Promotors	Prof. dr. ir. Jo Dewulf Faculty of Bioscience Engineering, Ghent University
	Prof. dr. Karl C. Vrancken Department Bio-Engineering, University of Antwerp Vlaamse Instelling voor Technologisch Onderzoek
Dean	Prof. dr. ir. Marc Van Meirvenne
Rector	Prof. dr. Rik Van de Walle

Macroscopic assessment of material flows in Flanders based on input-output tables

Thesis submitted in fulfilment of the requirements of the degree of Doctor (PhD)
of Applied Biological Sciences: Environmental Technology

Maarten Christis

2018

Nederlandse vertaling titel

Macroscopische analyse van materiaalstromen in Vlaanderen gebaseerd op input-output tabellen

Cite as:
Christis M. (2018) Macroscopic assessment of material flows in Flanders based on input-output tables. PhD thesis, Ghent University, Belgium

ISBN-number: 978-94-6357-141-8

Maarten Christis is granted by a research project of the Flemish Policy Research Centre of Sustainable Materials Management (steunpunt SuMMa).

Members of the jury

Prof. dr. ir. John Van Camp (Voorzitter)
Faculty of Bioscience Engineering, Ghent University

Prof. dr. ir. Brent Bleys
Department of General Economics, Ghent University

Dr. ir. Arjan de Koning
Faculty of Science, Leiden University

Prof. dr. ir. Steven De Meester
Faculty of Bioscience Engineering, Ghent University – Campus Kortrijk

Prof. dr. ir. Johan Eyckmans
Faculty of Economics and Business, KU Leuven

Synthesis

This dissertation provides insights into the research question: “What applications make the Flemish environmentally extended input-output model, extended with regional, national and international economical and material data, an important macro-economic tool for sustainable materials management policy making in Flanders?”. To answer this question, the dissertation first puts focus on material accounts. How can physical macro-economic models, like economy-wide material flow accounts (EW-MFA), physical supply and use tables (PSUT), and physical input-output tables (PIOT), improve the current Flemish environmentally extended input-output model? EW-MFA and derived indicators are designed to describe the metabolic performance of economies as a basis for further analysis (Bringezu et al., 2003). EW-MFA serves as a valuable item in the toolbox of the industrial ecologist, but one should be aware of its limitation regarding integrated environmental-economic accounting assessments. Its concept regards a national economy as a black box. EW-MFA does not provide information on material flows on the level of economic sectors, in particular on inter-industry relations, nor does it separate material inputs used for production processes from those directly delivered to final demand. It does not allow to analyse implications for resource use of structural and technological change, of changes in consumption behaviour and life-styles and of migration and urbanization (Giljum & Hubacek, 2009). However, EW-MFA and derived indicators provide a good basis for better understanding the metabolism of our economy and society focussing on current and retrospective analysis. Mainly because of its well-developed methodology and ability to derive indicators like domestic material consumption (DMC) and raw material consumption (RMC). Some other advantages are: (Bringezu et al., 2003; de Bruyn et al., 2004; Eurostat, 2001; Kleijn, 2000)

- it provides insights into the structure and change over time of the physical metabolism of economies;
- through its underlying data structure integrated with the national accounts it contributes to organise, structure and integrate available primary data and ensures their consistency;
- it is the starting point in the development of PSUTs and PIOTs;
- it provides a basic structure for the development and calculation of specific and specialized indicators;
- it traces environmental effects of consumption related to import and export and related to environment inputs and outputs; and
- it has the potential to become an instrument to integrate material flows and environmental impacts of material use into policies focussing on all phases of material use.

PSUT, and to a lesser extent EW-MFA, act as integration frameworks for different data sources. The material balance principles provide an accounting identity that forces these different data sources to be confronted. This process leads to a homogenization of classification schemes and data collection methods and may expose errors. In the process of the confrontation of data, decisions will be made about the relative quality of the data sources, which should lead to a better set of statistics. These accounts serve statistical purposes to provide an integrated framework for checking consistency and completeness of national accounts data.

A PSUT is used to assess the supplies and uses of materials and to examine changes in production and consumption patterns over time. In combination with data from monetary supply and use tables, changes in productivity and intensity in the use of natural inputs and the release of residuals can be examined. (SEEA, 2012)

PIOTs are used to identify material-intensive sectors and branches and to analyse the relationships between material use, goods produced and quantities of pollutants in various stages of production. The changes in the material intensity or material efficiency of the branches of production over time could serve as additional indicators for the development of the economy. An advantage of PIOTs is the analysis of complex value chain networks including materials flows and the indirect material burdens of production and consumption. In economic-environmental modelling the relationship between structural changes in the economy and the extraction and emissions of materials are of great importance. PIOTs and subsequent analysis render insights into the way the economic activities give rise to environmental problems and into what type of policies can alleviate them. It distinguishes between individual components of the economy, such as technology, exports, imports, consumption, stocks and investments to assess the impact of structural changes. (Hoekstra, 2005)

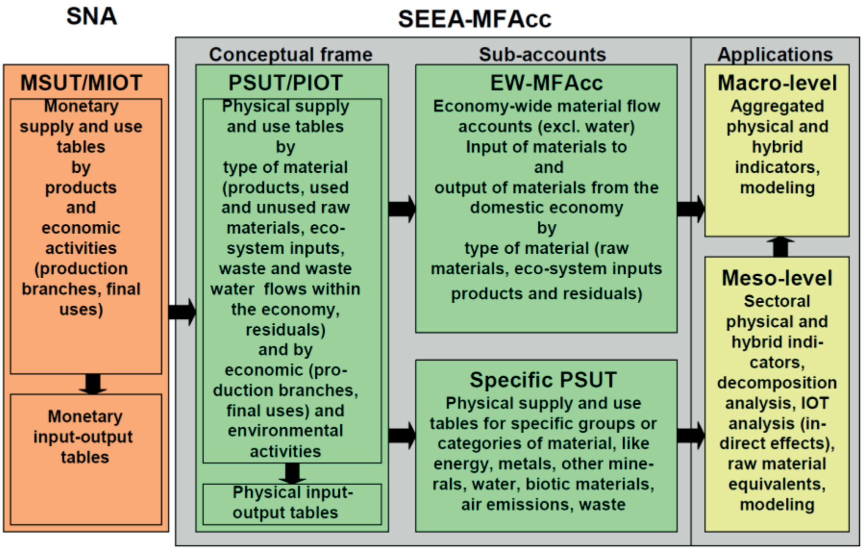

FIGURE 1: LINKING THE PHYSICAL FLOWS DESCRIBED BY SEEA TO THE MONETARY FLOWS DESCRIBED BY SNA.
(SOURCE: SCHOER AND GRAVGÅRD (2007))

Building upon one another the three physical models add information from EW-MFA to PSUT to PIOT, but the investments (in time, budget and know-how) increase likewise. In general, the EW-MFA and PSUT accounts are a helpful tool for a structured gathering of information on the metabolism of an economy. The PSUT are superior to PIOT tables for accounting purposes because the data that is available to national accounts is usually provided in commodity and industry dimension. Any conversion to a symmetrical PIOT table would require adjustment of the production statistics. PSUT are further capable of recording multiple products for a single industry, while these are not directly visible in PIOT's with heterogeneous sectors. Despite the superiority of PSUT for accounting, their direct use in modelling is limited as they don't allow complete production chain analysis. The PIOT table is more attractive for modelling because of the symmetrical structure of intermediate demand, which allows the calculation of the Leontief inverse. (Hernandez-Rodriguez et al., 2012; Hoekstra, 2005; OECD, 2007)

From the analysis, described in *chapter 1. Screening of existing macro-economic models for sustainable materials management* the dissertation concludes that predefined pathways need to guide the data gathering process and the compilation of PSUTs and PIOTs. The goals should be clear and set in advance as one does not want to get lost into an information overload. The pathways will guide the compilation of the tables and will reduce the workload as the focus is already set. Theoretically PSUTs should include all the physical flows within the economies and the exchanges with the environment. 'Theoretically', because the idea to have complete tables is considered from the experts of UN a very ambitious target and a less stringent approach might be applied, which considers only some specific physical accounts and not all of them (Merciai et al., 2011). The principal limitation of the bottom-up approach is that it is laborious and a long time is required to obtain an overall picture of the intersectoral exchanges within the socio-economic system (De Marco et al., 2009). Consistent material balances for all metabolic processes in units of weight are indispensable as a database for all further studies of the physical world, but there is no quick method to produce such tables that are consistent with IO-modelling assumptions.

A central critique of indicators derived from physical accounts is on the interpretation of their outcome: more does not necessarily mean worse and less does not necessarily mean better. Sometimes indicators are meaningless because interpretations and results are too general. All materials that enter an economy will sooner or later become residuals, but the magnitude of material flows rarely relates linearly to the environmental impacts they cause. The critique is a consequence of the difficulties in aggregating different types of material flows to derive indicators and the weak links between MFA indicators and environmental impacts (Bringezu et al., 2003; de Bruyn et al., 2004; Giljum et al., 2006; Kleijn, 2000). The limitations of weight based aggregated indicators are: (Statistics Austria & SERI, 2011)

- large materials flows dominate derived indicators and bias interpretation of aggregated results;
- unweighted indicators do not reveal anything about environmental impacts;
- the sole focus on the reduction of aggregated resource use is a necessary but not sufficient precondition for achieving sustainability; and
- aggregation should reflect the economic usefulness of materials, while weight is not a category that reflects economic values/decisions of end-users of materials.

The relationship between mass and environmental impacts of material flows on an economy-wide basis is weak (de Bruyn et al., 2004), so one can dispute if mass-based accounts are sufficient. The answer is that for material flow analysis these accounts will provide a good basis for further analysis. However, environmental impacts related questions always require further analysis, disaggregation and conversions to other units.

In practice, all approaches can be used in a consistent way. For example, the full PIOTs may be compiled every five years, full balances every second or third year and some individual accounts annually to allow regular and timely derivation of selected indicators. Recommended for Flanders is a regular year-to-year EW-MFA account, following the EU-regulation No. 691/2011. It takes (based on defined framework and compilation procedure) only a limited time-investment to compile. The time lag for EW-MFA accounts to be completed would be some 4-6 months for preliminary data and some 13 months for final data from the end of the year in question. The derived indicators indicate trends and identify areas for further investments. Note that the number of stakeholders involved increases with increasing levels of aggregation and it becomes unclear who is responsible for taking action

Based on the analysis described in *Chapter 1*, the current advice for Flanders is to not invest in PSUTs and PIOTS. The high data requirements and the high level of detail obstruct a wide acceptance because of data validation uncertainty and expert need to use them. Certainly the bottom-up and frequently compiled PSUTs and PIOTs have application to policy in mapping and analysing material flows. Nevertheless, the time investment is high, both in data gathering and compilation. Also, learning from experiences in Denmark and Germany which compiled PIOTs, shows that their high cost with limited use in policy did not foster further development (TRITEL & CE Delft, 2013). Finally, as Flanders is a small and open economy, import and export flows are too important. Without a widely accepted physical multiregion input-output model, it is impossible to analyse material flows in globalized production networks. A Flemish PIOTs would only reveal a very small piece in the complex puzzle. This last remark stresses the temporarily character of this guideline, as physical or hybrid multiregion input-output models will be available in the (near) future.

Therefore, this dissertation will build upon the existing Flemish input-output tables. But, to extend applications in material use, Flemish EW-MFA are compiled to derive material flow indicators. The overlap and differences between the derived DMC and RMC are discussed *chapter 6. Estimating and interpreting two material indicators for Flanders: Domestic Material Consumption and Raw Material Consumption*.

Building upon existing models, the dissertation provides an overview of (recent) applications of input-output analysis (IOA). *Chapter 2. Policy needs to be covered by EE-IO capabilities* addresses the types of application of input-output analysis relevant for (environmental) policy based on scientific literature. Which applications are relevant for environmental policy? A case-study on Flanders (Belgium) based on interviews with policy makers gives an overview of opportunities for using input-output analysis for environmental policy purpose giving insights in how to optimize the uptake of EE-IO in policy steps. The extended literature review provides an overview of the applications of IOA supporting environment-related policies focusing on methodologies and database usage.

Building an EE-IO model is finding a balance between the ability to serve many different (potential) users and making the model very context specific. For example, official internationally recognized EE-IO data models, based on worldwide harmonized bottom-up statistics, often lag behind in time and they lack in level of detail compared to more experimental databases. The experimental data models already serve well for the early policy phase of problem analysis and agenda setting as their use shows the policy relevance of new issues. At the same time their use shows the importance of strengthening international collaboration to develop harmonized worldwide statistics that will allow the set-up of internationally accepted EE-IO models.

The literature review shows a great variety in applications in which EE-IO models are combined with other data models to answer context specific policy questions. The typical economic matrix structure of IO models allows an easy linking of IO models to other (environmental) datasets, which increases the range of economic, social and environmental applications. EE-IO models were found to be useful in all stages of the DPSIR environmental policy framework (driving forces, pressures, state, impact, response), even in describing the state, despite the fact that an IO model is a flow model. In the interviews a variety of new needs were identified that would require further detailing and extending EE-IO models. In principle this detailing and extending is possible, however the challenge remains to harmonize databases internationally due to the globalization of value chains. Here lies the advantage of regional IO models, as the regional IO model can be detailed or extended depending on the regional policy focus. Still, the capability to capture complex and globalized value chains and related direct and indirect effects, is recognized as a key feature of IOA.

The list of topics addressed in the selected international publications suggests a potential relevance for IOA in policy making. Also, given the increase in available EE-MRIO models during the last years, it can be expected that more analyses will use these existing models and the need to develop an additional model for a specific application will decrease. However, policy makers ask scientific advice being not always aware of the latest methodological or database developments. Therefore, a key guideline is to regularly inform about database updates, methodological changes and improved applications to a non-export audience. A leverage effect could be achieved via putting efforts in the clear visualisation of results (e.g. infographics).

Based on the findings and conclusion of chapter 1 and 2, and the open character of the Flemish economy, this dissertation developed a methodology to link local (or national) input-output model to a EE-MRIO models to fully incorporate globalised value chains, to widen the application possibilities and to increase local policy interest and acceptance. The methodology is described in *chapter 3. Linking regional input-output tables to multiregional input-output tables*. Also, the importance of applying this methodology, especially in a small and open economy, is illustrated with an example on a number of monetary and environmental footprint indicators (e.g. carbon footprint and material footprint).

A combined environmentally extended local input-output (EE-RIO) and environmentally extended multi-region input-output (EE-MRIO) model results in the best local footprint estimation possible, as this estimation is based on all data available. For example, the domestic technology assumption or using national data to represent a local area results in substantial specification errors leading to unreliable indicator estimations. The resulting guidelines help researchers to reflect on the indicator being studied before choosing the optimum model: Is the indicator determined by mainly domestic or foreign economic/environmental characteristics? Does import play an important role in the estimation of the indicator? Is the footprint influenced by large country and/or sector differences? Are the underlying coefficients stable over time or subject to trends?

From a local perspective when facing the task of aligning local data with data in an (EE-) MRIO model, the preferable option is to use a combined or linked EE-RIO and EE-MRIO model with the highest available resolution, otherwise specification errors would become unacceptably large in a globalized world, due to the assumption of domestic technology and price levels abroad. By combining a EE-

RIO and a EE-MRIO model, the analysis is based on all the local data available, adapted to the local economic characteristics, and includes global sectoral use/creation/impacts. For open economies, such as Flanders, most indicators are determined both by local and global specific characteristics, resulting in large specification errors if not all country-specific data is included in the model. Indicators mainly determined by domestic characteristics require at least the use of an EE-RIO model; indicators mainly determined by foreign characteristics require at least the use of an EE-MRIO model.

From the footprints tested in chapter 3, we conclude that aggregation of non-neighbouring countries (i.e. aggregating no major trading partners) leads to small errors. All the indicators tested benefit from secondary sector disaggregation. Only some indicators benefit from primary sector disaggregation, for example the water and material footprint, as these indicators are largely determined by primary sector coefficients. Using data based on a different year is only a valuable option in estimations for indicators if coefficients tend to be stable over time. Trends could have only a small impact on coefficients and multipliers, however, the consistent over- or underestimation of coefficients and multipliers certainly results in deviated footprint estimations. A detailed reflection on the indicator under consideration to determine the optimum model helps to understand the possible estimation errors in final footprint estimations. The key consideration is to find the optimal balance between investments in model adoption and/or extension and the reliability of estimation results. This consideration should be done before the actual analysis and support the validation of the outcome.

Chapter 4. Comparing a territorial-based and a consumption-based approach to assess local and global environmental performance of cities differs from previous chapters, as it focus is on a city, using the case of Brussels Capital Region (Belgium). A city-level input-output analysis, especially with an extended focus on the environmental impact on the hinterland, stresses the importance of combining local specific data linked to databases covering the global production levels. The chapter presents a comparative analysis of a territorial-based and a consumption-based approach to estimate both direct and embodied resource use and pollution flows for the case of Brussels Capital Region (Belgium). The territorial-based approach is based on local energy, water and material consumption measured data as well as measured data on waste generation and pollution emissions. The estimation of indirect resource use and pollution emissions (or consumption-based approach) is based on the regional IO-tables of the city-region of Brussels extended with multi-region input-output tables, taking into account the global flows of consumption. The comparison of these two approaches is particularly relevant in the case of cities that have limited productive activities and limited or no extraction of materials as the impact on the hinterland is often underestimated or neglected by local (environmental) policies which are only based on territorial-based figures.

In the framework of pressing local and global environmental challenges it is essential to understand that cities are complex systems dependent on and linked to the rest of the world through global supply chains that embody an array of environmental flows. Cities are thus a complex articulation that intertwine local and global challenges which rely at their extended hinterland for their resource use and pollution emission. To assess the environmental sustainability of an urban area in a comprehensive manner, it is not only necessary to measure its local and direct environmental performance but also to understand and take into account its global and indirect environmental counterparts.

The results show that the indirect primary energy use, GHG-emissions and material use estimated by the consumption-based approach is more than three times higher than local measures indicate. The embodied water use, estimated via IOA, was over 40 times higher than the local water consumption. It shows that territorial-based approach underestimate the resource needs and pollution emissions of a city and can therefore be insufficient or even be misguiding. By mapping the origin of embodied flows it is in fact possible to illustrate the open character of an urban economy and its dependence on the global hinterland. Finally, this paper discusses the possibility and relevance to combine these two approaches to create a hybrid framework that measures the full environmental performance of cities both accurately and comprehensively.

Chapter 5. Value in sustainable materials management strategies for open economies - Case of Flanders uses the case study of Flanders. It describes an improved top-down methodology for estimating the substitution potential of intensifying specific SMM-strategies and material efficiency strategies. The covered strategies are: reuse, recycling, food waste prevention and energy recovery. Reaching higher levels of SMM-strategies may provide economic and environmental opportunities (i.e., in terms of GDP, jobs, reduced impacts), but not all options will have a net win–win–win property in practice, as they reduce the need for producing new commodities. The open economic characteristics of Flanders are fully integrated in this methodology. The method shows the potential industries affected by an intensified SMM-strategy represented by a budget, GHG-emissions saved and jobs lost. This budget can be used to create (local) GDP and (local) employment through new SMM-strategies. From a strict regional self-interest perspective, it is preferable to substitute foreign value chains with local economic activities.

For every million euro in expenditures saved on newly produced reusable goods by an intensified SMM-reuse strategy in Flanders, GHG-emissions are reduced globally by 700 ton CO_2-eq., and global employment is reduced by 31 jobs, 5 of which are in Flanders. On average, Flanders generates 34% value added in value chains of newly produced reusable goods. So, substituting one million euro of expenditures on newly produced reusable products with a reuse system, should at least generate 341,000 EUR value added and 5 jobs in Flanders to maintain the current economic level. Striving to a net positive environmental impacts, the new reuse system should not have more than 700 ton CO_2-eq. GHG-emissions per million euro substitution.

TABLE 1: CASE STUDY RESULTS. THE PERCENTAGES BETWEEN BRACKETS REPRESENT THE FLEMISH SHARE IN THE ENVIRONMENTAL AND EMPLOYMENT BUDGET.

SMM-STRATEGIES	ECONOMIC BUDGET	ENVIRONMENTAL BUDGET	EMPLOYMENT BUDGET
(unit)	*percentage local value added creation*	*in kt CO_2-eq. per million euro economic budget*	*in number of employees per million euro economic budget*
energy recovery	13.2	2.43 (26.3%)	22.99 (4.8%)
food waste prevention	29.8	1.47 (25.8%)	53.18 (9.4%)
recycling	9.8	2.56 (7.3%)	46.54 (2.2%)
reuse	34.1	0.70 (25.7%)	31.07 (15.8%)

The substitution potential for the SMM-strategies from the case study are summarised in **Table 1**.

The final chapter, *chapter 6. Estimating and interpreting two material indicators for Flanders: Domestic Material Consumption and Raw Material Consumption*, gives insights into the difference between DMC and RMC, using the case of Flanders. If assumed that resource efficiency, defined by the ratio between GDP and material use, is a good leading indicator. What is the overlap and what is the difference in measuring material use via the DMC or the RMC? Is the DMC superior to RMC or is RMC a better indicator?

