. Indicator calculations as well as interpretations must not be postponed until better data are available. On the contrary, first analyses have to be made while a strong emphasis must be set on the improvement of data quality and level of data collection.

With regard to **land use data**, EUROSTAT provides two complementary data sets (LUCAS and CORINE) of good quality, but the use for footprint-type indicators is limited, as focus is set on Europe. Most studies tracking land footprints on the global level use FAO data (or data sets created based on FAO). Land use data for agricultural production is relatively reliable, but data for grazing areas as well as forestry are problematic for footprint calculations. Built-up land is another difficult land use category.

Carbon emissions data are more reliable than water or land use data, as GHG emissions are in the focus of climate policies. EUROSTAT provides air emission accounts for European countries, but does not report emissions for other world regions. Global emissions data can be obtained from various sources, including the official GHG emissions reported by countries to the UNFCCC framework. The EDGAR database is another widely used database for carbon footprint calculations.

Finally, in terms of **resource efficiency coefficients**, only a few options exist. Ecoinvent is the most widely applied database in Life Cycle Assessments and allows deriving coefficients for all four categories of footprint indicators. For material footprint coefficients, the database maintained by the Wuppertal Institute in Germany is the most widely base applied in a number of material footprint studies.

4.3. Conclusions

As elaborated above, for input-output analyses as well as for all the four main categories of resource use data are available – though at different levels of disaggregation and quality – which allows for calculating footprint-type indicators and to compare resource-intensities of different sectors among different resource categories.

Especially data on material extraction and use and production of GHG emissions are already quite advanced, and the last gaps are being closed through ongoing research. In the cases of water and land use there is still a larger potential for improvement regarding accounting standards as well as data coverage, disaggregation and quality. However, the data available also allow for first analyses, and constant methodological and compilation improvements will ensure increasingly comprehensive and robust results.

5. Readiness of the available indicators

The past few years have seen a **boost in studies investigating the global environmental effects** related to consumption of countries and world regions from a footprint perspective. A few methodologies have proved to be the most promising ones in terms of being able to trace resource use along international supply chains, from resource extraction or agricultural production in one country, via processing and manufacturing in another and final consumption taking place in yet another country. The three key methodological options and the related data sets have been evaluated in detail in the previous chapters.

As indicated in the very beginning of the report, the main direction of messages derived from existing footprint calculations remains the same, independently of the methodology and data sources used, i.e. **Europe is being identified as a net-importer of embodied resources and carbon** in all studies. This clearly calls for paying attention to the issue of outsourcing of environmental burden and a proper evaluation of Europe's resource efficiency performance in a global context.

However, applying different methodologies and using different data sets can possibly deliver diverging results of footprint indicators, when it comes to country or sector detail. Only very few studies exist so far, which provided a comparative analysis of different methods and data. For example, Peters and colleagues (2012) compared the outcomes of carbon footprint studies based on various input-output frameworks. The main conclusion was that "*for embodied CO_2 emissions, estimates from independent studies are robust, and that differences between individual studies are not a reflection of the uncertainty in consumption-based estimates, but rather these differences result from the use of different production-based emissions input data and different definitions for allocating emissions to international trade*" (p. 3247). This calls for an effort to harmonise the environmental data, which are applied in the various footprint models.

At the same time, other studies point to the fact that also the detail of the methodological framework plays a crucial role. EUROSTAT has started to compare its approach for calculating material footprint indicators (RMC) with a disaggregation of 166 products/industries with results from other MRIO databases, such as EXIOPOL, WIOD and GTAP and found out that the resolution of the model has a huge impact on results (Stephan Moll, EUROSTAT, personal communication, April 2013). As a general direction, it is desirable to use a framework with as many sectors and products as possible.

5.1. Advantages and disadvantages of currently available options

Obviously, the ideal methodology and data base for calculating consistent, robust and timely footprint indicators for the EU does not yet exist. But which options are currently available and what are their advantages and disadvantages?

First, it is important to emphasise that **the four footprint indicators vary in terms of conceptual and methodological maturity**. Carbon footprints and material footprints are relatively advanced concepts, with methodological guidelines being available and ensuring a certain level of comparability. For those types of resource a possible use of one of the indicator options could be envisaged in the short term.

Regarding carbon footprints, the following options have been applied in empirical studies. All options cover a set of countries, i.e. national studies based on specific national data have been excluded.

Table 9: Advantages and disadvantages of options for carbon footprints

	Advantages	Disadvantages
EUROSTAT carbon footprint calculations	Involvement of the EU statistical institution Based on official input-output tables from EU countries Data system updated on a regular basis	Domestic technology assumption for EU imports Limitation to 59 branches and product groups Limited availability of time series data (2000-2006)
GTAP-based carbon footprint calculations	Long experience in applying and improving data system Availability of time series data (up to 2007) High number of countries (129 in latest version) Data system updated on a regular basis	Limited transparency of GTAP input-output data Limitation to 57 economic sectors (no environment focus)
EXIOBASE carbon footprint calculations	Very high disaggregation (129 sectors/product groups) 42 countries (all EU plus main trading partners)	Currently only available for year 2000 (update to 2007 ongoing)
WIOD carbon footprint calculations (by JRC)	Availability of input-output tables in time series (1995-2010)	Limited number of sectors (35 industries) Data update unclear

A similar picture can be observed for the area of material footprints. Again, studies on single EU countries are not considered in this list.