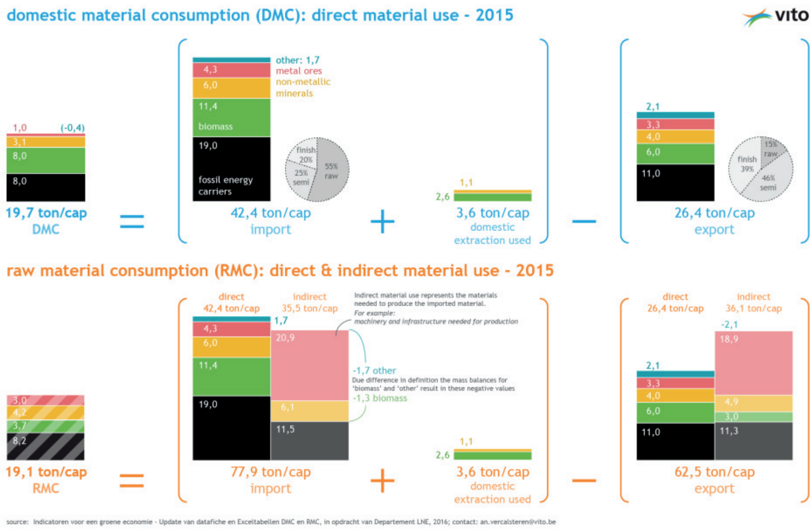

FIGURE 2: COMPARISON OF THE DMC AND RMC IN FLANDERS (2015).
(BASED ON: CHRISTIS ET AL., 2016B)

Figure 2 illustrates the overlap and the difference between the DMC and the RMC. The difference between these indicators is the exclusion or inclusion of the material rucksack of trade flows. The DMC is restricted to the actual import and export flow, while the RMC includes the material rucksack of import and export. In Flanders, the material rucksack of import is almost equal to the import flow, with a ratio between the import flow and its material rucksack of 0.8. In contrast, the material rucksack of export is larger than the actual export flow, with a ratio between the export flow and its material rucksack of 1.4.

The methodologies supporting the calculation of both indicators DMC and RMC are available. However, there is a difference in the availability of the data sources used to estimate them. Although Eurostat provided RME-coefficients, they are not country (or region) specific and are not available at the same level of detail provided in the trade statistics. Unavoidable, this leads to over- and underestimations in RMC-calculations. A major shortcoming of the DMC is its narrow focus. It is not robust against outsourcing, meaning a country could decrease its DMC via the outsourcing of material intensive activities. Import and export conversion to RME's overcomes this shortcoming, resulting in a RMC-indicator encompassing global production chains, while maintaining the focus on local consumption. So, the RMC is superior to DMC in estimating material used linked to consumption, however, its estimation needs further improvements via improvements in the RME data sources. Increased availability of EE-MRIO models provide a promising alternative to the RME data.

Samenvatting

Het doctoraat geeft inzichten op de onderzoeksvraag: "Welke toepassingen maken van het Vlaams uitgebreid milieu input-output model, uitgebreid met regionale, nationale en internationale economische data en materiaalgegevens, een belangrijke macro-economische tool voor beleidsvorming rond duurzaam materiaalbeheer in Vlaanderen?". Om een antwoord te bieden op deze vraag, is het doctoraat opgebouwd in verschillende stappen. Zo wordt eerst de nadruk gelegd op materiaalrekeningen. Hoe kunnen fysieke macro-economische modellen, zoals economiebrede materiaalrekeningen (*economy-wide material flow accounts*, EW-MFA), fysieke aanbod- en gebruikstabellen (*physical supply and use tables,* PSUTs) en fysieke input-output tabellen (*physical input-output tables,* PIOTs), het huidige monetair Vlaams uitgebreid milieu input-output model verbeteren? Economiebrede materiaalrekeningen en afgeleide indicatoren hebben als doel de metabolische doeltreffendheid van een economie te beschrijven als basis voor verder onderzoek (Bringezu et al., 2003). Hoewel deze rekeningen en afgeleide indicatoren een belangrijke meerwaarde kunnen bieden ter ondersteuning van onderzoek en beleid, moet men bewust zijn van de beperkingen. Bijvoorbeeld, economiebrede materiaalrekeningen laten geen geïntegreerde milieu-economische analyses toe, omdat het de binnenlandse economie als een black box beschouwd. Deze rekeningen bevat geen data op het detailniveau van sectoren. Het bevat geen data over materiaalstromen tussen sectoren, noch maakt het een onderscheid tussen materiaalstromen gelinkt aan productie en consumptie. Ook is het niet mogelijk om de gevolgen te analyseren van structurele of technologische veranderingen, veranderingen in consumentenbehoeften of levensstijlen, migratie en urbanisatie. Niettegenstaande zijn economiebrede materiaalrekeningen en afgeleide indicatoren een goede basis voor het beter begrijpen van het metabolisme van een economie of samenleving. Een belangrijke meerwaarde hierbij zijn de grondige methodologische uitwerking van economiebrede materiaalrekeningen op Europees niveau en de beschikbaarheid van twee afgeleide indicatoren: binnenlands materiaalconsumptie (*domestic material consumption,* DMC) en grondstofconsumptie (*raw material consumption,* RMC). Andere voordelen zijn: (Bringezu et al., 2003; de Bruyn et al., 2004; Eurostat, 2001; Kleijn, 2000)

- het model geeft een globaal overzicht van de structuur van het fysiek metabolisme van een economie en de verandering in de tijd hiervan;
- de datastructuur is nauw verbonden met en maakt gebruik van nationale rekeningen, waardoor het een bijdrage levert aan de integratie, organisatie, consistentie en structuur van primaire databronnen;
- het model vormt het vertrekpunt van fysieke aanbod- en gebruikstabellen en fysieke input-output tabellen;
- het model voorziet via zijn structuur de ontwikkeling en berekening van macro-economische materiaalindicatoren;
- het model laat toe de effecten op milieu van import en export ten gevolge van consumptie te onderzoeken; en
- het model heeft het potentieel om een beleidsinstrument te zijn dat materiaalstromen en effecten op milieu te integreren en dat in alle fases van het materiaalgebruik.

Fysieke aanbod- en gebruikstabellen, en in mindere mate de economiebrede materiaalrekeningen, zijn framewerken die de integratie en consistentie van data bevorderen. De achterliggende materiaalbalansen dwingen tot een confrontatie en afstemming van verschillende databronnen. Dit proces leidt tot het homogeniseren van classificeringssystemen en de inzamelingsmethoden van data. Daarnaast kan het fouten in datasets identificeren. Het confronteren van verschillende databronnen dwingt de onderzoeker tot een inschattingen van de datakwaliteit ervan en leidt mogelijk tot een verbetering van kwaliteitsarme databronnen. Tot slot leidt dit integratie framewerk tot een overzicht van de beschikbare statistieken en controle van de consistentie en compleetheid van nationale rekeningen.

Fysieke aanbod- en gebruikstabellen worden gebruikt om de leveringen en het gebruik van materialen te analyseren. Tijdreeksen bieden de mogelijkheid om veranderingen in productie- en consumptiepatronen te beschrijven. In combinatie met monetaire aanbod- en gebruikstabellen is het mogelijk om productiviteits- en intensiteitsindicatoren af te leiden. (United Nations et al., 2014)

Fysieke input-output tabellen worden gebruikt om materiaal intensieve sectoren te identificeren. In tegenstelling tot aanbod- en gebruikstabellen, laten fysieke input-outputtabellen analysemogelijkheden toe van productienetwerken, zoals relaties tussen materiaalgebruik, productiehoeveelheden en effecten op milieu in de verschillende stadia van de productieketen. Zulke modellen laten toe de ontwikkelingen in een economie te beschrijven aan de hand van veranderingen in materiaal intensiteiten en efficiëntie van productieketens. Dus, het voordeel van fysieke input-output tabellen is de mogelijkheid tot analyse van complexe waardeketens inclusief materiaalstromen en de indirecte belasting op de omgeving van dit materiaalgebruik, zowel ten gevolge van productie als consumptie. In milieu-economische analyses geeft de modellering van structurele veranderingen in de economie, het materiaalgebruik en emissies belangrijke inzichten. Fysieke input-output modellen en analyses geven inzicht in hoe economische activiteiten kunnen leiden tot milieuproblemen en ook hoe beleid hierin een rol kan spelen. Het model laat toe een onderscheid te maken tussen economische factoren, zoals technologie, handel, consumptie en investeringen en hun invloed op structurele veranderingen. (Hoekstra, 2005)

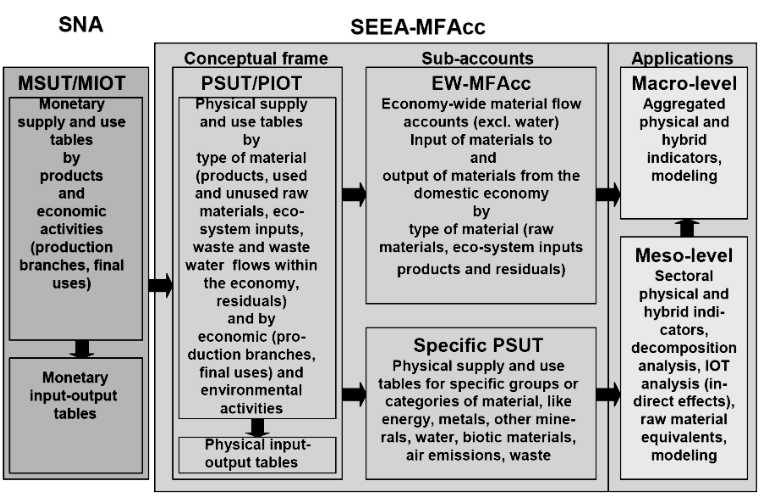

FIGURE 3: DE LINK TUSSEN FYSIEKE STROMEN BESCHREVEN IN SEEA EN MONETAIRE STROMEN BESCHREVEN IN SNA;
(SOURCE: SCHOER AND GRAVGÅRD (2007))

Van economiebrede materiaalrekeningen, tot fysieke aanbod- en gebruikstabellen tot fysieke input-output tabellen bouwen deze drie fysieke modellen op elkaar voort door informatie toe te voegen, maar de investering (tijd, budget en kennis) neemt ook toe. Economiebrede materiaalrekeningen en fysieke aanbod- en gebruikstabellen zijn een bruikbare tool voor het structuur geven aan ingezamelde data en beschrijven het metabolisme van een economie. Fysieke aanbod- en gebruikstabellen zijn superieur ten opzichte van fysieke input-output tabellen voor statistische doeleinden en het maken van materiaalbalansen en materiaalrekeningen, omdat nationale rekeningen meestal data bevatten in dezelfde dimensies als deze in aanbod- en gebruikstabellen. De verdere omvorming tot symmetrische fysieke input-output tabellen vereist aanpassingen aan bijvoorbeeld productiestatistieken om te voldoen aan het vereiste evenwicht in dit model. Ook gaat bij de omvorming van aanbod- en gebruikstabellen naar input-output tabellen een deel van de informatie verloren. Bijvoorbeeld, de heterogene output van sectoren is niet langer direct af te leiden uit het input-output model, terwijl dit wil kan met behulp van de aanbod- en gebruikstabellen. Ondanks de superioriteit op het vlak van statistiek, zijn input-output modellen superieur op het vlak van modellering. Enkel input-output analyse (die gebruik maakt van de Leontief inverse matrix) laat toe een volledige beschrijving te maken van productieketens en –netwerken. (Hernandez-Rodriguez et al., 2012; Hoekstra, 2005; OECD, 2007)

Op basis van *hoofdstuk 1. Screening of existing macro-economic models for sustainable materials management* besluit dit doctoraat dat duidelijke richtlijnen een ondersteuning moeten bieden aan de data inzameling en compilatie van economiebrede materiaalrekeningen, fysieke aanbod- en gebruikstabellen en fysieke input-output tabellen. De doelstellingen moeten op voorhand geformuleerd worden, omdat de kans om zoek te geraken in een overdaad aan informatie reëel is. De richtlijnen kunnen de werklast reduceren, daar de doelen op voorhand gekend zijn. In theorie zouden fysieke aanbod- en gebruikstabellen alle materiaalstromen moeten bevatten binnen economie en deze in relatie met de omgeving. Toch is volledigheid volgens UN-experten ambitieus. Een focus op deelaspecten is meer aangewezen (Merciai et al., 2011). De beperking van een bottom-up benadering is dat werklast en tijdsinvestering groot zijn alvorens een volledig fysiek overzicht bekomen wordt van alle intersectorale stromen en uitwisselingen met de omgeving (De Marco et al., 2009). Consistente materiaalbalansen voor alle metabolische processen zijn noodzakelijk voor een bruikbare database die de fysieke wereld beschrijft, maar er is, tot op heden, geen snelle manier om deze te produceren consistent met alle input-output assumpties.

Een vaak terugkerende kritiek op indicatoren afgeleid van de fysieke tabellen betreft de interpretatie ervan: een stijging betekent niet noodzakelijk slechter en een daling betekent niet noodzakelijk een verbetering. Indicatoren kunnen te generiek zijn, waardoor hun resultaten en interpretatie waardeloos zijn. Alle materialen die een economie binnenkomen worden vroeger of later afval, maar zelden staat de grootte van een materiaalstroom in (lineaire) verhouding tot de impact op het milieu dat het veroorzaakt. Deze kritiek is het gevolg van de problemen bij het aggregeren van verschillende materiaalstromen om één indicator te bekomen en de zwakke link tussen materiaalstroomindicatoren en de impact op milieu (Bringezu et al., 2003; de Bruyn et al., 2004; Giljum et al., 2006; Kleijn, 2000). De beperkingen van geaggregeerde materiaalindicatoren gebaseerd op massa zijn:

- grote materiaalstromen domineren de indicator die de interpretatie van geaggregeerde resultaten sterk beïnvloed (mogelijk bias);

- niet gewogen indicatoren geven geen inschatting van de milieu-impact;
- enkel een focus op de reductie van geaggregeerde materiaalindicatoren is onvoldoende voor het streven naar duurzaamheid; en
- aggregatie op basis van de massa van materialen is geen reflectie van de economie relevantie of waarde.

Er is slechts een zwakke correlatie tussen de massa en de milieu-impact van materiaalstromen (de Bruyn et al., 2004). Bijgevolg ontstaat de discussie of de op massa gebaseerde indicatoren voldoende zijn. Toch zorgen materiaalstroomanalyses op basis van deze massarekeningen voor een goede basis voor verdere analyse. Echter om de effecten van materiaalgebruik op milieu te beschouwen, zijn disaggregatie, conversies naar andere eenheden en bijkomende data noodzakelijk.

In praktijk kunnen de beschreven methodes op een consistente wijze gehanteerd worden. Bijvoorbeeld, de fysieke input-output tabellen kunnen elke vijfjaar worden opgesteld, met een tweejaarlijkse (of driejaarlijkse) update van de achterliggende balansen. Individuele rekeningen kunnen jaarlijks opgesteld worden voor een nauwgezette opvolging van bepalende stromen. Op basis van de literatuurstudie leidt dit doctoraat af dat ter ondersteuning van Vlaams beleid het aangewezen is een jaarlijkse opstelling van economiebrede materiaalstroomrekeningen, volgens de EU-regulering No. 691/2011. Dit vergt enkel een beperkte investering, wegens vooraf gedefinieerde en geteste methodologie en de beschikbaarheid van data op Vlaams niveau. De oplevering van eerste resultaten kan al 4-6 maanden na de periode onder beschouwing en definitieve resultaten kunnen volgen na ca. 13 maanden. De afgeleide indicatoren uit deze materiaalrekening tonen trends en identificeren gebieden voor verder onderzoek. Ook de vergelijkbaarheid met andere landen is een meerwaarde. Let wel, de investering loont pas indien de materiaalrekening voldoende detail biedt. Een te hoog niveau van aggregatie geeft geen duidelijk beeld van de verantwoordelijke actoren.

Tot op heden is het niet opportuun voor Vlaanderen om te investeren in fysieke aanbod- en gebruikstabellen of fysieke input-output tabellen. De hoge vereisten qua data, datavalidatie en de hoge mate van detail hinderen een eenvoudige opmaak en een wijd verspreid gebruik ervan. Frequent opgemaakte (bottom-up) tabellen hebben toepassingen, zoals het in kaart brengen en analyseren van materiaalstromen, die beleid ondersteunen. Toch weegt dit niet op tegen de tijdsinvestering die de opmaak van zulke tabellen vraagt. Ook blijkt uit de opmaak van fysieke input-output tabellen in Duitsland en Denemarken dat hun hoge kost en beperkte toepassingen in beleid de verdere ontwikkeling ervan geen boost hebben gegeven (TRITEL & CE Delft, 2013). Tot slot, in de open Vlaamse economie spelen import en export een zeer belangrijke rol. Hierdoor zou een fysiek model dat enkel Vlaanderen beschrijft, zonder mogelijkheid om dit te koppelen met een vergelijkbaar alternatief dat de wereld beschrijft, een te beperkt beeld schetsen van materiaalstromen. Een Vlaams model zou louter fragmenten uit complexe geglobaliseerde materiaalketens beschrijven. Zulk model beschrijft slechts enkele stukjes in een complexe puzzel. Deze laatste opmerking geeft ook aan dat de aanbeveling slechts tijdelijk is. Eens fysieke aanbod- en gebruikstabellen en fysieke input-output tabellen (vb. Exiobase versie 3) beschikbaar en getest zijn, kan een slimme investering in een Vlaamse uitbreiding opportuun zijn.

Op basis van de literatuurstudie in *hoofdstuk 1* is gekozen om verder te bouwen op de bestaande en beschikbare Vlaamse monetaire input-output tabellen. De toepassingen van dit model worden uitgebreid naar het analyseren van materiaalgebruik (bijv. via materiaalstroomindicatoren) door het toevoegen van

Vlaamse economiebrede materiaalrekeningen aan het model. Deze uitbreiding laat toe om materiaalindicatoren, zoals DMC en RMC, te koppelen aan economische factoren. De overlap en het verschil tussen de DMC en RMC is besproken in *hoofdstuk 6. Estimating and interpreting two material indicators for Flanders: Domestic Material Consumption and Raw Material Consumption*.

Aangezien het doctoraat verder bouwt op bestaande monetaire input-output tabellen is het belangrijk de reeds beschikbare toepassingen van deze modellen beschreven in de (recente) internationale literatuur op te lijsten. *Hoofdstuk 2. Policy needs to be covered by EE-IO capabilities* geeft dit overzicht. Het hoofdstuk geeft inzicht in de vraag: 'Welke milieugerichte toepassingen zijn ontwikkeld op basis van input-output tabellen?'. De literatuurstudie biedt een overzicht aan toepassingen, methodologieën en gehanteerde databases. Niet alleen input-output databases, maar ook de koppeling met andere databases en –modellen (bijv. huishoudbudget enquête) is relevant. De casestudy Vlaanderen op basis van interviews met Vlaamse beleidsmakers geeft een overzicht van de opportuniteiten en ondersteunt de verdere ontwikkeling van het milieu-uitgebreid input-output model en haar toepassingen ter ondersteuning van Vlaams beleid.

Verdere ontwikkelingen van input-output modellen en databases zijn een afweging van het behartigen van algemene doelen, gespreid over verschillende toepassingsdomeinen, en ontwikkelingen richting zeer specifieke toepassingsdoeleinden. Bijvoorbeeld, de ontwikkeling van officiële internationaal geaccepteerde milieu-uitgebreide input-output tabellen gebaseerd op globale geharmoniseerde bottom-up statistieken zijn vaak al gedateerd bij oplevering en het detailniveau is te beperkt in toepassingen vergeleken met de meer experimentele modellen. De experimentele modellen daarentegen zijn geschikt voor probleemanalyses en prioritering in een vroeg stadium van beleid, maar hun globale acceptatie is een struikelblok.

De literatuurstudie toont een grote variëteit in toepassingen aan van input-output analyses, vooral na koppeling met andere statistieken en datasets. Input-output tabellen beschrijven de economische structuur gebruik makende van gestandaardiseerde nomenclaturen. Dit laat toe om een koppeling te maken met andere (milieu gerelateerde) statistieken. De literatuurstudie toont aan dat het model in alle fases van het DPSIR framewerk (*driving forces, pressures, state, impact en responds*) gebruikt wordt. Enkele beleidsbehoeften worden beschreven in de interviews, maar deze vereisen een groter detailniveau of een verdere uitbreiding van de input-output modellen. Hoewel dit mogelijk is, is de uitdaging om zowel optimaal gebruik te maken van lokale statistieken én internationale statistieken om ook internationale waardeketens mee in rekening te kunnen brengen. Lokale statistieken beschrijven op gedetailleerde wijze de lokale economie. Bijvoorbeeld, het detail van de sectorindeling kan in lokale tabellen afwijken van de standaardindeling om belangrijke sectoren in groter detail weer te geven. Anderzijds is er de nood voor het gebruik van internationale statistieken om de directe en indirecte impact van globaal verspreide productieketens te kunnen meten.

De uitgebreide lijst aan onderwerpen beschreven in internationale publicaties suggereert een potentiële relevantie voor beleidsmakers van input-output analyses. Ook, gegeven de recente toename in de beschikbaarheid van multiregionale input-output modellen, kan verwacht worden dat meerdere analyses beschikbaar zullen komen. Toch blijft een belangrijke richtlijn van onderzoekers om duidelijk de stand van zaken te blijven beschrijven in verband met nieuwe databases, methodologieën en toepassingen. Een mogelijke hefboom hierbij is het gebruik van een attractieve visualisatie van resultaten (bijvoorbeeld infografieken).

Op basis van de conclusies uit de eerste twee hoofdstukken en gegeven de open Vlaamse economie, zet dit doctoraatsproefschrift in op de ontwikkeling van een methodologie voor het koppelen van lokale (of nationale) input-output modellen met multiregionale input-output modellen. Dit moet toelaten om de geglobaliseerde waardeketens volledig te beschrijven vanuit het standpunt van een lokale economie (zowel lokale productie als consumptie). Het behouden van de lokale statistieken als vertrekpunt in analyses is een belangrijke meerwaarde naar de interesse en acceptatie van resultaten door beleidsmakers. De methodologie is beschreven in *hoofdstuk 3. Linking regional input-output tables to multiregional input-output tables.* Naast de methodologie geeft dit hoofdstuk het belang van de toepassing weer voor een kleine open economie (case Vlaanderen) aan de hand van enkele monetaire en milieu-indicatoren.

Het gecombineerd model op basis van lokale en multiregionale milieu uitgebreide input-output tabellen resulteert in de best mogelijke schatting voor regionale voetafdrukken, omdat deze schatting is gebaseerd op alle beschikbare gegevens. Bijvoorbeeld, de aanname van de 'binnenlandse technologie assumptie' (geïmporteerde producten worden geproduceerd op dezelfde wijze als binnenlandse producten) of het gebruik van nationale gegevens voor regionale schattingen leidt tot aanzienlijke specificatiefouten en bijgevolg tot onbetrouwbare schattingen. Naast de specificatiefouten, gaat dit hoofdstuk ook in op aggregatiefouten en tijdsfouten. Het hoofdstuk concludeert met een aantal richtlijnen voor onderzoekers in verband met de keuze van het model en eventuele aanpassingen daaraan in functie van de te schatten indicator(en). Enkele belangrijke vragen hierbij zijn: Wordt de indicator bepaald door voornamelijk binnenlandse of buitenlandse economische/milieukarakteristieken? Wat is het belang van import in de schatting van de indicator? Wordt de voetafdruk beïnvloed door grote sectorspecifieke of landspecifieke eigenschappen? Zijn de onderliggende factoren (zogenaamde multiplicatoren) onderhevig aan trends? In open economieën, zoals de Vlaamse economie, worden de meeste indicatoren bepaald door zowel lokale als globale kenmerken en bevat ze een belangrijk aandeel van niet-lokale impact. Hierdoor geeft het gebruik van een gecombineerd model met lokale en multiregionale data in de hoogst beschikbare resolutie de best mogelijke en meest betrouwbare schatting. Indicatoren die hoofdzakelijk bepaald worden door binnenlandse kenmerken vereisen tenminste het gebruik van een lokaal milieu-uitgebreid input-output model, terwijl indicatoren hoofdzakelijk bepaald door buitenlandse productie tenminste het gebruik van een multiregionaal model vragen.

Uit de in hoofdstuk 3 getoetste voetafdrukken concludeert dit proefschrift dat de aggregatie van niet-buurlanden (dit komt overeen met het niet samenvoegen van de belangrijke handelspartners) leidt tot kleine fouten. Alle geteste indicatoren profiteren van secundaire sector disaggregatie. Slechts enkele indicatoren profiteren van de disaggregatie van de primaire sector, bijvoorbeeld de water- en materiaalafdruk, aangezien deze indicatoren grotendeels bepaald worden door de primaire sectorcoëfficiënten. Het gebruik van gegevens op basis van een ander jaar is slechts een waardevolle optie in schattingen voor indicatoren als de achterliggende coëfficiënten stabiel zijn over de tijd. Trends kunnen slechts een kleine impact hebben op coëfficiënten en multiplicatoren, maar de consistente overschatting of onderschatting ervan resulteert in afwijkende schattingen. Een reflectie op de indicator is noodzakelijk om het optimale model te bepalen en helpt bij het begrijpen van de mogelijke schattingsfouten. De belangrijkste overweging is het bepalen van het optimale evenwicht tussen investeringen in model adaptatie en/of uitbreiding en de betrouwbaarheid van de uiteindelijke schatting. Deze overweging moet worden gedaan voor de feitelijke analyse en dient ter ondersteuning van de validatie van de uitkomst.

Hoofdstuk 4. Comparing a territorial-based and a consumption-based approach to assess local and global environmental performance of cities verschilt van de vorige hoofdstukken, aangezien de focus op een stad ligt, namelijk het Brussels Hoofdstedelijk Gewest (België). Het voorbeeld van een input-output analyse op stadsniveau benadrukte het belang van het combineren van lokale specifieke gegevens in verband met multiregionale databases. Het laat toe om de globale impact van lokale consumptie en productie van een stad in te kunnen schatten. In dit hoofdstuk wordt een vergelijkende analyse gegeven van een territoriale en consumptie-gebaseerde aanpak om zowel het directe als het indirecte gebruik van materialen en emissies in het Brussels Hoofdstedelijk Gewest (België) te schatten. De territoriale aanpak is gebaseerd op lokale meetgegevens over energie-, water- en materiaalverbruik, evenals over afval en emissies. De schatting van het indirecte gebruik van hulpbronnen en emissies (verbruik gebaseerde aanpak) maakt gebruik van de regionale IO-tabellen van de stadsregio Brussel, uitgebreid met multiregionale input-output tabellen. De vergelijking van deze twee benaderingen is bijzonder relevant voor steden met beperkte productieactiviteiten en beperkte of geen extractie van materialen, aangezien de impact op omliggende regio's vaak onderschat of verwaarloosd wordt door lokaal (milieu) beleid dat (vaak) uitsluitend is gebaseerd op territoriale-cijfers. In het kader van het bewerkstelligen van lokale en mondiale milieu-uitdagingen is het essentieel om te begrijpen dat steden complexe systemen zijn die afhankelijk zijn van en verbonden zijn met de rest van de wereld door middel van wereldwijde waardeketens. Om de duurzaamheid van een stedelijk gebied op een uitgebreide manier te beoordelen is het niet alleen nodig om zijn lokale en directe milieuprestaties te meten, maar ook om haar globale en indirecte milieupartners te begrijpen en in rekening te nemen.

Uit de resultaten blijkt dat het indirecte primaire energieverbruik, de uitstoot van broeikasgasemissies en het gebruik van het materiaal meer dan drie keer hoger is wat de lokale statistieken aangeven (let wel, consumptie gebaseerde aanpak versus territoriale aanpak). Het watergebruik, geschat via IOA, was ruim 40 keer hoger dan het lokale waterverbruik. Dit laat zien dat de territoriale benadering de behoeften van hulpbronnen en de emissies van een stad onderschat en derhalve onvoldoende of zelfs misleidend kunnen zijn. Door de herkomst van de stromen te visualiseren is het mogelijk zo het open karakter van een stedelijke economie en zijn afhankelijkheid van de rest van de wereld te illustreren. Tenslotte bespreekt dit hoofdstuk de mogelijkheid en relevantie om deze twee benaderingen te combineren om een hybride kader te creëren die de volledige milieuprestaties van steden zowel nauwkeurig (lokaal) als meer uitgebreid (globaal) meet.

Hoofdstuk 5. Value in sustainable materials management strategies for open economies - Case of Flanders maakt gebruik van de casestudy Vlaanderen. Het beschrijft een top-down methodologie voor het schatten van het substitutiepotentieel van intensivering in specifieke SMM-strategieën en strategieën voor materiaal-efficiëntie. De beschreven strategieën zijn: hergebruik, recyclage, preventie van voedselafval en energierecuperatie. Het bereiken van hogere niveaus van SMM-strategieën kan economische en milieukansen bieden (dwz in termen van BBP, banen, verminderde milieu effecten), maar niet alle opties hebben in de praktijk een netto win-win-win-eigenschap, omdat ze de behoefte aan nieuwe producten produceren. De open economische kenmerken van Vlaanderen zijn volledig geïntegreerd in deze methodologie. De methode laat de potentiële industrieën zien die getroffen zijn door een geïntensiveerde SMM-strategie, vertegenwoordigd door een begroting, vermeden GHG-emissies en verloren banen. Dit budget kan gebruikt worden om (lokale) bbp en (lokale) werkgelegenheid te creëren via nieuwe SMM-strategieën. Vanuit een strikte regionale zelfbelangsperspectief is het beter om buitenlandse waardeketens te vervangen door lokale economische activiteiten.

Voor elke miljoen euro in uitgaven dat wordt bespaard op nieuw geproduceerde herbruikbare goederen door een intensievere SMM-hergebruiksstrategie in Vlaanderen, worden de GHG-emissies wereldwijd met 700 ton CO_2-eq. verminderd en is de wereldwijde werkgelegenheid verminderd met 31 banen, waarvan er 5 in Vlaanderen zijn. Vlaanderen genereert gemiddeld 34% toegevoegde waarde in waardeketens van nieuw geproduceerde herbruikbare goederen. Dus, met 1 miljoen euro uitgaven voor nieuw geproduceerde herbruikbare producten met een hergebruikssysteem, moet minstens 341.000 EUR toegevoegde waarde en 5 banen in Vlaanderen genereren om het huidige economische niveau te handhaven. Streven naar een netto positieve milieueffect, zou het nieuwe hergebruikssysteem niet meer dan 700 ton CO_2-eq. GHG-emissies per miljoen euro substitutie moeten hebben.

Het volledige substitutiepotentieel voor de SMM-strategieën uit de casestudy is samengevat in **Table 2**.

TABLE 2: CASE STUDY RESULTATEN. DE PERCENTAGES VERMELDT TUSSEN HAKEN GEVEN HET VLAAMS AANDEEL IN HET MILIEU- EN TEWERKSTELLINGSBUDGET.

SMM-STRATEGIEËN	ECONOMISCH BUDGET	MILIEU BUDGET	TEWERKSTELLING-BUDGET
(eenheid)	*lokale creatie van toegevoegde waarde (percentage)*	*in kt CO_2-eq. per miljoen euro economisch budget*	*in aantal werknemers per miljoen euro economisch budget*
energie recuperatie	13.2	2.43 (26.3%)	22.99 (4.8%)
preventie van voedselafval	29.8	1.47 (25.8%)	53.18 (9.4%)
recyclage	9.8	2.56 (7.3%)	46.54 (2.2%)
hergebruik	34.1	0.70 (25.7%)	31.07 (15.8%)

Het laatste hoofdstuk, hoofdstuk *6. Estimating and interpreting two material indicators for Flanders: Domestic Material Consumption and Raw Material Consumption*, geeft inzicht in het verschil tussen DMC en RMC, met een cijfervoorbeeld voor Vlaanderen. Als aangenomen wordt dat grondstoffenefficiency, gedefinieerd door de verhouding tussen het BBP en het materiaalgebruik, een goede leidende indicator is, wat is dan de overlap en wat is het verschil in het meten van materiaalgebruik via de DMC of de RMC? Is de DMC superieur aan RMC of is RMC een betere indicator?

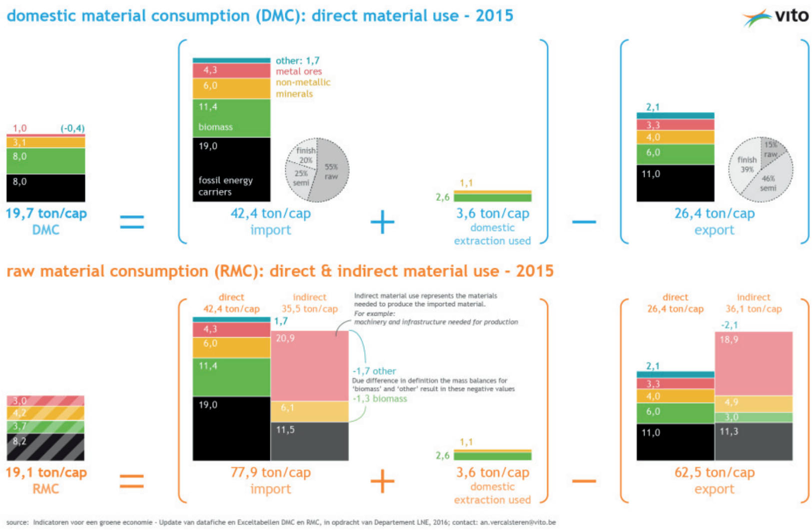

Figure 4: Vergelijking tussen de DMC en de RMC in Vlaanderen (2015). (Based on: Christis et al., 2016b)

Figure 4 illustreert de overlap en het verschil tussen de DMC en de RMC. Het verschil tussen deze indicatoren is het uitsluiten of opnemen van de grondstoffenrugzak van de handelsstromen. De DMC is beperkt tot de daadwerkelijke import- en exportstroom, terwijl de RMC de grondstoffenrugzak van import en export bevat. In Vlaanderen is de materialenrugzak van import bijna gelijk aan de invoer zelf, met een verhouding tussen de invoer en zijn grondstoffenrugzak van 0,8. Daarentegen is de grondstoffenrugzak van de export groter dan de werkelijke exportstroom, met een verhouding tussen de exportstroom en zijn grondstoffenrugzak van 1,4.

De methodologieën die de berekening van beide indicatoren DMC en RMC ondersteunen zijn beschikbaar. Er is echter een verschil in de beschikbaarheid van de ondersteunende gegevens die gebruikt worden om ze te schatten. Hoewel Eurostat RME-coëfficiënten (raw material equipvalents) heeft verstrekt, zijn deze niet land (of regio) specifiek en zijn ze niet beschikbaar op hetzelfde detailniveau als de handelsstatistieken. Onverbiddelijk leidt dit tot over- en onderschatting in de RMC-berekeningen. Een belangrijke tekortkoming van de DMC is zijn beperkte focus. Deze indicator is niet robuust tegen outsourcing, waardoor een land haar DMC kan verminderen via de uitbesteding van grondstofintensieve activiteiten. De conversie van invoer- en uitvoerstromen naar RME's komt tegemoet aan deze tekortkoming, wat resulteert in een RMC-indicator die wereldwijde productieketens omvat, waarbij de focus op het lokale verbruik wordt behouden. Zo is de RMC superieur aan DMC in het beoordelen van grondstoffen die wordt gebruikt in verband met consumptie, maar de schatting heeft nog verdere verbeteringen nodig door het verhogen van de kwaliteit in de RME-gegevensbronnen. De toegenomen beschikbaarheid van EE-MRIO-modellen biedt een veelbelovend alternatief voor deze RME-gegevens.

List of abbreviations

ABBREVIATION	DESCRIPTION
CPA	statistical classification of products by activity in the European Economic Community
DE	domestic extraction
DEU	domestic extraction used
DHF	domestic hidden flows
DHF	domestic hidden flows
DMC	domestic material consumption
DMI	direct material input
DPO	domestic processed output
EE	environmentally extended
EE-IO	environmentally extended input-output
EE-MRIO	environmentally extended multiregion input-output table
EW-MFA	economy wide material flow analysis
FHF	foreign hidden flows
GDP	gross domestic products
HF	hidden flows
IO	input-output
IOA	input-output analysis
IOT	input-output table
MFA	material flow analysis
MIOT	monetary input-output table
MIPS	material input per service unit
MRIOT	multiregion input-output table
NACE	statistical classification of economic activities in the European Community
NAS	net additions to stock
PIOT	physical input-output table
PPP	purchasing power parity
PRC	policy research centre
PSUT	physical supply and use table
PTB	physical trade balance
RAMON	reference and management of nomenclatures
RIOT	regional input-output table
RMC	raw material consumption
RME	raw material equivalents
RMI	raw material input
RoW	rest of worlds
SEEA	system of environmental-economic accounting
SMM	sustainable materials management
SNA	system of national accounts
SuMMa	sustainable materials management
SUT	supply and use table
TDO	total domestic output
TMC	total material consumption
TMI	total material input
TMO	total material output
TMR	total material requirement
UM	urban metabolism

Content

0. The PhD: What's it all about?

Sustainable material management is the cornerstone of the future green and circular economy and it is an essential theme from a transition management perspective. The policy research centre (PRC) sustainable material management (SuMMa) created and gained in-depth scientific insights, gave scientific support and built competences related to sustainable material management with respect to transition management in an interdisciplinary approach. This PhD project on assessing material flows in Flanders on a macroscopic level, was performed in the context of SuMMa.

FIGURE 5: LOGO OF SUMMA.

FIGURE 6: CONSORTIUM PARTNERS OF SUMMA.

As this dissertation is part of the SuMMa project, it is framed within the following 4 boundaries:

- the materials considered in SuMMa are non-food, non-energy materials;
- a transition management perspective is used;
- an integrated and interdisciplinary approach is followed:
    - integrated = interaction with other transitions (green economy, energy,...) is guaranteed, amongst others through close interaction with other policy research centres; and
    - three pillars of sustainability (including economic efficiency and social equity) are considered.
- relevant for Flemish policy, but embedded in European and global context.

The scientific research of this PRC is organized in a matrix of clusters (see **Figure 7**). The clusters represent essential domains for sustainable materials management. In the clusters, competences are brought together and developed. Each cluster contains one or more research lines that elaborate concepts and methodologies related to the cluster's domain. This dissertation covers cluster 2 'monitoring and evaluation' research line 4 'macroscopic assessment of material flows in Flanders based on physical input-output tables'. Note the difference between the title of this dissertation 'macroscopic assessment of material flows in Flanders based on input-output tables' and the title of research line 4 'macroscopic assessment of material flows in Flanders based on *physical* input-output tables'. This already indicates the shift during this project from the development of pure physical input-output tables (PIOTs) for Flanders to the improvement in monetary input-output tables (MIOTs) combined with physical databases. A detailed description of this shift is described in chapter one.

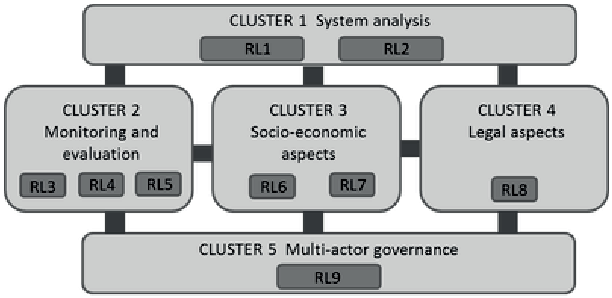

FIGURE 7: SCHEMATIC DIAGRAM OF THE WORKING STRUCTURE OF SUMMA.

Research cluster 2 aims to quantify and assess material flows in Flanders and trade-related flows outside of Flanders. Understanding these flows is crucial for evaluating policy measures with respect to SMM (SEEA, 2010; EC, 2012; EPA, 2009; OECD, 2011; UNEP, 2011). These material flows can be studied on a macroscopic and a microscopic level. To assess the material flows, data is required on the one hand, and on the other hand these data needs to be translated into an evaluation of the resource efficiency. In order to achieve this, research cluster 2 consists of three research lines:

- RL3: dynamic environmental and economic assessment of materials recycling (Andrea Di Maria, KU Leuven);
- RL4: macroscopic assessment of material flows in Flanders, based on physical input/output tables; and
- RL5: resource efficiency in material cycles and implementation of indicators (Sofie Huysman, University of Ghent).

Research line 4 extends the Flemish environmentally extended input-output (EE-IO) model with physical data that allow the monitoring of material loops on a macroscopic level. In the framework of research line 4 criteria for an optimal dataset are proposed. Additionally, the aim is to set up this extended model for Flanders with available data. Based on the developed criteria and the construction of the actual model, recommendations for improved data collection will be made towards statistical institutions and policy actors. The use of the extended model will be demonstrated by evaluating the effects of specific policy measures and possible market changes.

The results of this research cluster will provide relevant indicators and assessments in view of follow up and policy evaluation. They will provide basic material for national and international reporting initiatives such as MIRA (the Flemish Environmental Report).

The following of **Chapter zero** frames this dissertation in the context of the years 2012-2018. It describes the principles of an EE-IO model and analysis and specifies what is available in Flanders. Chapter zero outlines the starting point for this research. In this context, the objectives and research questions are derived that gave this research project a clear direction.

0.1 WHAT IS AN INPUT-OUTPUT MODEL AND WHAT IS INPUT-OUTPUT ANALYSIS?

An input-output model is a database of matrices listing the flows between economic actors. It is a static model assuming linear relationships between production and consumption. The flows are listed in monetary, physical or a combination of monetary and physical units (hybrid accounts). Input-output models and analyses are described by the System of National Accounts (SNA, 2008). The three basic matrices in a input-output model are:

- an inter-industry matrix (Z) detailing flows between industries or sectors;
- a primary input matrix (K) containing the primary inputs to industries; and
- a final demand matrix (F) of flows from industries to final demand categories.

The rows of an input-output model detail the deliveries by industries to other industries (in matrix Z) and to final demand categories (in matrix F). The columns depict the use by sectors of products inputs (matrix Z) or primary inputs (matrix K). The row total of a sector equals its column total, meaning total input equals total output. Vector x contains total output of all sectors. By dividing the inter-industry matrix by the output vector results in the input matrix A (constant technical coefficients) with values ranging between 0 and 1.

$$\mathrm{A} = \mathrm{Z} \times \hat{\mathrm{x}}^{-1}$$

with ^ representing a diagonalized vector.

Every column of matrix A describes the input value of a certain product per output value, implying that there is only one ‘production recipe’ per sector output. Total output is the sum of all delivers to industries and final demand.

$$\mathrm{x} = \mathrm{Z}\,\mathrm{i} + \mathrm{F}\,\mathrm{i}$$

with i a summation column vector.

Rearranging results in

$$\mathrm{x} = \mathrm{A} \times \mathrm{x} + \mathrm{F}\,\mathrm{i}$$

or

$$\mathrm{F}\,\mathrm{i} = (\mathrm{I} - \mathrm{A}) \times \mathrm{x}$$

with matrix I the corresponding identity matrix containing ‘1’ on the main diagonal and ‘0’ elsewhere. Rearranging the previous formula gives

$$\mathrm{x} = (\mathrm{I} - \mathrm{A})^{-1} \times \mathrm{F}\,\mathrm{i}$$

In this equation is $(\mathrm{I} - \mathrm{A})^{-1}$ the Leontief inverse (matrix L), the basis of input-output analysis. Matrix A describes the direct inputs of a sector per output value, while matrix L describes the required cumulative (=direct + indirect) input of a sector per output value.