Table 10: Advantages and disadvantages of options for material footprints

	Advantages	Disadvantages
EUROSTAT RME/RMC indicators	Involvement of the EU statistical institution Based on very detailed input-output table for the EU Hybrid method with additional coefficients for raw materials and basic products	Data only available for aggregated EU level Domestic technology assumption for EU imports, if not calculated by additional coefficients Time series data only now being developed (base year: 2005)
GTAP-based material footprint calculations	Availability of time series data (up to 2007) High number of countries (129 in latest version) Data system updated on a regular basis	Limited number of extraction sectors for non-renewable materials (aggregation errors) Limited transparency of GTAP input-output data
EXIOBASE material footprint calculations	Very high disaggregation (129 sectors/product groups), with many material extraction sectors 42 countries (all EU plus main trading partners)	Currently only available for year 2000 (update to 2007 ongoing)
WIOD material footprint calculations (by JRC)	Availability of input-output tables in time series (1995-2010)	Limited number of sectors (35 industries) (aggregation errors) Data update unclear
Material footprints based on coefficients (by Wuppertal Institute)	High specificity of factors for certain raw materials and products	Limited number of material coefficients for higher-manufactured products → incomplete picture Limited availability of geographically and time specific factors

In contrast to carbon and material footprints, methodological refinements still need to be done in the area of water and land footprints. For those types of footprints we would not recommend suggesting one specific option for immediate use, but focus on clarifying the methodological questions first.

Regarding water footprints, discussions are still ongoing on which aspects to include in water footprint assessments: Should the focus be set on water abstraction or water consumption? Should green, blue and grey water be included in water footprint assessments?

Also with regard to land footprints, key questions need to be discussed and decided, before a more standardised methodology can be presented. Those questions include, for example: Which type of land should a footprint indicator include? Only agricultural land or also sealed surfaces? Is land a resource flow or not rather a resource stock? How to consider land-use changes? And how to deal with the differences between land cover and land use?

Furthermore, calculation frameworks for material, carbon, water and land footprints have so far mostly been developed independently. A **large potential for synergies** can be expected particularly for the joint examination of global flows of biomass (a subcategory of material resources), land, water, and land use related GHG emissions. When this potential is unlocked through some targeted research efforts, this will expectedly lead to major advancements in the robustness and consistency of the results obtained in national footprint assessments for all four key resource categories under consideration.

6. Recommendation for improvement of footprint indicators

In an ideal situation, a methodology for calculating the various footprint indicators would have the following features:

- **One consistent data base** as the core of the footprint calculation model to ensure consistency across resource categories with possible adaptations and specific levels of detail for different footprint indicators
- A **multi-regional input-output data base** at the heart of the footprint model to ensure completeness on the global level and allow considering country-specific resource intensities
- A **high sector disaggregation** of the input-output tables and trade data to allow separating a large number of products and avoid errors due to aggregation
- An **extension** of the core model by **bottom-up resource intensity coefficients** derived from process analyses to cover those products, which are not represented in the input-output framework with sufficient detail
- **Time series** of input-output tables and coefficients, including data for very recent years, to take recent developments in technology, economic structures and trade into account

In order to proceed towards this best-suited methodology, further improvement shall be focused on the following areas (see also Wiedmann et al., 2011):

1. Improve the **level of disaggregation** in input-output models, in order to reduce the error when aggregating a large number of products with different resource intensities.
2. Further develop, test and harmonise **hybrid models** which integrate both input-output and process-based data for various resource categories.
3. Improve the **quality of environmental data** on the global level, in particular regarding certain material flows (construction materials, unused material extraction), water use data (in non-agricultural sectors) and land use (change) data.
4. Put efforts into producing **more timely data** (in particular in the area of input-output tables) and develop and test now-casting methods in order to increase the policy relevance of the footprint indicators.
5. Produce **time series data** for the various footprint indicators in order to enable trend analysis, analysis of drivers and as a basis for developing models for the future scenarios.
6. Assess the **uncertainty** of different methodologies and data sources and perform **sensitivity analyses** to assess, which methodological assumptions or input data have the highest impacts on the overall results.

7. Identify overlaps and **synergies between** the assessment procedures for **different resources** (e.g. biomass – land – water – GHG emissions from LULUC) and harmonise the methodologies and data bases where possible, in order to overcome the variety in results for footprint indicators.

In order to realise the required improvements, also **institutional factors will play a crucial role**. So far, major advancements in methodological development and improvement of the data situation for footprint calculations on the international level mostly took place in the research community outside the official statistical system (apart from first pilot studies on material and carbon footprints undertaken by EUROSTAT).

Indicators calculated based on those types of data bases, however, are **often not accepted by policy makers**, which call for data produced and quality-checked by the official statistical institutions. A closer involvement of the statistical system is therefore highly desirable, if footprint indicators are to gain in acceptance.

National statistical institutions are in the best position to provide detailed country data and thus play an important part in such a concerted effort. At the same time, **international institutions**, such as EUROSTAT, the OECD or the UN are better positioned to take care of the alignment of national data and provide consistent, multi-country data sets as a basis for footprint calculations (Wiedmann et al., 2011).

Europe would be in position to take the stewardship for further developing and aligning footprint indicators. What is required is a long-term commitment to actively establish strong institutional links between statistics, research and policy, and ensure continuous and adequate funding for both methodological and data development. The European Commission could establish an international forum for exchange and further development of footprint indicators, including core international research bodies such as the IPCC and the UNEP International Resource Panel, international statistical data providers, such as the UN and OECD, along with a group of stakeholders, who are demanding for footprint-type indicators (policy makers, companies and business associations, civil society organisations).

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