An input-output model is often supplemented with extension or satellite tables (vector e), resulting in environmentally extended input-output (EE-IO) models. The extension tables contain sector specific data on material use, emissions, labour input, etc. Via an input-output analysis the extension is linked to final demand:

$$\mathrm{e} \times \mathrm{L} \times \mathrm{F}$$

This analyses enables the use to calculate the total use of an extension in the production of products consumed by (a part of) final demand. The complete compilation process of the supply, use and input-output tables is described in detail in a manual by (Eurostat, 2008).

The following example of a hypothetical, but simple, closed economy illustrates the basic building blocks of an IO-model. This example is reused in section 5.8. Assume an economy that contains five sectors: (A) extraction of non-energy raw materials, (B) extraction and production of energy from fossil sources, (C+D) metal sector and (E) the production of applications (e.g., domestic household appliances). Additionally, it contains one final demand category consuming energy from sector B and appliances from sector E.

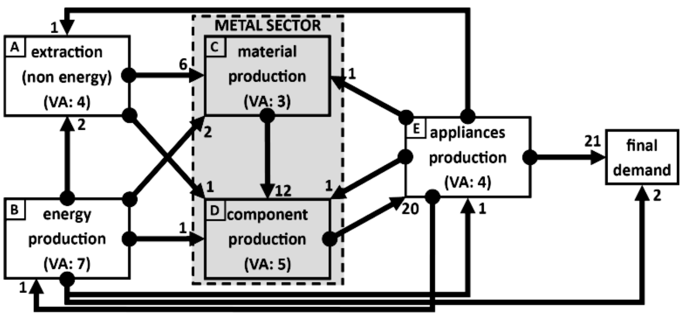

FIGURE 0.1: HYPOTHETICAL ECONOMY CONTAINING FIVE SECTORS AND ONE FINAL DEMAND CATEGORY. ALL NUMBERS ARE IN MILLION EUROS; VA: VALUE ADDED.

From Figure 0.1 we can deduct matrices Z (interindustry matrix), A (interindustry coefficient matrix) and L (Leontief inverse) and vectors f (final demand vector), x (output) and k (value added). e (employment vector) is added to include one non-economic parameter. $\mathrm{e}^{\mathrm{coef}}$ (employment coefficient vector) is deducted from e. I is an identity matrix: '1' on the main diagonal and '0' elsewhere. Numbers in Z, F, x are in million euros, e is in number of employees, matrices A and $\mathrm{k}^{\mathrm{coef}}$ are coefficient matrixes (dimensionless) and matrix $\mathrm{e}^{\mathrm{coef}}$ is in number of employees per one million euro output.

$$\mathrm{Z} = \begin{bmatrix} 0 & 0 & 6 & 1 & 0 \\ 2 & 0 & 2 & 1 & 1 \\ 0 & 0 & 0 & 12 & 0 \\ 0 & 0 & 0 & 0 & 20 \\ 1 & 1 & 1 & 1 & 0 \end{bmatrix};\ \mathrm{f} = \begin{bmatrix} 0 \\ 2 \\ 0 \\ 0 \\ 21 \end{bmatrix};\ \ \mathrm{x} = \begin{bmatrix} 7 \\ 8 \\ 12 \\ 20 \\ 25 \end{bmatrix}$$

$$\mathrm{k} = [4 \quad 7 \quad 3 \quad 5 \quad 4]$$
$$k^{\mathrm{coef}} = \mathrm{k} \times \hat{\mathrm{x}}^{-1} = [0.57 \quad 0.88 \quad 0.25 \quad 0.25 \quad 0.16]$$

$$\mathrm{e} = [90 \quad 150 \quad 60 \quad 80 \quad 40]$$

$$e^{coef} = e \times \hat{x}^{-1} = [12.9 \quad 18.8 \quad 5 \quad 4 \quad 1.6]$$

$$A = Z \times \hat{x}^{-1} = \begin{bmatrix} 0 & 0 & 0.5 & 0.05 & 0 \\ 0.29 & 0 & 0.17 & 0.05 & 0.04 \\ 0 & 0 & 0 & 0.6 & 0 \\ 0 & 0 & 0 & 0 & 0.8 \\ 0.14 & 0.13 & 0.08 & 0.05 & 0 \end{bmatrix}$$

Every column of matrix A describes the direct input value of a certain product per million euro output value of the sector. For example, the sector 'appliances production' requires the input of 0,04 million euro from the energy production and 0,8 million euro from the component production to produce one million euro of output. The remaining input is gross value added generated in the sector itself.

$$L = (I - A)^{-1} = \begin{bmatrix} 1.06 & 0.04 & 0.56 & 0.41 & 0.33 \\ 0.34 & 1.04 & 0.36 & 0.3 & 0.28 \\ 0.1 & 0.07 & 1.11 & 0.7 & 0.56 \\ 0.17 & 0.12 & 0.18 & 1.17 & 0.94 \\ 0.21 & 0.15 & 0.23 & 0.21 & 1.18 \end{bmatrix}$$

Every column of matrix L describes the total input value (=direct + indirect) of a certain product per million euro output value of the sector. For example, to produce one million euro of output of the sector 'appliances production' requires the output of 0,33 million euro from the extraction sector (non-energy), 0.28 million euro from the energy production, 0.56 from the material production, 0.94 million euro from the component production and 1.18 from the appliances production.

So delivering an output of one million euro of appliances to final demand triggers economic activity in all sectors in this economy. As all sectors rely on employment in their production, this demand also triggers employment. If final demand of the sector 'appliances production' is one million euro, it generated employment in all five sectors of the economy: 4.3 in the extraction sector (non-energy), 5.3 in the energy production sector, 2.8 in the material production sector, 3.8 in the component production sector and 1.9 in the appliances production sector.

0.2 The Flemish input-output database

In Flanders, three monetary input-output databases are available (based on the European System of National and Regional Accounts version 1995[1]). Each database consists out of the monetary supply and use tables, monetary input-output tables, environmental extension tables and detailed household consumption tables. Models exist for 2003, 2007 and 2010. The models for 2003 and 2007 are regional input-output tables, whereas the model for 2010 is an interregional input-output table. The difference is in the representation of the Brussels Capital Region and the Walloon region. In 2003 and 2007 these regions are only included via interregional import and export, while in 2010 both regions are available in detail, including intersectoral trade, value added at sector level and final demand. The latest versions contain 119, 122 and 124 sectors and products for 2003, 2007 and 2010, respectively.

[1] A new edition of the European System of National and Regional Accounts is published in 2013, referred to as 'ESA 2010'. Changes are described in 'Manual on the changes between ESA 95 and ESA 2010 - 2014 edition' by Eurostat.

0.3 CONTENT OF THIS DISSERTATION

The **objective** of this PhD is to demonstrate **the application of the Flemish EE-IO model with multi-regional monetary and physical IOTs and other databases as a tool for sustainable materials management**. Extending the Flemish EE-IO model with both monetary and physical multi-regional data will allow the application of the EE-IO model as an evaluation tool for the assessment of policy measures and of the effectiveness and efficiency of closing material loops.
In order to reach this objective, the PhD will focus on the following topics:

- The evaluation of setting up Flemish PIOTs. The benefits of constructing a PIOT for Flanders need to be weighed against the needed investments and disadvantages of constructing one. Considering that setting up PIOTs for Flanders with the existing data will only be possible using estimations, calculations and extrapolations and the lack on foreign physical (and monetary) data. Another option to evaluate is using existing national PIOTs or multi-regional PIOTs. (*elaborated in Chapter 1 and Chapter 6*)
- The evaluation of the current Flemish EE-IO tables. The evaluation will list the shortcomings, both in structure and in application possibilities, specifically related to the macro-economic assessment of material flows in Flanders and will provide solutions to increase usability for policy advice. (*elaborated in Chapter 2*)
- The construction of an improved Flemish EE-IO model extended with both monetary and physical (material) data. (*elaborated in Chapter 3 and Chapter 6*)
- Once the improved model is available, the use in different cases and policy topics will be demonstrated. The model will allow to evaluate the efficiency of the materials management system. Are materials moving in closed loops? Where are the loopholes, material excesses and black spots? What is the impact of policy measures (e.g. economic support, subsidies,..) on material flows and environmental impacts of the recycling system? The listing, evaluation and testing of applications of the newly developed model on Flemish policy topics and recommendation for further optimization is discussed *in Chapter 4, Chapter 5* and the conclusion chapter.

The main **research questions** is:

"What applications make the Flemish environmentally extended input-output model extended with regional, national and international economical and material data an important macro-economic tool for sustainable materials management policy making in Flanders?"

Chapter one 'Screening of existing macro-economic models for sustainable materials management' is a literature review of material flow analysis (MFA), material flow accounts and material flow indicators. Next to the overview on terms, definitions and principles of MFA, a description on three models is provided: economy-wide material flow accounts (EW-MFAs), physical supply and use tables (PSUTs) and PIOTs. With a focus on the Flemish context, these models and indicators are described, interpreted and evaluated. Two extra sections describe the link with monetary supply, use and input-output accounts and the importance of multi-region input-output models in the context of a globalized economy. The chapter concludes with guidelines for the macro-economic assessment of material flows in Flanders based on MFA.

This first chapter provides insights in the following questions:

- How can physical macro-economic models (e.g. economy-wide material flow analysis, physical supply and use tables and physical input-output tables) improve the current Flemish environmentally extended input-output model?
- What option are available to adopt and/or extend the current Flemish EE-IO model with monetary and/or physical data?
- What are the benefits and costs of these solutions?

Chapter two 'Policy needs to be covered by EE-IO capabilities' covers the summary of two tasks:

- the project 'Onderzoek naar beleidstoepassingen van milieu input-output modellen' (Vercalsteren et al., 2015); and
- the paper [in revision] 'Policy needs to be covered by environmentally extended input output analysis'.

The project results in an overview of the different possibilities of environmental input-output (IO) models with regard to (environment-related) policy in general, Flemish policy in particular, and to estimate the usefulness of and the modifications required to the Flemish environmental input-output model for the applications most relevant to the Flemish policy. The paper answers three questions: (1) What type of applications of IOA relevant for (environmental) policy are described in international scientific literature?, (2) Which applications are relevant for environmental policy? What opportunities do Flemish policymakers see for using input-output analysis for environmental policy purpose? and (3) How can the uptake of EE-IO in policy process steps be optimized?. The chapter includes a copy of the submitted paper and provides a summary and a listing of policy relevant conclusions.

Chapter 2 provides insights in the following questions:

- What are the shortcomings and limitations of the current Flemish environmentally EE-IO model to be an effective macro-economic tool for sustainable materials management?
- What are the applications of the current Flemish environmentally extended input-output model and what application possibilities are still missing to fully support Flemish policy topics?
- Based on the shortcomings and limitations of the current Flemish environmentally extended input-output model and its applications, which solutions are available to overcome these problems?
- Which solution(s) will, in the current context, optimally adopt and extend the Flemish environmentally extended input-output to be a macro-economic tool for sustainable materials management policy making in Flanders?

Chapter three 'Linking regional input-output tables to multiregional input-output tables' results from the VITO SBR[2] project 'Chains of added value from primary resources to final use' started in 2013. The chapter contains four consecutive steps. First, the Flemish specific economic context of an open economy stresses the importance and relevancy for adequate policy advice to connect regional input-output tables (RIOT) to multiregional input-output tables (MRIOT). This connection enables research based on Flemish statistics embedded in global economic networks. Second, an explanation is given on how and which Flemish RIOTs are connected to MRIOTs. This includes a description of the available MRIOTs and their specifications. Some recent developments on this topic are listed. The third section is a copy of the published article 'Improving footprint calculations of small open economies: combining local with multi-regional input-output tables'. The last section summarizes, highlights and explains the findings relevant for Flemish policy makers.

This chapter provides insights in the following questions:

- Based on the shortcomings and limitations of the current Flemish environmentally extended input-output model and its applications, which solutions are available to overcome these problems?
- Based on the optimal solution(s), how to appropriately adopt and extend the current Flemish EE-IO model with monetary and/or physical data?
- What are the application possibilities (listing, testing and evaluating) of the newly developed model?

Chapter four 'Comparing a territorial-based and a consumption-based approach to assess local and global environmental performance of cities' is an application of the knowledge acquired in the previous chapter. This published paper was developed in close collaboration with Aristide Athanassiadis (Université Libre de Bruxelles). This paper presents a comparative analysis of the results of an urban metabolism (UM) and an input-output analysis (IOA) approach to estimate direct and indirect flows in the Brussels Capital Region. The UM approach is based on local data of energy, water and material consumption as well as data on waste production and pollution emissions (micro-level data). The calculation of embodied resource use and pollution emissions are based on the RIOTs extended with MRIOTs, taking into account the global impacts of intermediary consumption by industries and final consumption by households, governments and investments (meso-level data). The paper provides a comparison of results from both methodologies and how they complement each other.

Chapter 4 provides insights in the following question:

- What are the application possibilities (listing, testing and evaluating) of the newly developed model?

Chapter five 'Value in sustainable materials management strategies for open economies - Case of Flanders' comprises a published paper. Reaching higher levels of reuse, recycling and energy recovery may provide economic and environmental opportunities, but not all options will have a net win property in practice, as they reduce the need for producing new commodities. This paper describes a top-down methodology for estimating the substitution potential of

[2] Strategic Basic Research

intensifying specific sustainable materials management (SMM) strategies and material efficiency strategies. The methodology allows to compare different SMM and material efficiency strategies in terms of the maximum available budgets for reaching them on a break even basis, maximum savings in global warming emissions and substituted employment effects, both through a regional and global perspective. Although it is a methodological paper, it focusses on open economies illustrated by a Flemish case study. Although the paper focusses on four generic sustainable materials management strategies: reuse, recycling, energy recovery and food waste prevention, but the methodology is applicable to multiple cases related to sustainable materials management.

This chapter provides insights in the following questions:

- What are the application possibilities (listing, testing and evaluating) of the newly developed model?
- How does the newly developed model contribute to calculate and analyse new material related business and policy concepts (e.g. circular economy)?

Chapter six 'Estimating and interpreting two material indicators for Flanders: Domestic Material Consumption and Raw Material Consumption' provides two indicator: the domestic material consumption (DMC) and the raw material consumption (RMC). It provides insights into the difference between DMC and RMC, using a case of Flanders. What is the overlap and what is the difference in measuring material use via the DMC or the RMC? Is the DMC superior to RMC or is RMC a better indicator?

Chapter 6 provides insights in the following questions:

- Based on the optimal solution(s), how to appropriately adopt and extend the current Flemish EE-IO model with monetary and/or physical data?
- What are the application possibilities (listing, testing and evaluating) of the newly developed model?

The **conclusions, applications and policy relevance** gives an overview of this dissertation and highlights policy relevant findings.

This chapter provides insights in the following question:

- How can the newly developed model be further improved?

CHAPTER 1

1. Screening of existing macro-economic models for sustainable materials management

How can physical macro-economic models improve the current Flemish environmentally extended input-output model? Should Flanders invest in physical macro-economic models? What are the benefits and costs of these models? To give insights into these questions the literature overview starts with a description of the concepts of a MFA. Terms and definitions clarify the most relevant concepts and principles of material flows account and indicators. Next, the requirements for policy are elaborated. It states the needs for physical models in general and specifies this for Flanders. The last part discusses the two main parts of such models: material flow accounts and material flow indicators (OECD, 2008). Material flow accounts in physical units and based on balancing principles provide a structure for data on material flows. Material flow indicators are derived from these accounts and convey messages to a(n) (non-expert) audience about the significance of material flows with respect to the economic and environmental issues of concern. Also, in section 4 monetary macro-economic models and in section 5 multi-region models are discussed. A final section concludes the first chapter and lists recommendations.

1.1 MATERIAL FLOW ANALYSIS

Material flow analysis (MFA) is the study of physical flows of materials into, through and out of a given system (usually the economy). "What goes in, comes out." is the basis idea behind it (Eurostat, 2010, p.75). Every material which is put into an economy will sooner or later come out of it. Due to technical developments, it is possible to transform those inputs (only a few hundred basic natural inputs) into many thousands of different products. As materials flow through the economy, they may become embodied in more complex products fulfilling different human needs. Our society is to a large extent based on the production and consumption of those materials and complex products, as they form a fundamental and indelible part of it (Hoekstra, 2005).

A counterpart of this use of resources and materials is that it triggers environmental effects. The bundle of effects from material inflows, outflows and stock changes is defined by a function of material volume and impacts per volume unit. The use of resources and the production and consumption of goods and services result in environmental effects, causing direct environmental problems such as global warming and indirect environmental problems such as losses in biodiversity. Sustainable material management should be fundamental to our society as it assures that we have adequate resources to meet today's needs and those of future generations. It is an approach to serving human needs by using and reusing resources most productively and sustainably throughout their life cycles, generally minimizing the amount of materials involved and all the associated environmental impacts. (Allen et al., 2009; EPA, 2009; Moll et al., 2005)

MFA is a concept with economic-environmental applications and fits well in the (sustainable) material management concept as it offers insights in the relationship between the economy and the environment via their material flows and stocks. Knowledge on the use of materials is an important step and key requirement to move towards sustainable welfare. MFA consists out of a family of tools based on the material balance principle used to describe the metabolism of an economy, the environment or a specified part of them. The family of tools allows to take into account the structure of the economy including different elements, such as technology, sector structure, consumption patterns, investments, imports and exports and the related physical flows of natural inputs, products and residuals. The analysis includes the shifts in material flows and stocks due to a constantly moving economy. (Dittrich et al., 2012; Hoekstra, 2005; OECD, 2008)

To strive to a more sustainable use of resources, it is vital to understand current as well as past patterns of resource use within as well as across countries (Kovanda et al., 2012). A thorough understanding of the current and past patterns of material flows enhances the understanding and prediction of future patterns. In MFA, all past and current physical flows can be accounted regardless of their economic importance or environmental impacts (value neutral) (Matthews et al., 2000). Flows are measured in physical weights (e.g. tons) which can be multiplied with price per weight or environmental impact per weight to add other dimensions.

The functions of MFA in sustainable development include the building of a systematic database or information pool to monitor (e.g. by developing indicators) and analyse material flows to improve their efficiency and efficacy. It determines critical links or pathways and detects losses or inefficient use of resources. Also, it identifies key material or products (i.e. bundle of materials fulfilling human needs) for environmental policy formulation and sustainable environmental planning and management. It can optimize material use and processing by modelling interactions of a dynamic socioeconomic system. (Huang et al., 2012)

Material flow analysis essentially compromises the following steps: (Bringezu & Moriguchi, 2002; Hendriks et al., 2000; Huang et al., 2012)

- defining goals, research objective and questions of the study;
- describing and defining the system including scope, boundaries, time frame and identification of relevant flows, processes and stocks;
- data acquisition;
- material and mass balances, modelling and scenario building; and
- illustration, evaluation and interpretation of results and conclusions.

1.1.1 Terms and definitions

The OECD (2008) defines material flow analysis as: “The study of physical flows of materials into, through and out of a given system (usually the economy). It is generally based on methodologically organised accounts in physical units. It uses the principles of mass balancing to analyse the relationships between material flows (including energy), human activities (including economic trade developments) and environmental changes. Material flows can be analysed at various scales and with different instruments, depending on the issue of concern and the purpose of the study. The term MFA therefore designates a family of tools encompassing a variety of analytical approaches and measurement tools, including accounts and indicators.”. (OECD, 2008, p.13) Another definition of material flow analysis is: “The systematic accounting of the flows and stocks of materials within a system defined in space and time. It connects the sources, the pathways and the intermediate and final sinks of a material. Because of the law of conservation of matter, the results of an material flow analysis can be controlled by a simple material balance comparing all inputs, stocks and outputs of a process." (Brunner & Rechberger, 2004, p.7). Material flow analysis is used to construct regional technological material cycles and to trace specific materials through defined systems. (Harper, 2008)

These definitions of MFA highlight its capabilities of monitoring material flows into, through and out of a given system. It is an evaluation method which assesses the efficiency and efficacy of the use of material based on material flow accounting data (Hoffrén, 2010). The definition of the OECD stresses the capability of MFA to describe the relation between the economic and environmental system, whereas the definition of Brunner and Rechberger stresses the capability of monitoring the different stages of a material flows in an economy.

A framework of MFA, which is based on the above definitions, is introduced in **Figure 8**. It models the material flows in an economy and the interrelation between the environment and the socio-economic system. The socio-economic system is split in two: the domestic economy and the rest of world. Although the focus is often on a regional economy or a part of it, trade flows play an important role since the socio-economic system is embedded in a globalised world.

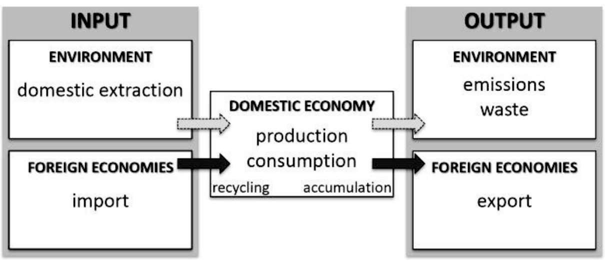

FIGURE 8: A MACRO-ECONOMIC FRAMEWORK OF MATERIAL FLOW ANALYSIS.

Although the framework presented in **Figure 8** is general and basic, it already encounters several problems/questions. What are materials? What are natural inputs/products/residuals? Which materials are included or excluded? Which flows are included or excluded? How are flows measured? One of these problems is the definition of the regional economic boundary and the regional environmental boundary. This problem is illustrated with an example of the import of clay by Flanders from the Netherlands. Which amount of inflow of clay should be included in the accounts? One could include only the imported amount of clay or one could include both the imported amount of clay and the indirect flows associated with the extraction of clay in the Netherlands. Those indirect flows do not enter the Flemish economy as transactions, but are potentially relevant from an environmental burden and consumption perspective.

The above example shows the importance of a clear definition of the concepts and boundaries to develop a consistent and comparable methodology for material flow accounts and indicators. This is not only important for the development of reliable accounts and indicators, but also helps to interpret the results unambiguously and to increase the possibilities for further use in other analysis and applications. Also, at all levels of aggregation, the same concepts, definitions and standards are applied such that the organisation of data and the development of a broader information system can be supported (SEEA, 2014). Therefore several concepts are described and defined:

- monetary and physical accounts (p.14);
- materials (p.15);
- activities (p.18);
- industrial metabolism (p.19);
- system boundaries (p.20);
- principle of mass balancing (p.22);
- flows and stocks (p.23); and
- economic categories (p.26).

Monetary and physical accounts

Accounts can be expressed in monetary or physical terms or a combination of these two (hybrid accounts). Monetary accounts express material flows and services in monetary units (e.g. EUR), whereas physical accounts express material flows in physical units (e.g. tonnes). Hybrid accounts are a combination of both monetary and physical accounts as they bring both types of data together. A simple hybrid account differs from the monetary account only by replacing the first step of the production chain by physical information. In the expanded hybrid account more than only the first step of the production chain is replaced by or supplemented with physical information. (OECD, 2007; Schmidt et al., 2012)

Although some concepts are applicable to both monetary and physical account, most differ between the two. Some differences are listed here. An explanation is given below. (Giljum et al., 2006; OECD, 2007; Schmidt et al., 2012)

- *Physical accounts are not subjected to price fluctuations.* Unlike monetary accounts, physical accounts are not subjected to price fluctuations. For the same volume of materials, prices can fluctuate in time. Monetary accounts are subjected to those fluctuation in prices, whereas physical flows will monitor the volumes that are immediately comparable in time. Measuring material flows in physical accounts measures the real change in flows form one period to another. (SNA, 2009)
- *Physical accounts contain information on transactions where no monetary counter flows are present.* Physical accounts contain information on transactions where no monetary counter flows are present. As far as flows within the socio-economic system are concerned, the physical tables mirror the monetary tables, extending them with flows of residuals. However they show, in addition, the material flows between the socio-economic system and the environment. All material flows related to the economic system can be recorded in physical accounts and do not need to be counterbalanced by monetary flows as in monetary accounts. (OECD, 2007)
- *Physical accounts do not include immaterial flows.* All monetary transaction are recorded in monetary accounts and all material flows are recorded in physical flows. The consequence is that immaterial flows (e.g. services) are recorded in monetary accounts, but not recorded in physical accounts. Services as long as they do not include material flows are not recorded in physical accounts. (OECD, 2007)
- *Physical accounts include the relation between the economy and the environment.* Material flows between the economy and the environment are included in physical accounts. This is an important feature of physical

flow accounts, as it is a supplement to the monetary accounts. Both natural inputs (flows from the environment to the economy) and residuals (flows from the economy to the environment) are recorded in the physical accounts. (OECD, 2007)

- *Discrepancy in treating capital goods and stocks.* An unavoidable discrepancy between monetary and physical data concerns the 'exit' of capital goods and stocks. In monetary accounts those disappear gradually as their value declines in function of time (depreciation). In contrast, in physical accounts capital goods and stocks disappear all-at-once. For example, consider a machine bought by a company of 100,000 EUR and weighing 1 ton with an economic and technical life expectancy of 10 years. In monetary accounts this machine will enter the account in year 0 with a value of 100,000 EUR and decline following a predefined pattern (depending on the depreciation method) to 0 EUR in year 10. In physical accounts the machine will enter the account in year 0 as 1 ton. It will keep this value until year 10 as it leaves the company all-at-once. In other words, capital goods and consumer durables lose their economic value gradually, but remain in the respective kinds of stocks of accumulated materials until disposed of. (OECD, 2007)
- *Discrepancy in the treatment of the government in the framework.* Unlike in the monetary accounts, no entries in the physical accounts are made in relation to the government. Government's final consumption expenditure represents the acquisition and consumption by governments of their own output and do not have any direct associated physical flows (SEEA, 2014). All physical flows related to the intermediate consumption of governments (e.g. computers, paper) are recorded under the relevant industry (e.g. public administration). The generation of residuals by governments is also recorded in the accounts of the related industry. (OECD, 2007)
- *Implications of using a different measurement unit.* In monetary accounts all flows are measured in a monetary unit (e.g. EUR). Although influenced by price changes, they can be (dis)aggregated. In physical accounts, for many outputs there is a natural unit of measurement, which is the unit that best describes the functionality of an input in technological processes or consumption. For example, energy is measured in GJ, while mining and quarrying is measured in tons. If the natural units differ in unit, aggregation is difficult. A less aggregated table with second-best measurement units has to be accepted in developing a physical account. (Hoekstra, 2005)
- *Hybrid accounts.* Physical accounts and monetary accounts differ in scope. For example, physical accounts describe a.o. flows that have no correspondence with economic flows. However, physical flows do not cover immaterial flows and therefore do not cover activities that do not involve materials directly. Therefore, a combination of monetary and physical accounts (hybrid accounts) can give the most complete overview of a socio-economic system. (OECD, 2007)

Materials

A material denotes actually observed flows which are often a mix of various substances flowing inside or crossing the borders of a socio-economic system. It designates all material flows, at whatever level of specification or aggregation. Always related to material and material flows are activities that immediately imply qualitative and/or quantitative changes in the physical or chemical status of some matter (OECD, 2007, 2008). The framework presented in **Figure 9** schematically describes the basis for the different types of material flows: natural inputs, products and residuals (SEEA, 2014). The flows from the environment to the economy are recorded as natural inputs, the flows within the borders of the economy are recorded as products and flows from the economy to the environment are recorded as residuals. Due to changes in economic factors and technological development, the classification of material flows is a dynamic process.

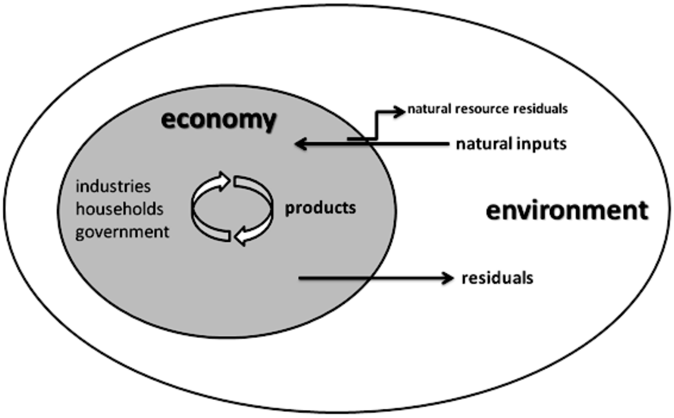

FIGURE 9: THE MACRO-ECONOMIC MATERIAL FLOW TYPES IN MATERIAL FLOW ANALYSIS (MFA). (SOURCE: SEEA, 2014)

Material flow studies can cover any set of materials at various level of detail, from the complete collection of aggregated resources and products flowing through a system, to groups of materials at various levels of detail or to specific products. The level of detail chosen in a MFA depends on the purpose of the account, on the characteristics of the materials and on the data available. (Eurostat, 2000; OECD, 2008)

<u>Natural inputs</u>

Both SEEA and CREEA describe natural inputs as: “all physical inputs that are moved from their location in the environment as a part of economic production processes or are directly incorporated into economic production processes”. Natural inputs are fundamental to our economy as they provide raw materials, energy, food, water and land as well as environmental and social services, but their use has economic, social and ecological consequences. Economic consequences are related to short-term costs and long-term economic sustainability, strategic supplies and the productivity of economic activities. Social consequences relate to the exploitation and use of natural resources affecting humans and ecosystems. Environmental consequences relate to the rate of extraction and depletion of renewable and non-renewable resource stocks, the extent of harvest, the reproductive capacity and natural productivity of renewable resources and the associated environmental burden and its effects on environmental quality and related environmental services. (OECD, 2008; Schmidt et al., 2012) By definition the socio-economic system does not contribute to the output of environmental resources. For example, biomass from humanly controlled forestry activities is not an environmental resource, but a product of the socio-economic system, whereas biomass from natural reserves is an environmental input. (OECD, 2007; Schmidt et al., 2012)

Natural inputs used in an economy stem from raw materials extracted from natural resource stocks. Natural inputs are extracted from the sub-soil and water bodies, taken from the air or harvested from natural forests (not cultivated). The usable parts of these resources enter the economy as natural inputs where they become priced goods that are traded, processed or used. Other parts remain unused in the environment (e.g. mining overburden and excavation leftovers) and are called natural resource residuals. They never enter the socio-economic system, but are moved because of an economic activity. (OECD, 2007, 2008)

Three classes of natural inputs exist: natural resource inputs, inputs from renewable energy sources and other natural inputs: (SEEA, 2014)

- *Natural resource inputs* comprise physical inputs to the economy from environmental assets defined as natural resources. These include mineral, energy, natural timber, natural fish, water and other natural biological resources, but exclude cultivated biological resources. Natural resource inputs that do not subsequently become used in production and instead immediately return to the environment are termed natural resource residuals.
- *Inputs from renewable energy sources* are the non-fuel sources of energy provided by the environment.
- *Other natural inputs* are inputs from air and soil. Inputs from soil comprise nutrients and other elements present in the soil that are absorbed by the economy during production processes. Inputs from air are substances taken in by the human socio-economic system from the air for purposes of living, production and consumption.

The classification of natural inputs with more detailed classifications is described in SEEA (2012). (Schmidt et al., 2012)

Products

Products are produced form natural inputs, residuals or other products and are used in human activities. At the moment when resources and ecosystem inputs are taken from the natural environment, they enter the socio-economic system and their matter is therefore embodied in products, regardless of the degree of processing of the materials. In general, products have a positive monetary value, although there is not always paid for (e.g. resources extracted and used in own production activities or products produced for own use). (OECD, 2007; Schmidt et al., 2012)

To produce outputs an enterprise may undertake ancillary production. This involves the production of supporting services that can be purchased from other enterprises, but are produced in-house to support the production of primary and secondary products. The production of these services and their relevant material inputs are recorded as overall inputs to the production of the enterprise's primary (and secondary) products. (SEEA, 2014)

A conceptual difference is made between market products, own final use and non-market products: (SNA, 2009)

- Market establishments produce products mostly for sale at prices that are economically significant.
- Producers for own final use produce products mostly for final consumption or fixed capital formation by the owners of the enterprises in which they are produced.

- Non-market establishments supply most of products they produce without charge or at prices that are not economically significant (e.g. governmental services).

Residuals

Schmidt et al. (2012) defines residuals as: “Physical flows of solid, liquid and gaseous materials and energy that are discarded, discharged or emitted by businesses and households through processes of production, consumption or accumulation. Residuals may be discarded, discharged or emitted directly to the environment or be captured, collected, treated, recycled or reused by economic units. The various transformation processes may lead to the generation of new products that are of economic value to the unit undertaking the transformation even if the residual, when first discarded or emitted may have no economic value to the person or business discarding or emitting the residual.” This definition includes products that people no longer have any use for, which they either intend to get rid of or they have already discarded (Eurostat, 2010). Residuals may have a positive value for a unit other than the generator. However, incidental and undesired outputs with a positive value for the generator are not treated as residuals, but as (by-)products. Physical flows of residuals correspond to zero-monetary flows or a monetary flow in the same direction as the physical flow, whereas physical flows of products correspond to monetary flows in the opposite direction as the physical flow (OECD, 2007; Schmidt et al., 2012).

Residuals are incidental and undesired outputs of human activities that have no or a negative economic value to their generator. They mainly flow from the socio-economic system to the environment. Small amounts flow back from the environment to the socio-economic system. Closely related to residuals are materials for treatment which are material flows from human activities that remain in the technosphere but cannot directly displace the functionality of another product (Schmidt et al., 2012). After processing in a waste treatment activity, the (partly) recovered materials in materials for treatment may substitute other products. Note, controlled and managed landfill sites, emissions capture and storage facilities, treatment plants and other waste disposal sites are considered to be within the economy. (OECD, 2007; SEEA, 2014)

Activities

An activity is a disaggregated category of the technosphere. The sum of all industrial, governmental and household activities represent all human activities. In general, any human activity uses inputs in terms of products, natural inputs and residuals. These inputs are balanced by outputs in terms of products, emissions, materials for treatment and stock changes. This balance is illustrated in **Figure 10**. (Schmidt et al., 2012)

A distinction is made between accumulation activities and transformation activities. Materials accumulate in systems through accumulation activities, whereas in transformation activities the material inflow is different from the material outflow as inputs are transformed trough processes into different outputs. This difference implicates a different approach in modelling for accounting. Aggregated activities can combine transforming and accumulating activities.

Accumulation activities have the same materials on the input and on the output side of their material accounts. For example, a merchant of raw clay buys and sells raw clay. In his/her account there is an inflow of X tonnes raw clay equal to the amount bought by the merchant in a defined period. The outflow is equal to Y tonnes raw clay and represents the amount sold by the merchant in that same period. The difference between X and Y denotes the stock changes (stock increase or decrease). Instead, the material accounts of transformation activities have different inputs and outputs. For example, a building brick producing company uses raw clay together with other inputs (e.g. sand, energy) to produce building bricks and other output (e.g. emissions). (OECD, 2007, 2008)

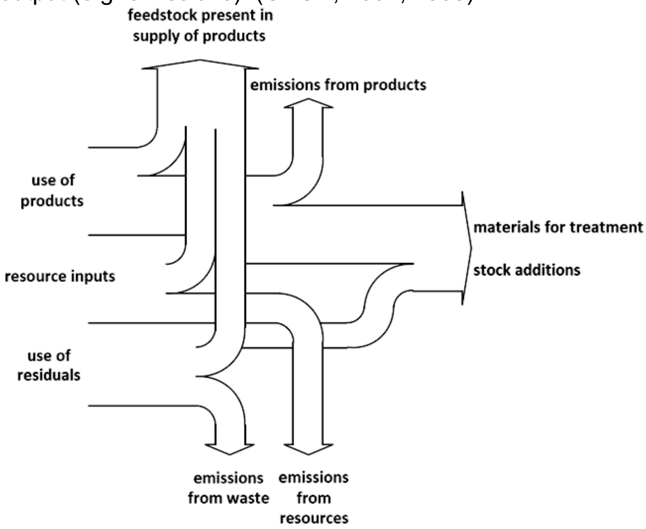

FIGURE 10: THE PHYSICAL INPUT AND OUTPUT BALANCE OF AN ACTIVITY.
(SOURCE: SCHMIDT ET AL., 2012)

Alternatives to the classification of activities into transformation and accumulation activities are, for example, dividing activities into principal, secondary and ancillary activities: (European Commission et al., 2009)

- The principal activity of a producer unit is the activity whose value added exceeds that of any other activity carried out within the same unit.
- A secondary activity is an activity carried out within a single producer unit in addition to the principal activity and whose output, like that of the principal activity, must be suitable for delivery outside the producer unit. The added value of a secondary activity is rather small compared to the output of a principal activity.
- An ancillary activity is incidental to the main activity of an enterprise. It facilitates the efficient running of the enterprise but does not normally result in goods and services that can be marketed.

Industrial metabolism

The study of the industrial metabolism aims to provide an understanding of the functioning of the societies' physical basis, the linkages of processes and product chain webs within the anthroposphere and the exchange of material and energy with the environment. The metaphor of the metabolism hints at the fact that to maintain function, both biological and industrial systems are characterized by uptake, transformation, storage, recycling and excretion of materials. MFA is used to analyse the societal metabolism to understand how it works and as the basis for evolution and possible restructuring in terms of sustainability. (Bringezu et al., 2003)

Daniels and Moore (2002) referred to the economic metabolism and the related material balance principles as one of the basic underlying characteristics of the physical economy: “The metabolic viewpoint is closely linked to the acceptance of materials balance principles in which the modelling of materials and energy flows is governed by the laws of conservation of matter and energy.” (Daniels & Moore, 2002, p.74). It provides a comprehensive system perspective of the interaction between environment and economy/society whereby the material flows between the anthroposphere and nature constitute the interface between human activities and environmental impacts. (Moll et al., 2005)

Like biological organisms and ecosystems, regions also have a metabolism that induces high energy and material flows largely due to high population densities and their large and relativity dense material stocks (Hendriks et al., 2000). R. Ayres (1994) describes the industrial metabolism as: “The whole integrated collection of physical processes that converts raw materials and energy plus labour into finished products and wastes in a more or less steady state condition. [...] The system is stabilized, at least in its decentralized competitive market form, by balancing supply of and demand for both products and labour through price mechanisms. [...] The key to regional analysis is the existence of a well-defined geographical border or boundary across which physical flows of materials and energy can be monitored.” (Ayres, 1994, pp.23-25). In this book R. Ayres described a condition of long-run material sustainability. He stated that there are only two possible long-run fates for waste materials: recycling and reuse or dissipative loss. His statement follows from the law of conservation of mass and as a long-run situation is considered, accumulation does not exist. The more materials are recycled, the less will be dissipated into the environment, and vice versa. Dissipative losses must be made up by replacement from virgin sources. A long-term sustainable steady-state economy would necessarily be characterized by near-total recycling of toxic, hazardous and non-renewable sources, as well as a significant degree of recycling of materials whose disposal constitutes an environmental problem. (Ayres, 1994)

System boundaries

A well-defined system boundary should be presented to develop unambiguous and consistent models. However, the system boundary between economy and nature does not necessarily have to be identical in all accounts, as long as the concepts that are treated differently between the accounts are clearly mentioned and described. In general, all flows of goods in the socio-economy system and between the socio-economic system and the environment are considered. To describe and understand the functioning of a material world, it is useful to divide it into parts or (sub)systems. Systems are distinct and (in theory) non-overlapping parts of the world. Although the definition of a systems appears simple, closer examination reveals that there is uncertainty about the notion of a system boundary. As the aim of a material flow account is to describe the circulation of material inside the focus system it is necessary to differentiate its activities to be able to capture the materials as they pass from one activity to another. Different MFA tools focus on different (sub)systems, that are defined at various levels of aggregations in both materials and activities. Once a system is identified, the boundary can be defined between it and its outer world. Given a well-defined boundary between two systems, the material stocks belonging to each of them are distinguished and the material flows between the systems are identified as crossing boundaries. These cross-boundary flows implicitly define system boundaries. (OECD, 2007)

Common systems in an economy are the domestic economy, the foreign economy, the domestic environment and the foreign environment (see **Figure 8**). The domestic economy is a subsystem inside the domestic environment. Likewise, the foreign economy is embedded in the foreign environment. Imports or exports are flows crossing the boundary between the domestic economy and the foreign economic system. Extraction and processed output are flows crossing the boundary of the economic system and environmental system.

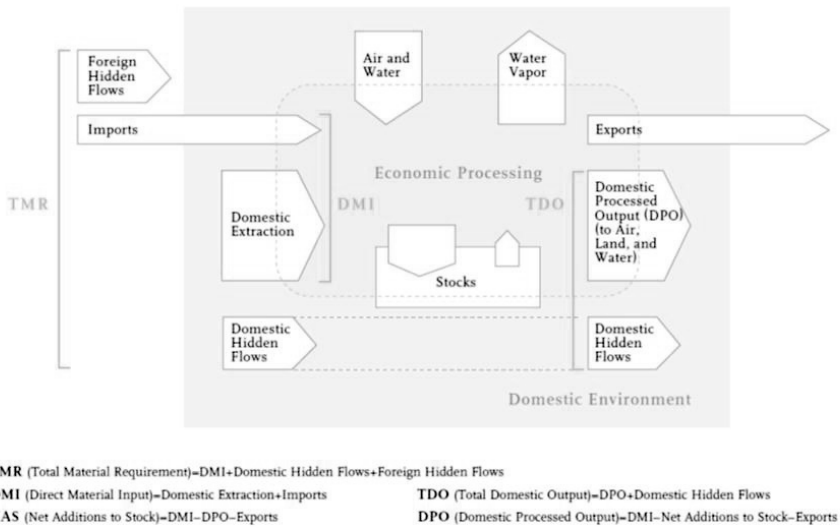

FIGURE 11: THE SYSTEM BOUNDARIES OF AN ECONOMY. THE INDICATORS ARE ELABORATED IN SECTION 1.1.4 MATERIAL FLOW INDICATORS.
(SOURCE: MATTHEWS ET AL., 2000)

In the definition of system boundaries, special attention is needed in the treatment of following concepts: semi-natural systems and the residence principle. Agricultural land and what grows on it, cultivated forests and landfills have in common the characteristics of not being totally under control of humans. Weather conditions still play a major role in agricultural production and the decomposition of waste in a landfill is beyond the reach of those who manage the site. The flows from and to these semi-natural systems can neither be considered fully natural nor fully under the control of humans. (OECD, 2007)

In the literature two different approaches are described and used to define the system boundary of cultivated and natural biological resources: the ecosystem approach and the harvest approach: (Schmidt et al., 2012)

- Using the *ecosystem approach* means that cultivated biological resources are recorded within the production boundary and natural vegetable resources are counted within the environment. The non-human contributions to the growth of cultivated biological resources (e.g. natural inputs) are recorded as flows from the environment to the economy.

- In the *harvest approach* both cultivated biological and natural vegetable resources are recorded as flows from the environment to the economy. As all cultivated resources (e.g. trees, crops, livestock and fish) are recorder as inputs from the environment to the economy the extended harvest approach is used. It is also possible to apply different approaches to different resources.

For clearance, cultivated biological resources cover animal and vegetable resources whose natural growth and regeneration are under the direct control, responsibility and management of institutional units, whereas natural biological resources are not under direct control of human activities. Controlled and managed landfills should be considered as operating within the production boundary. All flows to controlled landfill sites are treated as flows within the economy. (Schmidt et al., 2012; SEEA, 2014)

The residence principle is defined by all economic activities by its residents independent of where those activities take place geographically (residence principle versus territory principle). An institutional unit is said to be resident within the economic territory of a country when it maintains a centre of economic interest in that territory. The SNA and SEEA are compiled for resident units (following the residence principle consistent with national accounts). There is a large overlap between resident units and those located within the geographic boundaries of a country, but they are not exactly the same. However, any error causes by this would normally be well within the margin of error of the whole exercise. (Schmidt et al., 2012)

Another aspect of system boundaries is related to the scope of this PhD. A Flemish macro-economic material flow model is a description of the physical metabolism of a region and not of a country. Compared to the large number of MFA studies on the national level, published studies on the regional or local level are limited and standardised methods are, if available, not readily applicable. The main difference concerns the data sources. On a regional level, data availability often is much scarcer. The consequence is that data gathering will be a more time consuming process and probably require more assumptions. For example, on a regional level trade flows have to be separated into interregional or intra-national trade flows and international trade flows (NBB et al., 2014). Also, confidentiality of data will be more of an issue as sectors are more easily dominated by a limited number of companies. (Hammer et al., 2003)

Principle of mass balancing

All material flow accounts are all based on balancing principles, but one of these principles is the same for all accounts, namely the mass balancing principle. The principle of mass balancing is founded on the first law of thermodynamics (the law of conservation of matters) stating that matter is neither created nor destroyed by any physical process. Other balancing principles (e.g. supply-use, input-output, material accumulation algebraic identities) are deviated from this principle of mass balancing. The mass balancing principle is expressed in the accounting identity: (Eurostat, 2000; Hoekstra, 2005; OECD, 2007, 2008)

$$\text{total inputs} = \text{total outputs} + \text{net accumulation} \qquad \text{(eq. 1)}$$

meaning that what goes into the system will either be accumulated in the system or will leave the system as an output. Also, what leaves the system has been either an input or a decrease in stocks. Applied to a MFA and from the perspective of a domestic economy the principle is expressed as: (Eurostat, 2001)

$$\begin{aligned}&\text{domestic extraction} + \text{import}\\ &\quad = \text{domestically processed output} + \text{export}\\ &\quad + \text{net addition to manmade stocks}\end{aligned} \qquad \text{(eq. 2)}$$

The principle is based on the knowledge that matter is neither created nor destroyed in any natural process or human action, except from a tiny (in this case negligible) portion of matter transformed in energy in some activities. (Eurostat, 2001)

Equation 1 and 2 are based on the systems perspective of the material balance principle. The same principle can be applied in a flow perspective resulting the following accounting identities:

$$\text{origin} = \text{destination} \qquad \text{(eq. 3)}$$

$$\text{supply} = \text{demand} \qquad \text{(eq. 4)}$$

$$\text{resources} = \text{uses} \qquad \text{(eq. 5)}$$

This means that all flows have an origin and a destination and a breakdown by origin must be exhaustive in the sense that the sum of masses by origin must be equal to the sum of masses by destination. (Eurostat, 2001)

One of the advantages of the mass balancing principle is to use it as a check of accuracy of empirical data, to improve consistency and to 'fill in' missing data. This is usually performed on the basis of stoichiometric or technical coefficients and may be assisted by computer simulation based on mathematical modelling. (Bringezu & Moriguchi, 2002)

Flows and stocks

A flow is a variable that measures a quantity per time period, whereas a stock is a variable that measures a quantity per point in time (EC, 2011). For measurement purposes the economy is represented by both stocks and flows. The measurement of flows delineates the economic activities of production, consumption and accumulation. Stocks of economic assets provide inputs to production processes and are a source of wealth for economic units. They refer to the total quantity of assets at a given point in time. Economic assets can be produced from an economic activity but many are non-produced natural assets. Both assets provide inputs to the production of goods and services. Flows recorded in asset accounts represent changes in these stocks from one period to another (SEEA, 2014). They identify and describe the exchange of materials between and within activities or (sub)systems with reference to the accounting period and have a well-defined direction. Taken together they define the material metabolism. (OECD, 2007)

Based on the OECD definition of material flow analysis, four types of material flows can be defined: flows inside an socio-economic system, flows inside the environmental system, flows from the socio-economic system to the environmental system and flows from the environmental system to the socio-economic system (Hoekstra, 2005). The types of material flows are presented in **Figure 12**. This dissertation focuses on the first, second and third quadrant of this figure. Flows between the borders of the environmental system are not taken into account, as they are considered as external flows to the domestic economy. Dividing the socio-economic system into Flanders and rest of world (RoW) and considering the Flemish economy as the object of the study, only the flows inside the Flemish socio-economic system are defined as internal flows, all flows into and out of the Flemish economy are defined as cross-boundary flows and all other flows are external flows. Only the internal and cross-boundary flows are considered and should be taken into account; the external flows are not taken into account. However, external flows do contain valuable information, for example to calculate embodied impacts in trade flows.

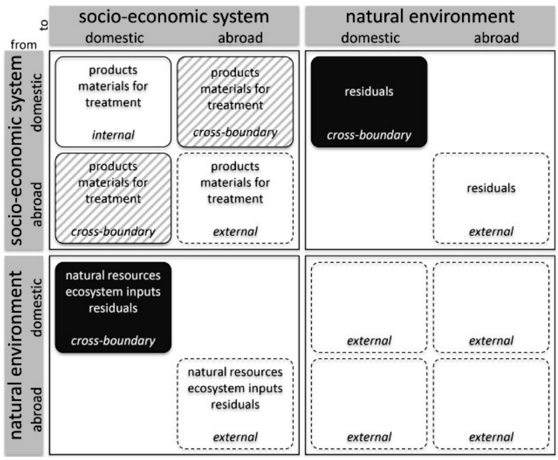

FIGURE 12: TYPOLOGY OF MATERIAL FLOWS IN MACRO-ECONOMIC MATERIAL FLOW ANALYSIS (MFA).
(ADAPTED FROM: HOEKSTRA, 2005; OECD, 2007)

The magnitude of material flows in accounts can vary. On the condition that the definition of the system boundary remains the same, cross-boundary flows will always amount to the same magnitude independent of the level of aggregation by material or by activity. The total amount of internal flows are independent of the aggregation level of materials, but dependent on the aggregation level of activities. The more activities are aggregated, the more internal flows are within these aggregated activities and are no longer accounted for in material flow analysis which, next to cross-boundary flows, only accounts for internal flows between its individual non-aggregated activities. (OECD, 2007)

Accumulation in the societal system serves as an early warning signal for future emissions. As estimations of future emissions and waste flows are important information for environmental policy, the detailed recording of stocks is necessary. Material flow analysis can give information on stocks and related future emissions, but requires specialised forecasting analysis. (van der Voet et al., 2002)

In addition to the classification given in **Figure 12**, other classifications exist. Relevant classifications to this paper are:

- the distinction between direct and indirect flows;
- the distinction between used and unused flows (or hidden flows (HF));
- ecological rucksacks;
- raw materials;

- raw material equivalents (RME);
- ancillary flows; and
- excavated or disturbed flows.

TABLE 3: CLASSIFICATION AND DEFINITIONS OF MATERIAL FLOWS.

CLASSIFICATION	DEFINITION
direct flows	Direct material flows refer to the actual weight of goods and do not take into account the life-cycle dimension of production chains. It contains used materials which enter the socio-economic system for further processing or direct material consumption. (Eurostat, 2009; Hinterberger et al., 2003)
indirect flows and ecological rucksacks	Indirect material flows indicate all materials that are required in manufacturing. These flows take into account the upstream resource requirements Indirect flows are calculated as the life-cycle-wide material inputs minus the mass of the product itself. (Eurostat, 2009; Hinterberger et al., 2003) The simple weight of traded goods provides a somewhat incomplete picture as it does not take into account the raw materials originally necessary to produce these traded goods. (Eurostat, 2001) Ecological rucksacks of a products is the sum of all resources which are not physically included in the economic output under consideration, but which were necessary for production, use, recycling and disposal. (Spangenberg et al., 1998) The idea behind ecological rucksacks is that the use of materials carries a rucksack full of environmental impacts it has already caused on its way to consumption. In other words, a material flow leaves footprints behind. (de Bruyn et al., 2004; Hammer et al., 2003)
used flows	The category of used materials is defined as the amount of extracted resources, which enter the economic system for further processing or direct consumption. It refers to an input of resources in an economy. (Hinterberger et al., 2003)
unused flows and hidden flows (HF)	Unused flows of HF refer to materials that never enter the socio-economic system. This category comprises overburden and parting materials from mining, by-catch and wood harvesting losses from biomass extraction and soil excavation as well as dredged materials from construction activities. (Hinterberger et al., 2003) Unused extraction are materials that are moved or extracted from the environment without the intention of using them. They can be associated with the domestic or foreign extraction of raw materials or construction activities. Important is that these flows do not enter the economic system (not in production or consumption activities), but their displacement can have adverse environmental effects. These flows have no economic value and can be considered as physical market externalities. (Eurostat, 2009; Hinterberger et al., 2003; OECD, 2008) It is important to note that these flows, often in large quantities, do not all damage the environment as they often only modify the environment without environmental harm; hidden flows per definition do not have a negative connotation. Classifying hidden flows as a simultaneous input to and output from the economy is a convention that enables these flows to be measured in an accounting year, without creating an imbalance on either the input or output site of the accounts. (Matthews et al., 2000)
raw material	The Eurostat manual (2009) states that: “Materials extracted from the environment are always raw materials, while in contrast imported and exported materials are always products which have already undergone a more or less intensive transformation process before entering or leaving the focal economy.”. (Eurostat, 2009) Raw materials comprise both used (domestic extraction used) and unused materials.

raw material equivalents (RME)	Indirect material flows are connected to raw material equivalents (RME). It denotes the upstream requirements of used extraction associated with imports or exports. Indirect material flows can be taken into account for both domestic and imported products. Converting traded products into RME includes the indirect use of resources in the weight of the this product. (Eurostat, 2009; OECD, 2007) RME are introduced in order to account for the correct weight of raw materials needed to produce manufactured products. Usually this weight is a few times greater than the weight of the products themselves. When imports and exports are expressed in RME, they comprise all the raw materials needed worldwide to produce imported/exported commodities. Imports are considered as an environmental pressure shifted abroad; exports are considered as environmental pressures shifted from the producing country to the country of export (demanding country). (Kovanda & Weinzettel, 2013)
ancillary flows	Ancillary material flows cover materials that must be removed from the natural environment, along with the desired material to obtain the desired materials. Some examples are: the portion of an ore that is processed and discarded to concentrate the ore, the plant and forest biomass that is removed from the land along with the logs and grains but later is separated from the desired material before further processing, etc. (Adriaanse et al., 1997)
excavated and disturbed flows	Excavated and/or disturbed material flows are materials moved or disturbed to obtain a natural resource or to create and maintain infrastructure. Included in this category is the overburden that must be removed to permit access to an ore body, the soil erosion from agriculture and the material moved in the construction of infrastructure such as a highway or a building or in the dredging of harbours and canals. (Adriaanse et al., 1997)

Economic categories

To establish a parallel between physical and monetary flows and to allow further analysis the socio-economic system is subdivided into production/industries and their intermediate consumption, final consumption and accumulation. A breakdown of the aggregates establishes a detailed insight into the immediate causes of the flows and allows further analysis to the drives and sources of these flows. The breakdown by activity and by material is important to analyse the supply chain including linkages between driving forces and resulting pressures on the environment. (OECD, 2007)

Major categories of activities are: production, capital formation, final consumption and accumulation (consumer durables and waste). These categories can be further subdivided to get a structured overview of economic categories and their impact on material flows. For example industries can be subdivided into the primary, secondary and tertiary sector. The categories of materials are natural inputs, products and residuals (and materials for treatment) and can also be further subdivided to detail material flows and widen the applications of MFA (OECD, 2007). Using international standards in the subdivision of categories will increase the capability to compare and benchmark with indicators developed in other countries. (Mäenpää, 2004; Wernick & Irwin, 2005)

Natural resources can be harvested directly by households for own account use, but in practice the measurement of it may be difficult. Ecosystem inputs flow from the environment to production and consumption. Products are reported in material flow analysis as far as they incorporate natural resources and ecosystem inputs (no services are included). By definition all products originating from production go to other production activities (intermediate consumption), to households to satisfy final consumer needs or to capital formation (final consumption). Household's final consumption can be further subdivided into current final consumption (transformed in residuals in the same accounting period) and durable goods (transformed in residuals after repeated use). Capital formation is used once in production in some subsequent accounting period as intermediate input (inventories) and to be used as an instrument in production of other products repeatedly and over a period of time longer than the accounting period (other capital). (OECD, 2007)

1.1.2 Policy requirements

As the world population will continue to grow, so will the world economy. Increasing constrains on a variety of material and energy recourses and the global environment will increase world market prices on key resources (OECD, 2008). Decoupling growth from material use (dematerialisation) decreases the dependency on resource availability and world market price fluctuations. In the literature a distinction is made between absolute and relative decoupling. Relative decoupling occurs when the input of materials or resources stagnate or increase to a lesser extent than the increase in GDP. Absolute decoupling occurs when material or resource inputs decrease with increasing levels of GDP. Several common dematerialisation strategies are, for example, increasing the efficiency of material use, materials substitution, re-use/recycling of materials and material sharing. (Dittrich et al., 2012; Kovanda et al., 2012; van der Voet et al., 2004)

The Flemish Parliament Act on materials of 23 December 2011 is partially a conversion of Directive 2008/98/EG of the European Parliament. Its goal is to adopt measurements for establishing material loops, protecting the health of humans and environment from the harmful effects of the generation and management of residuals and countering the depletion of renewable and non-renewable resources, the waste of materials and energy in general and the harmful effects on humans and the environment related to material use and consumption.

Concerning environmental issues, policy makers have interested in: the complete life cycle of materials and products, the amounts of materials involved, the inputs of energy and water resources along the life cycle, the amounts of residuals and the associated environmental impacts along the material/product chain (Allen et al., 2009). As the Flemish government invested in the policy research centre sustainable materials management as one of the cornerstones of the future green economy, it confirmed its worries/interest in materials and material flows in Flanders. (SuMMa, 2011)

As a member of the OECD, Belgium supports sustainable resource use and initiatives to promote waste prevention, sustainable material management, integrated product polices, 3R (reduce, re-use and recycle) related policies and circular economy approaches aiming to close material loops and extending the lifespan of materials trough longer use and the increased use of secondary raw materials (OECD, 2008). Material flow analysis is a tool to support these initiatives by fulfilling information needs and closing knowledge gaps by providing detailed data accounts on material flows and relevant comparable indicators.

Spangenberg et al. (1998) wrote in their report on material flow based indicators that decision makers must steer the economy not by scratching the ecological guardrails, but by staying clear of them, keeping the economy in the middle of the road towards sustainability. But what is staying in the middle and how to control it? An economic system can be environmentally sustainable only as long as it is physically in a (dynamic) steady-state. This means that the amount of resource used to generate welfare is permanently restricted to size and quality that does not overexploit the sources or overburden the sinks provided by the ecosphere. Closely linked is the concept of environmental space defined by Spangenberg et al. (1998): "Environmental space is a normative concept which takes into account the physical as well as the social and developmental aspects of sustainability. Physically, environmental space is described as the capacity of the biosphere environmental functions to support human activities, the upper limit given by the carrying capacity. The social dimension of environmental space is given by the "global fair shares" of "equity principle" derived from the definition of sustainable development, assigning to all living people a right to achieve a comparable level of recourse use and to future generation a right to an equivalent supply." (Spangenberg et al., 1998). Living within our environmental space would mean living in-between a floor of a minimum of necessary use of environmental space for satisfying human needs and a ceiling of a maximum use of environmental space given by the carrying capacity of the eco-systems. A MFA can measure the three core categories of environmental space: materials, energy and land. (Hammer et al., 2003; Spangenberg et al., 1998)

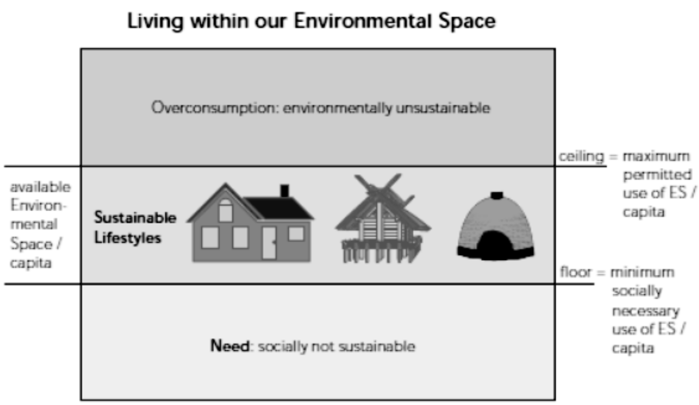

FIGURE 13: THE ECOLOGICAL GUARDRAILS OF AN ECONOMY DEFINING THE MIDDLE OF THE ROAD TOWARDS SUSTAINABILITY.
(SOURCE: SPANGENBERG ET AL., 1998)

The idea of Spangerberg et al. (1998) is closely related to the doughnut economics by Kate Raworth. The inner ring of the doughnut represents the social foundation, the situation in which everyone on the planet has sufficient food and social security. The outer ring represents the ecological ceiling, beyond which excess consumption degrades the environment beyond repair. The aim is to get humanity into the area between the rings, where everyone has enough but not too much. (Toye, 2017)

The mutual interrelationship between economic, social, political and environmental processes is highly complex and available information, judgement of experts and public awareness are often controversial or insufficient. MFA can offer many

insights in the material/product chain and should be an important tool with regard to material management as it provides consistent information and supports the monitoring of the (future) sustainability of resource use. The availability of material flow accounts and derived indicators are a prerequisite for informed and rational policy making. However, since it only illuminates some of their issues, it must be used in conjunction with other analysis tools. (Allen et al., 2009; OECD, 2007)
To provide necessary insights, the various MFA tools should be positioned within a broader architecture of accounts, indicators and analytical tools, including economic modelling and qualitative assessments. This should help to see interrelationships between different types of information tools. Value-neutral physical accounts that include all materials, regardless of their economic importance or environmental impacts, provide decision makers with an improved understanding of the functioning of their region so that they can prepare for, and react to, present and future material flow and stock issues. It provides insights in the coherence of environmental problems, so one can work out structural solutions and not a shift in problems. (Hammer et al., 2003; Hendriks et al., 2000; OECD, 2008; van den Bergh et al., 2002)

The users' needs set certain requirements for the accounting framework for recording flows and stocks. First, it should provide an overall picture of the economy, but the picture must be simplified in order to be both comprehensible and manageable. A model only is a limited aspect of a society. A model builder must always make a choice between simplicity and realism. The simpler a model is, the less realistic but the better comprehensible it is and vice versa. Second, it should faithfully represent economic behaviour by covering all important aspects without neglecting or giving too little emphasis to some aspects or giving others too much prominence. Finally, it should portray all significant economic interrelations and the results of economic activities. Although meeting these requirements is necessary, they are somewhat contradictory. Achieving the right balance between them is not an easy task. Simplifying can lose sight of or neglect important aspects of economic behaviour; complexity overburdens the picture, reduces insights, lowers comprehension and misleads (non-expert) users. (SNA, 2009, p.16) (Ibenholt, 2002)

The general applicability of material flow analysis to policy making is summarized in **Table 4**. For a more detailed description and examples see OECD (2008), p20-23.

TABLE 4: SUMMARY OF THE APPLICATIONS OF MATERIAL FLOW ANALYSIS IN POLICY MAKING. (SOURCE: OECD, 2008)

POLICY AREA	MFA FUNCTION	MFA TOOL
1. economic, trade and technology development policies		
economic policies	- measure aspects of the physical performance of the economy in relationship with the economic performance - analyse the material requirements for activities that involve construction, reconstruction, maintenance and disposal of infrastructure - measure the degree of (absolute and relative) "decoupling" between direct and indirect environmental pressures (pollution,	- EW-MFA - physical IOA in conjunction with: - productivity measures - economic modelling (e.g. monetary IOA) - analysis of energy requirements

	waste, primary resource inputs) and economic growth	
trade aspects & supply patterns	- support structural analysis of the global economy in physical terms: effects of globalisation on international material flows; substitution of domestic raw materials with imported ones; interaction with production and consumption patterns - monitor the structural effects of trade, environment measures on international materials markets and on flows of environmentally significant materials (e.g. hazardous materials; secondary raw materials, recyclable materials) - monitor the environmental implications of changes in international material flows, including (i) environmental pressures from indirect flows abroad associated with trade; (ii) environmentally significant materials embedded in imported goods; (iii) environmental risks related to international transport of materials, etc.	- EW-MFA covering trade flows by origin/destination - MIO analysis - environmental IO-analysis in conjunction with: - monetary IO-tables - international trade statistics - international transport statistics
technology development	- guide the development of new technologies and identify those that would severely strain material availability or generate excessive additional environmental pressures - identify potential areas for research on substitutions of materials and on the availability of materials for the development of new technologies - detect opportunities for new technologies that help reduce inefficiencies in energy and materials use, increase domestic reuse or recycling and the use of alternative materials	- material system analysis and material specific accounts - life cycle analysis of products in conjunction with: - value chain analysis
2. natural resource management policies		
natural resource management	- assess the status and trends of a country's natural resources and monitor sustainable production levels (e.g. forest resources) and support related management plans - examine the demand, scarcity and raw material requirements, based on the full material cycle and understand what is behind price and production trends in commodities over extended periods of time - assess mineral systems by tracking (i) raw materials used in the economy, (ii) the flow of a specific material in the economy as a commodity (iii) the flow of different materials as a product, (iv) material stocks in use, reuse and disposal in a country - assess energy systems by tracking energy carriers used in the economy, by giving insights into multiple uses, including non-fuel uses (e.g. plastics, synthetic fibres)	- material system analysis and resource specific accounts in conjunction with: - natural resource accounts - information on proven reserves and rates of discovery - energy accounts and statistics - modelling

3. environmental policies		
pollution prevention & control	- map the flows of nutrients or contaminants in a region, country or river basin and identify whether, where and to what extent these flows contribute to environmental degradation "downstream" - estimate environmental pressures from metal ore extraction and metal production, the part due to inefficiencies in production technologies and the benefits that could be gained from new technologies and from improved recovery and recycling - monitor and help understand indirect and unused materials flows and their effects on the environment, at home and abroad	- economy-wide MFA with detailed breakdown of materials - substance flow analysis - material system analysis and material specific accounts In conjunction with: - waste statistics & accounts
waste and materials management	- analyse trends in waste generation, and how they affect opportunities for (i) resource conservation, (ii) resource productivity, and (iii) material recovery and recycling - assess the economic benefits and costs to keeping materials in the active materials stream and to minimising the amounts going to final disposal - assess developments in markets for reused and recyclable materials - identify areas for research on (i) energy conservation and recovery, (ii) materials recycling, (iii) alternative materials and (iv) new technologies	- various MFA tools distinguishing between primary and secondary raw materials, and recyclable materials. in conjunction with: - waste statistics & accounts - cost benefit analysis - modelling
product related policies	- examine source reduction, substitution, and recyclability of the materials composing a product and help understand the synergistic nature of the flows of these materials - examine environmental impacts of products, in particular products with toxic ingredients - explore design issues that affect the environment at the end of product life and identifying leverage points for green design and pollution prevention and implications of a policy shift	- life cycle assessment
others	- analyse the effects of environmental policy instruments on material flows and on the material supply mix - analyse the benefits of government purchasing policies (e.g. for the availability of recycled or redesigned products to the market) and how they affect material flows - monitor environmental performance targets with industry and government.	- various MFA tools in conjunction with: - cost benefit analysis - modelling - environmental modelling software

The importance and relevance of material flow analysis and its scientific and academic development is highlighted by the recommendations of the OECD Environmental Policy Committee. They recommend: “To promote resource productivity by strengthening their capacity for analysing material flows and the associated environmental impacts and work to improve measurement systems for material flows and resource productivity, drawing on the expertise of all relevant ministries and departments of government, research and other non-governmental organisations, on OECD guidance and experience on measurement and analysis of material flows and resource productivity and on other international work; and this effect: (i) improves the scientific knowledge [...], (ii) upgrades the extent and quality of data on material flow [...] and internal comparability of data [...], (iii) works to improve and use soundly based, relevant and internationally compatible material flow accounts [...], (iv) further develops and promotes the use of indicators [...], (v) co-operates with non-member economies to strengthen their capacity for analysis of material flows and associated environmental impacts and (vi) shares OECD guidance and experience [...].” (EPOC, 2008).

Policies focussing on materials can focus on the actual use of materials or on the environmental impacts that are related to material use. Although a relationship exist between these two, it is the focus on the actual use of materials that has the closest relation to MFA (de Bruyn et al., 2004). The framework of sustainable materials management by J. Fiksel (2006) goes further, encompassing the social, ecological and economic dimensions of sustainability management. Analytic methods based on mass flow alone do not provide sufficient information regarding these impacts stressing the need for further exploration (Fiksel, 2006). The challenge of sustainability is where the physical necessities of sustainability (land, energy, water and non-renewable resources) meet the needs (industry, nature, agriculture and domestic needs). (Graedel & van der Voet, 2010)

A study by Tritel (2012) investigated the potential of material accounts in Flanders. The need for gathering detailed data is two-fold. The need for data arises in both evaluating and preparing policies. Also industries are searching for data on macro-, meso- and micro-level material use. **Table 5** details the material data requirements of both the government and industries in Flanders. (TRITEL & CE Delft, 2013)

TABLE 5: THE MATERIAL DATA REQUIREMENTS FOR FLEMISH POLICY.
(SOURCE: TRITEL & CE DELFT, 2013)

	DATA REQUIREMENT	DATA LEVEL
1. policy		
evaluation	- benchmarking - monitoring economy-wide indicators - indicators for closing material loops - monitoring policy instruments - identification of eco-innovative companies	country level regional level company level
preparation	identification of hotspots of (in)efficient material use which sectors to focus on in a material policy which materials to focus on in a material policy closing of material loops	sector level material level product level
2. industry		
macro	identification of material flows for domestic/regional use identification of hoarding identification of leakages proposal of priorities for material policies (material flows with a large impact)	material level
meso	identify availability of secondary materials (quality/quantity) calculation of environmental impacts of materials uses (comparisons) monitor different groups of material flows (fossil, biomass, residuals, ...) calculation of material efficiency identification of end point in material cycles identification of start points in material cycles	material level

micro	identification of material content in landfills, products, material flows, ... monitoring the evolution of raw materials calculation of material use efficiency, recycling efficiency, ... identification of available residual flows calculations of quality (potential) raw materials identification of alternative raw materials	material level company level

At a regional scale, MFA result could be applied in several ways: (1) to derive measures for improving the regional management of materials (e.g. to optimize resource exploitation, consumption and environmental protection within the constraints of the region, (2) to set up monitoring programs to evaluate the effects of policy measures and (3) as a tool for early recognition of the impacts of different scenarios of socioeconomic development. However, despite their stated usefulness, policy makers do not exploit the full potential of MFA results in their decision making at a regional level. The main reasons can be found at a methodological level (no general framework, low data availability, high data uncertainty, weak structure for interpreting MFA results) and in the difficulty of directly applying the results (management or transition goals are not always known and relevant information should be clarified). It is stated that the application of MFA results could be improved by combining MFA with socioeconomic and assessment methods to make the results more relevant for policymakers. The limited application possibilities of MFA for use in forecasting is also a limitation factor in a widespread use. Finally, the adherence to a clear methodologic framework should overcome the methodological issues as it will increase transparency and comparability. (Binder, 2007)

1.1.3 Material flow accounts

The OECD (2008) defines material flow accounts as: "Methodically organised accounts in physical units (usually tonnes) that quantify the flows of different types of materials into, out of and possibly within a given system at different levels of detail and completeness. They record material flows from extraction and harvesting through product manufacture, product use, reuse/recycle and disposal, including discharges to the environment that are associated with each stage of these flows.". However, it is not obvious that all physical flows can simply be aggregated or that all physical flows should be recorded in a similar way. Consequently, three subsystems have been developed within the broad MFA framework: material flow accounts, water accounts and energy accounts. They include the recording of physical flows of products, air emissions, solid waste and other residual flows. While all three systems only represent part of the total physical flows, each subsystem is a complete and balanced system of flows. (OECD, 2008; SEEA, 2014)

Separate accounts are developed for water and energy flows as they will dominate other material flows. In standard MFA's, water is only included as it is an embedded component of a material (e.g. in fuel) and where it is part of the fresh weight of certain outputs. Although the same accounting principles and definitions are used, the separate treatment of materials, energy and water gives a clear overview of the three categories while they do not distort or bias each other. (Adriaanse et al., 1997; Matthews et al., 2000; SEEA, 2014)

Material flow accounts are applied to a wide range of economic, administrative or natural entities (macro level), studying the flows of materials within the global or local economy (meso-level), within an economic activity or within a city, ecosystem or plant (micro level). All three levels are shortly discussed. For a more detailed description, see OECD (2008) or Daniels and Moore (2002). First, the macro-level is useful to (i) support decisions in areas such as economic, trade and environmental policy integration, (ii) sustainable development strategies and action plans and (iii) national waste management and resource conservation policies. Next, the meso-level enables a more differentiated tracking of information and a more detailed analysis of material flows within the economy, distinguishing not only categories of materials, but also industries or branches of production. Finally, the micro-level provides detailed information for specific decision processes at business or local level or concerning specific substance or individual products. The type of material flow analysis best suited for any particular case depends on the issues of concern and the questions being addressed as the characteristics of material flow analysis tools are divergent. (OECD, 2008)
The material flow account and related analysis and indicator best suited depends on many factors and the type of application. Most important are the issues of concern, the questions being addressed and the availability of time and budget. Several material flow accounts exists each having their own pro's and contra's. Some general criteria are: (Daniels & Moore, 2002)

- whether they typically cover the entire economy, a major economic activity fields, specific sectors or are designed to focus only upon one material flow or environmental repercussions of specific goods, services or processes regardless of their location;
- the nature and detailing of system components and flow interconnections; and
- the comprehensiveness and types of flows and materials covered.

Six common material flow accounts are compared by the OECD ('six ways to analyse material flows', 2008). Here, the comparison is supplemented with information from other authors to create the overview in **Figure 14**. Columns one to three focus on substances, materials or products, whereas columns four to six focus on businesses, economic activities or regions/countries. Whereas the tools in the first three columns are often performed from a technical engineering perspective, the tools in the last three columns are more directed to socioeconomic relationships. Based on these two top rows, six types of analysis and corresponding measurement tools are defined, which are explained below the figure. (Bringezu & Moriguchi, 2002; OECD, 2008)

object of interest	substance	material	product	business	economic activity	region;country
issue of concern	environmental impacts, supply security or technology development within businesses, economic activities, countries or regions			general environment and economic concerns related to the throughput of substances, material and manufactured goods		
type of analysis	substance flow analysis	material system analysis	life cycle assessment	business level MF analysis	input-output analysis	economy-wide MF analysis
measurement tool	substance flow analysis	individual MF accounts	life cycle inventories	business MF accounts	physical IOT and SUT	economy-wide MF accounts
abbreviation	SFA	MIPS	LCA	business MFA	PIOT/PSUT	EW-MFA
production system extent	selected substance	selected material	selected good	enterprise	economic activity	economy
inputs to economy	specific substances	bulk material	specific good	enterprise input	bulk;specific	bulk material
outputs to environment	++	++	++	enterprise output	++	++
material loops	++	++	+	+	++	+
stock changes	++	+++	+	+	++	+
specific products	++	+	+++	+	++	+
production processes	+	+	+	+++	++	-
inter-industry flows	+	+	+	+	+++	-
socio-institutional entity	national;local	national;local	specific good	enterprise	economy;product	national;local
geographic scale	global;local	global;local	global;local	enterprise	global;local	global;local
temporal study boundaries	year	year;life cycle	Year;life cycle	year	year	year
value chain flows	++	++	+++	-	+++	-
hidden flows	-	++	+++	-	++	+
main measurement tool	mass;volume	mass;volume	study dependent	study dependent	mass	mass
mass balancing	+++	++	+	++	++	++

FIGURE 14: OVERVIEW OF THE DIFFERENT TYPES OF MATERIAL FLOW ACCOUNTS. THE SIGNS INDICATE WHETHER IT IS A CHARACTERISTIC OF THAT TOOL (+) OR NOT (-). A SINGLE PLUS SIGN SHOWS WHEN AN ITEM IS ONLY INCLUDED IN THE ANALYSIS IN A PARTIAL OR CONDITIONAL WAY, TWO POSITIVE SIGNS ARE ALLOCATED WHEN THE FEATURE IS GENERALLY INCLUDED IN THE TECHNIQUE AND THREE POSITIVE SIGN ARE SHOWN WHEN THE ITEM IS A DEFINING FEATURE OF THAT TOOL. IN LINKING ATTRIBUTES TO TOOLS IT IS SOMETIMES NECESSARY TO USE A RANGE OF VALUES 'MAXIMUM;MINIMUM'.
(SOURCE: BRINGEZU & MORIGUCHI, 2002; DANIELS & MOORE, 2002; OECD, 2008)

The definitions of the six material flow accounts follow from the OECD (2008) and Bringezu and Moriguchi (2002):

- *Substance flow analysis and accounts* monitor flows of specific substances (e.g. CO2, CFC, Cd) that are known for raising particular concerns regarding environmental health risks associated whit their production and consumption. It has been used to determine the main entrance routes to the environment, the processes associated with these emissions, the stocks and flows within the industrial system as well as the transmedia flows between industry and environment, chemicals physical and biological transformations and resulting concentrations and accumulation in the environment.
- *Material system analysis* is based on material specific flow accounts. It focuses on selected raw materials or semi-finished products at various levels of detail and application (e.g. cement, paper, iron, copper, plastics) and considers life-cycle-wide inputs and outputs. It applies to materials that raise particular concerns and to the sustainability of their use, the security of their supply to the economy and/or the environmental consequences of their production and consumption.
- *Life cycle assessments (LCA)* are based on life cycle inventories. They focus on materials connected to the production and use of specific products (e.g. batteries, cars, computers, textiles) and analyse the

material requirements and potential environmental pressures along the full life cycle of the products. LCA can equally be applied to both services and goods and is standardised in ISO 14010.

- *Business level material flow analysis and accounts* monitor material flows at various levels of detail for a company, a firm or a plant. The primary interest lies in the metabolic performance of a firm. The main task is to evaluate the throughput of an entity to find the major problems, supporting priority setting, check the possibilities for further improvement measures and provide tools for monitoring their effectiveness.
- *IOA* is based on PIOTs that record material flows at various levels of detail into, out of and through the economy categorised by economic activities and final demand categories. It can also make use of NAMEA-type tables or of hybrid flow accounts.
- *Economy-wide material flow analysis* (EW-MFA) is based on national economy-wide material flow accounts that record all materials entering or leaving the boundary of the national economy. Data from these accounts can easily be aggregated for communication purposes and serve as a basis for deriving aggregated MFs and resource productivity indicators. EW-MFA builds on a fairly detailed data basis that, if well structured, can be used for many other purposes (e.g. in-depth analysis and material specific indicators).

Several significant disparities in conceptualization and methodological procedures and the criteria and subsequent classification of approaches exist. First, dimensions used to classify material flow analysis and distinguish them from other physical economy accounting approaches relate to essential differences in scope, goal orientation, historical development and implementation of the techniques within varying disciplinary contexts. A major obstacle is the ambiguity about what the primary system boundary is meant to encompass. A second disparity is about the differences in methodology of material flow tools. As the first ambiguity is related to different material flow tools and their classification and characteristics, the second ambiguity is related to the inconsistency in methodological aspects of a single tool. Initiatives are taken to streamline concepts and methodological procedures e.g. by Eurostat, but different views result in different applications. An example of such different of methodology is given in Daniels (2002). The example is about PIOTs in Germany, Denmark, the Netherlands, Finland and Japan. All studies examined mass flows and the physical accumulation of material and energy commodities within the economy using standard disaggregation into economic categories covering industry branches, household consumption, tangible assets and the rest of the world and flows between the economy and the natural environment, but the exact methodological form and coverage varies considerably across the nations. (Daniels, 2000; Daniels & Moore, 2002) Without a clear internationally agreed methodologies, these national results will be incomparable and cannot be integrated. Meaning, national studies will have a national focus, neglecting or incorrectly including (possibly important) foreign influences.

1.1.4 Material flow indicators

The OECD (2008) defines that material flow indicators are: “Quantitative measures which point to, inform about and describe the characteristics of material flows and material resource use and which have a meaning or a significance that goes beyond what directly can be associated with the underlying statistics. The term ‘material flow indicator’ designates all indicators that report on material flows and material resource use, ranging from aggregated measure to measures of individual material flows including substance flows.”. They can measure progress in resource productivity and material use and are widely used for communicating the results of material flow studies to a non-expert audience. Indicators may contribute to condensed and comprehensible information formation useful for target setting and score keeping. They allow for direct comparisons between both different time periods and regions. (OECD, 2008)

An advantage of defining and embedding indicators within accounting frameworks is the explicit exposure of definitions and concepts. A consistent representation of indicators and accounts undoubtedly improves the communications between different stakeholders: accounting aggregates or indicators provide the main messages while on a more detailed level the accounts deliver the statistical tools required for remedy evaluation as illustrated in **Figure 15**. (Gravgård & de Haan, 2009)

Material flow accounts can provide environmental pressure indicators but does not address environmental impacts (Reisinger et al., 2009). Material flows follow complex paths and one weighting value cannot adequately capture the full picture, but they provide information (e.g. on the relationship between flows) that enables people to ask the right questions. Like many macro indicators, aggregated material flows combine many different kinds of materials in order to demonstrate the absolute and relative magnitudes of economic activities in terms of mass. Material flow accounts provide an important basis for the derivation of environmental indicators and indicators for sustainability addressing questions concerning: (Bringezu & Moriguchi, 2002; Matthews et al., 2000; OECD, 2008)

- material requirements of an activity;
- dependency of an activity/economy on material inputs;
- efficiency of material resources in use;
- potential for improvements in resource productivity;
- main environmental risks and pressures associates with material use; and
- main environmental consequences of material flows.

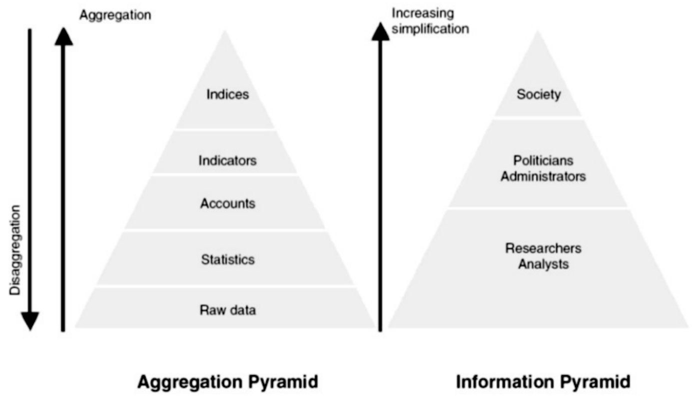

FIGURE 15: AGGREGATION AND INFORMATION PYRAMIDS EXPLAINING THE ROLE OF INDICATORS. THE INFORMATION PYRAMID SHOWS THAT THE PROVISION OF INFORMATION AT VARIOUS LEVELS SERVES DIFFERENT USERS WITH VARIOUS BACKGROUNDS AND INTERESTS.
(SOURCE: PEDERSEN & DE HAAN, 2010)

The purposes of using indicators can be summarized in three concepts: summarising analysis, political guidance and communication. Indicators should be based on world-wide recognised methodologies and valid data, should provide links with players, causes and instruments and should be vivid and as easily understandable as needed. Indicators in policies are used to define and quantify benchmarks and to measure the effects of policies. Also, it implicitly legitimises policies, for example, as an indicator shows undesired evolutions it can justify the use of a policy instrument. Considering this, it is important that indicators closely connect to policy goals. (de Bruyn et al., 2004; Spangenberg et al., 1998)

In **Table 6**, the main types of material flow indicators related to input, consumption, output, efficiency, intensity and balancing are described. For example, regarding the output material flows, several critical indicators can be calculated and analysed determining the quantity of materials flowing out of the economy in a year like the retention time of materials in the economy, which is increased by recycling and reuse, and the destination of output flows within the environment (air, water and land) (Matthews et al., 2000). In the synthesized framework by Huysman et al. (2015) only the efficiency, productivity and intensity indicators are level 1 macroscale indicators: resource efficiency at flow level, measuring the benefits over resource flows (or resource flows over benefits). The other indicators measure resource flows.

TABLE 6: COMMONLY USED MATERIAL FLOW INDICATORS.
(BASED ON: BRINGEZU ET AL., 2004; EUROSTAT, 2013; FINNVEDEN & MOBERG, 2005; HINTERBERGER ET AL., 2003; KOVANDA ET AL., 2012; KOVANDA ET AL., 2009; MATTHEWS ET AL., 2000; MOLL ET AL., 2005, PP.24-28; MULALIC, 2005; OECD, 2008; REISINGER ET AL., 2009)

INDICATOR	DESCRIPTION
1. input indicators	
input indicator	*describes the materials mobilised or used for sustaining economic activities, including the production of products for export. They are closely related to the mode of production in a particular country or region and are sensitive to changes in the level and patterns of foreign trade and to other factors such as a country's endowment in natural resources and its level of technology development.*
domestic extraction used	DEU measures the flows of materials that originate from the environment and that physically enter the economic system for further processing or direct consumption (they are "used" by the economy). They are converted into or incorporated in products in one way or the other and are usually of economic value. Overburden or unused harvest residuals are considered as unused extraction and therefore not included in DEU.
direct material input	DMI represents materials supply into the economy. It measures the direct input of materials for use, i.e. all materials that are of economic value and are used in production and consumption activities; DMI equals domestic extraction used plus imports.
raw material input	RMI is defined as the sum of DMI and imports expressed in RME. It measures the global use of resource linked to the input into the domestic economy by converting the import into RME. By including the indirect flows of import, the RMI is robust against outsourcing.
total material requirement	TMR includes, in addition to RMI, both the unused domestic extraction and the unused extraction associated to imported products. It measures the total ‘material base’ of an economy by adding both domestic and foreign hidden flows. Since all material inputs will sooner or later be transformed to material outputs, TMR

	also constitutes as a proxy for potential future environmental pressures, on a life-cycle-wide basis, to the domestic as well as the foreign environment.
domestic/foreign hidden flows or unused domestic extraction	DHF and FHF are the total weight of materials moved or mobilized in the domestic and foreign environment, respectively, in the course of providing commodities for economic use, which do not themselves enter the economy. Hidden flows occur at the harvesting or extraction stage of the material cycle. They comprise two components: ancillary flows and excavated and/or disturbed material flows.
2. consumption indicators	
consumption indicator	*describes the materials consumed by economic activities. They are closely related to the mode of consumption but are fairly stable over time. The difference between consumption and input indicators is an indication of the degree of integration of an economy with the global economy, which also depends on the size (geographical and population) of the economy.*
domestic material consumption	DMC represents domestic materials use. DMC measures the total amount of materials directly used in an economy (i.e. the direct apparent consumption of materials, excluding indirect flows). It equals DMI minus exports and is an important measurement of future domestic waste and emissions as all materials consumed will be converted into waste sooner or later.
raw material consumption	RMC measures the global material use associated with domestic production and consumption activities, including indirect flows related to imports (see RMI) and excluding exports and associated indirect flows of exports. RMC equals RMI minus exports and their indirect flows. Hidden flows or unused extraction are not counted by RMC. Thereby, it represents the global amount of used extraction to provide products for domestic final demand. In opposite of RMI, in international statistics both TMC and RMC avoid double counting of resources, because exports and related flows are attributed to the consuming country.
total material consumption	TMC measures the global material use associated with domestic production and consumption, including both indirect and hidden flows. TMC equals TMR minus exports expressed in RME and including hidden flows associated to the exported products.
3. balance indicators	
balance indicator	*describes the physical growth of materials within the economy. They show net flows of materials added to the economy's stock each year. Note the close and important link between balance indicators and consumption indicators.*
net additions to stock	NAS reflect the physical growth of the economy, i.e. the net expansion of the stock of materials in buildings, infrastructures and durable goods. NAS may be calculated indirectly as the balancing item between the flow of materials entering the economy minus those leaving it, taking into account the appropriate items for balancing. NAS may also be calculated directly as gross additions to material stocks, minus removals (such as construction and demolition wastes and disposed durable goods, excluding recycled materials).
physical trade balance	PTB reflects the physical trade surplus or deficit of an economy. It is defined as imports minus exports (calculations can exclude or include hidden flows). In general, a negative PTB indicates that a region exerts environmental pressures on other regions through its trade. In the case of a positive PTB, the situation is inverted.
4. output indicators	
output indicator	*describes the material outflows related to production and consumption activities of a given country. They account for those materials that have been used in the economy and are subsequently*

	leaving it either in the form of emissions and waste, or in the form of exports.
domestic processed output	DPO represents the waste and pollution from materials use. DPO measures the total weight of materials flowing back to the environment. These flows occur at the processing, manufacturing, use, and final disposal stages of the production-consumption chain. Included are emissions to air, industrial and household wastes deposited in (uncontrolled) landfills, material loads in wastewater and materials dispersed into the environment as a result of product use (dissipative flows).
total domestic output	TDO represents the environmental burden of materials use, i.e. the total quantity of material outputs to the domestic environment caused by economic activity. TDO equals DPO plus unused domestic extraction.
total material output	TMO measures the total amount of material leaving the economy including unused extraction and exports. TMO equals TDO plus exports.
5. efficiency and productivity indicators	
efficiency or productivity indicator	*relates economic output indicators (such as GDP or value added) to economy-wide or sectoral MF indicators providing information about the material productivity or intensity of the economy or economic activity sectors.*
GDP per DMI	GDP per DMI indicates the direct materials productivity
GDP per DMC	GDP per DMC indicates the domestic materials productivity
GDP per RMC	GDP per RMC indicates the raw material productivity
GDP per TMR	GDP per TMR indicates the total material productivity
gateway flows	Considering the first point of entry, gateway flows describe the share of DPO or TDO which exits the economy by each of the three environmental gateways (air, water and land).
sector flows	Sector flows are the share of DPO or TDO which can be directly attributed to the activities of individual economic sectors. Hidden flows are attributed to the mining (or industry in general), whereas combustion process are attributed to different economic sectors.
6. intensity indicators	
intensity indicator	*provides information about the intensity of materials use in an economy or economic activity sectors.*
DMI per GDP	DMI per GDP describes the amount of materials used as inputs in the economy per unit of GDP (material intensity indicator).
TMR per GDP	TMR per GDP includes the direct material input, the amount of unused extraction and indirect flows associated with imports. To know the intensity the total is divided by GDP (resource intensity indicator).
dissipative flows	Dissipative flows indicate the quantity of materials dispersed into the environment as a deliberate or unavoidable consequence of product use. These flows compromise two components: dissipative uses (e.g. fertilizer or salt spread on roads) and dissipative losses (e.g. rubber worn of tires or solvents in paint).

The use of material flow indicators often concerns highly aggregated indicators which can hide important variations in their constituent variables. The value of highly aggregated indicators can be dominated by one single material group that masks developments in other material groups. Proper interpretation of such an indicator therefore requires extra documentation and breakdown of the indicator. Also indicators can be mistakenly assumed to reflect the environmental impacts of material resource use, while the actual environmental pressure of material flows depends on many factors. Highly aggregated indicators of material flows should not be interpreted as direct indicators of environmental impacts as big flows are not automatically bad and small flows are not automatically better. As MFA indicators are weight-based, there is a possibility that small material flows that actually have huge environmental effects due to relatively low weight contributions are neglected. (Hoffrén, 2010; Matthews et al., 2000; OECD, 2008)

An example of such a misinterpretation is given in Reisingner et al. (2009). The example is about a sentence in the Thematic Strategy on the Sustainable Use of Natural Resources: “An analysis of materials and waste streams in the EU, including imports and exports, showed that, in the last 20 years, overall consumption per inhabitant has remained virtually unchanged in the EU at around 16 tonnes per year, and yet the economy has grown by 50% over that period”. This example shows the ease of misinterpretation the results as the system boundary effect is neglected. A system boundary effect is shown by the interpretation of the 16 tonnes per year. A closer look reveals this is the average European amount of extraction per inhabitant. In the last 20 years domestic extraction and processing to some extent is replaced and/or extended by imports of processed materials and products which causes a decrease or steady state in domestic material extraction, but not a decrease on environmental pressure worldwide. (Reisinger et al., 2009; Schütz et al., 2004)

To increase the usability and understanding and enabling the comparison between data, valuable information like reference values, time series, etc. should be added. Reference values might be qualitative objectives, targets, baselines, thresholds, references or benchmarks. Developing time series makes it possible to analyse trends in the use of specific materials or categories of material, which are of concern either because of their impacts or because of their economic or strategic interest. (Matthews et al., 2000; OECD, 2008)

The next sections discuss EW-MF accounts first, then PSUTs and last PIOTs. EW-MF accounts are first discussed as they contain the least, although valuable, information of the three. It also forms a starting point for the other two accounts. PSUTs include supply and use tables containing the information of EW-MF accounts extended with material flow data of the internal domestic economic structure. PIOTs merges those two tables into one table revealing the detailed metabolic system of the economy. In other words, to develop a PSUT it is necessary to first develop EW-MF accounts and to develop a PIOT it is necessary to first develop a PSUT.

1.2 Economy-wide material flow accounts (EW-MFA)

EW-MFA is the backbone of an environmental reporting system which provides economy-wide, reliable and comparable time-series data and indicators for material use. EW-MF accounts are consistent compilations of the overall material inputs into national economies, the changes of material stock within the economic system and the material outputs to other economies or to the environment. It illustrates the “big picture” of the physical properties of an economy. The detailed accounts provide a rich empirical database for numerous analytical studies. They are also used to compile material flow indicators for national economies at various levels of aggregation. (Eurostat, 2009; Mäenpää, 2009)

An EW-MFA includes two main categories of material flows: flows from and to the domestic environment and trade flows with other countries. The general purpose is to describe the interaction of the domestic economy with the natural environment and the rest of the world (RoW) economy in terms of materials. EW-MFA measures flows excluding water and air but including the water content of materials (Eurostat, 2013). It allows to analyse a link between welfare and environmental pressure. Our welfare depends, to some extent, on the use of materials and at the same time the use of these materials affects the environment, human living conditions and the options of future supply of materials. It is the exchange of material between economy and environment (namely the resource extraction and the release of emissions and waste) that exerts pressures on the environment. Trade flows impose those same effects, but in other countries. Also, the continuous accumulation of materials within the economy poses problems that are related to future waste flows as well as land use. (Bringezu et al., 2003; de Bruyn et al., 2004)

The description of EW-MFA is divided into three sections: system description, material balances and modelling and indicators.

1.2.1 System description

To get comparable and consistent data on material flows, it is crucial to have a clear definition of the system boundaries (see *System boundaries*, p.20). EW-MFA is conceptually based on a simple systemic model of an economy embedded in its physical environment. The socio-economic system under investigation is in general conceived as a materially and energetically open system economy (industrial metabolism) in which four types of material flows are possible. On the input side, inputs from the natural environment and material imports from other economies are distinguished. Likewise, on the output side, outputs into the environment and material exports to other economies are distinguished (Figure 16). (Eurostat, 2009)

Only cross-boundary flows (both on the input and output side) are counted. Material flows between the national economy and the natural environment consist of the extraction of primary materials from and the discharge of materials to the natural environment. Material flows between the national economy and RoW-economies encompass trade flows. The socio-economic system (or domestic economy) including production and consumption activities is treated as a black box (e.g. inter-industry deliveries of products are excluded) (**Figure 16**). (Eurostat, 2009; Hammer et al., 2003)

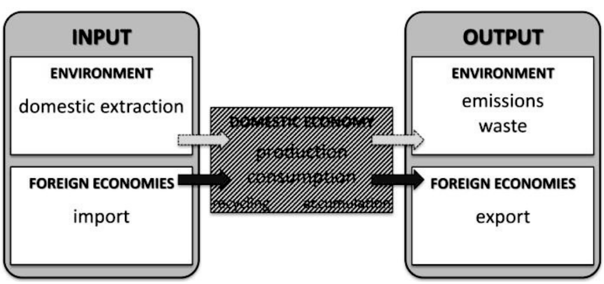

FIGURE 16: THE SCOPE OF AN ECONOMY-WIDE MATERIAL FLOW ANALYSIS (EW-MFA).

As mentioned in *section 1.1.1 Terms and definitions* special attention is needed for the treatment of semi-natural systems and the residence principle. Following the guidelines of Eurostat and consistency with the SNA (ESA 95), an EW-MFA complies with the residence principle. Although the territory principle is used by some other authors (e.g. OECD, 2007) for consistency with data sources, it is more useful to have a comparison between different accounts based on the same principles. For most parts, the sources of statistical data employed in an EW-MF account compilation are consistent with the residence principle, although in some cases adjustments are required. In general, fuel consumed in international transport, tourism and activities in extraterritorial enclaves are areas where source data is not (fully) consistent with the residence principle. In accordance to the residence principle, fuel that is consumed by resident units abroad has to be accounted for in EW-MFA, while vice versa fuel provided to non-resident units domestically has to be excluded. However, the related material flows of tourism and activities in extraterritorial enclaves are of a comparatively small size in most cases and statistical data or standardized estimation procedures are hardly available. Therefore, deviations from the residence principle for these areas should be considered in EW-MFA, on the condition that this is accompanied by a description of the deviations. (Eurostat, 2009; Hammer et al., 2003)

Semi-natural systems in EW-MFA are treated as natural stocks, except for controlled landfills which are considered within the socio-economic system. Treating plants as part of the national economy would create the necessity to account for water, CO_2 and plant nutrients as the primary inputs from the environment. As EW-MFA treat the domestic economy as a black box, cultivated plants would not be visible in the account. Effectively, this would mean that the system boundary between a national economy and its environment would have to be drawn at the inorganic level and statisticians would be forced to convert rather robust and valid data on annual agricultural and timber harvest to comparably weak estimates of the primary inputs needed to produce these plants. Moreover, all differentiation between types of crops would be lost, as well as the conceptual link to the SNA. It is hard to imagine how such data could possibly be interpreted in a meaningful way, given the limitation of a black box accounting system in the EW-MFA. Therefore, cultivated plants are treated as environmental inputs, and not their nutrition, water and CO_2-uptake. (Eurostat, 2009)

1.2.2 Hidden flows

The main categories of an EW-MFA are illustrated in **Figure 17**. Several opinions exist on the inclusion or exclusion of HF's and indirect flows associated to imports and exports. From Eurostat (2012): "Unlike the direct flows, unused extraction and indirect flows do not enter the socio-economic system and are not considered in EW-MFA.", but as Femia and Vignani (2006) conclude: "Indirect flows are quantitatively and qualitatively important and policy relevant. These flows are an important component of the total material requirements of highly developed economies and should therefore not be disregarded in a global sustainability perspective.". There are always upstream material flows associated to imports and exports that are not physically imported or exported. The importance of HF's and indirect flows can be shown by citing several authors:

- Femia et al. illustrate the importance of indirect flows and hidden flows associated to imports in case of the Italian economy as it represents on average 46% of the TMR, from 1980 to 2003 (Femia & Vignani, 2006). A study by Bringezu et al. (2004) for a selection of countries (Finland, Germany, Italy, the Netherlands, UK, Poland, Czech Republic, EU-15, USA, Japan and China) indicates that the dominant share (on average 65%) of TMR is made up by indirect and hidden flows which ranges between 18 and 60 tonnes per capita.
- Imported products represent more natural resources than they actually embody. These hidden flows should be accounted for in MFA to give a complete overview of the physical economy and to be able to make a

meaningful time comparison. Indirect flows related to imports are not in any immediate relationship with the national physical environment (nor with the national economy), but represent the additional material flows activated abroad by the demand for imported products. Including indirect flows implies going beyond national economic and territorial boundaries and providing information that is valuable in a global perspective on ecologically sustainable development, but much less from a local perspective. (Femia & Vignani, 2006)

- The mass of products is smaller than the mass of raw materials which were used in the upstream production chain of these products, independent of the production location. Since the aim of a material footprint accounts is to account for the total pressure of regional/national consumption imposed on the environment, the import and export should include all upstream flows used and should be expressed in RME. (Kovanda et al., 2009)
- The relative and absolute value of global hidden flows increases over time (1980-2002) from 48% to 51% of total extraction and to a worldwide amount of 58 billion tonnes in 2002 respectively. Three factors are responsible for this increase: changing factors of unused extraction per used amount of extraction of a certain natural resource over time, a relative shift towards materials with larger ecological rucksacks and a shift of extraction locations to regions with larger hidden flows for identical materials. (Behrens et al., 2007)

Although the importance of including indirect and HF's flows into MFA is clear, the practical inclusion is far from simple. There are at least two possible approaches to calculate indirect flows, though the current calculation methods may not be fully convincing and require refinement to fulfil the quality standards of official statistics. The most common calculation method is by making use of product-specific coefficients (LCA coefficient approach). It uses material intensity analysis or materials input per service unit (MIPS). Although a detailed analysis is possible, it requires enormous amounts of material input data at each stage of production. Therefore, indirect material flows have only been estimated for a very small number of finished products. The other method is the application of IO-modelling by using input coefficient matrices (input-output approach) (e.g. multi-regional IO-analysis (MRIO)) which allows the comprehensive accounting of direct and indirect resource flows activated by final demand. Using the input-output approach to calculate the indirect flows of a large number of finished products, only a rough or aggregated estimation is possible (Femia & Vignani, 2006; Giljum, 2006; Kovanda et al., 2009; Moll et al., 2006). The RME-coefficients developed by Eurostat are an example of the application of (hybrid) IO-modelling (Eurostat, 2015).

HFs in EW-MFA signify the movements of the unused material associated with the extraction of raw materials, both nationally (DHF) and abroad (FHF). The FHF associated to imports include all unused extraction abroad associated to imports; FHFs associated to exports include all unused extraction domestically and abroad (related to all preceding steps in the supply chain) associated to exports. The HF are accounted, but are not considered as an input nor as an output. As these flows do not enter the domestic economy, they are only mentioned in the accounts and do not have an impact on them. Some problems in reporting HF are: weak data availability, country specific (require knowledge on the value chains of imports) and tendency to change over time (Eurostat, 2001; Hoffrén, 2010)

1.2.3 Material balances and modelling

The material balance of an EW-MFA is:

$$\text{DE} + \text{import} + \text{input balancing item} \\ = \text{DPO} + \text{export} + \text{output balancing item} + \text{NAS} \quad \text{(eq. 6)}$$

In EW-MFA the mass balancing principle applies for materials entering and leaving the system: the sum of all material inputs into a system equals the sum of all outputs plus the stock increases minus the releases from stocks in the same period. The mass balance principle is used to check the consistency of the accounts and makes stock estimations possible. The basic premise of EW-MFA is that the amount of resource inputs of an economy determines the amount of all outputs to the environment. NAS are considered as outputs in future periods (short or long term). The limitation of EW-MFA is the weak link between inputs and outputs. (Bringezu et al., 2003; Eurostat, 2009)

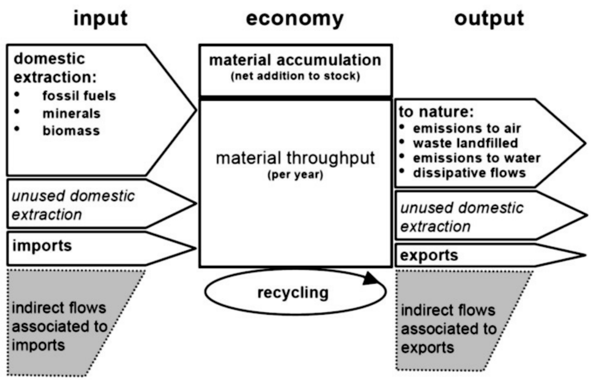

FIGURE 17: SCHEMATIC REPRESENTATION OF ECONOMY-WIDE MATERIAL FLOW ANALYSIS (EW-MFA) AND THE MAIN MATERIAL FLOW CATEGORIES. BALANCING ITEMS COMPRISED WATER AND AIR FLOWS THAT MUST BE TAKEN INTO ACCOUNT TO COMPLETE THE BALANCE (E.G. OXYGEN USED IN COMBUSTION PROCESSES). NAS REFERS TO THE DIFFERENCE BETWEEN THE INPUT AND OUTPUT FLOWS AND IS RELATED TO THE CONSUMPTION PATTERN. A DESCRIPTION OF THE MATERIAL FLOWS CATEGORIES IS GIVEN IN TABLE 7.
(SOURCE: EUROSTAT, 2001)

TABLE 7: A DESCRIPTION OF THE MAIN MATERIAL FLOW CATEGORIES IN ECONOMY-WIDE MATERIAL FLOW ACCOUNTS (EW-MFA).

MATERIAL FLOW CATEGORY	DESCRIPTION
domestic extraction (DE)	The aggregated flow 'DE' covers the annual amount of solid, liquid and gaseous raw materials extracted (except for water and air) from the natural environment to be used as material inputs in economic processes. The term used refers to acquiring value within the economic system. DE consist of biomass, construction and industrial minerals, gross ores and fossil fuels. Concerning the water content of the raw materials, the convention is to account for all raw materials in fresh weight, with the exception of grass harvest, fodder directly taken up by ruminants and timber harvest. These raw

	material are accounted for with a standardised water content of 15%.
physical import and export	Physical imports and exports are aggregates covering all imported or exported commodities. Traded commodities comprise goods at all stages of processing from basic commodities to highly processed products.
NAS	NAS measures the physical growth of an economy. It measures the quantity (weight) of new construction materials used in buildings and other infrastructure and of material incorporated into extra durable goods such as cars, industrial machinery and household appliances. Materials are added to the economy's stock each year and are removed from stocks as buildings are demolished and durable goods are disposed of. These decommissioned materials, if not reused or recycled, are accounted for in DPO. Mostly, the NAS are not calculated by balancing additions to stock and stock depletion, but as statistical balance between inputs and outputs.
DPO	DPO are flows occurring in the processing, manufacturing, use and final disposal stages of the production-consumption chain and comprise emissions to air, industrial and household wastes deposited in uncontrolled landfills, material loads in wastewater and material dispersed into the environment as a result of product use (dissipative flows).
input and output balancing	Although bulk water and air flows are excluded from EW-MFA, material transformations during processing may involve water and air exchanges which significantly affect the mass balance. Balancing items are estimations of these flows, which are not part of other input or output flows. Balancing items mostly refer to the oxygen demand of various combustion processes, the emissions of CO_2 and water vapour from biological respiration and during the combustion of fossil fuels containing water and/or other hydrogen compounds. In the compilation of economy wide accounts only a few quantitatively important processes are taken into account via an estimation using generalized stoichiometric equations.

Figure 18 and **Figure 19** include the essence of modelling an EW-MF account. In **Figure 19**, an EW-MFA balancing framework shows on the resource side: imports, DE and input balancing items and on the use side: exports, DPO and output balancing items. In practice, the net addition to stocks is only accounted either on the resource side if the net addition is negative or on the use side if the net addition is positive. Net additions to stocks makes sure the framework is balanced. Stocks will decline if an economy uses (output) more materials than that resources (input) enter the economy; stocks will increase if an economy uses (output) less materials than that resources (input) enter the economy.

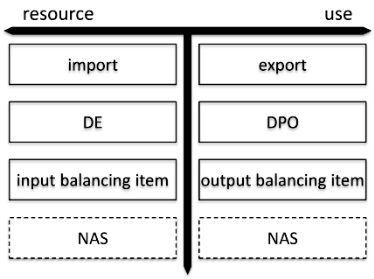

FIGURE 18: AN ECONOMY-WIDE MATERIAL FLOW ANALYSIS (EW-MFA) BALANCING FRAMEWORK SHOWING ON THE RESOURCE SIDE IMPORT, DOMESTIC EXTRACTION (DE) AND INPUT BALANCING ITEMS AND ON THE USE SIDE: EXPORT, DOMESTIC PROCESSED OUTPUT (DPO) AND OUTPUT BALANCING ITEMS. NET ADDITIONS TO STOCKS (NAS) BALANCES THE ACCOUNT.

In principle, the total amount of material additionally stocked within the economy could be derived as a residual item from balanced accounts of inputs and outputs. However, data on inputs and outputs are subject to uncertainties. Hence, the derivation of stock changes as a residual item from total inputs and outputs risks lumping significant statistical discrepancies and real stock changes together. Therefore it is recommended, if data is available, to estimate net additions to material stock (NAS) by separately estimation the flows that make up the net change (i.e. gross additions and removals from stocks). (Eurostat, 2001)

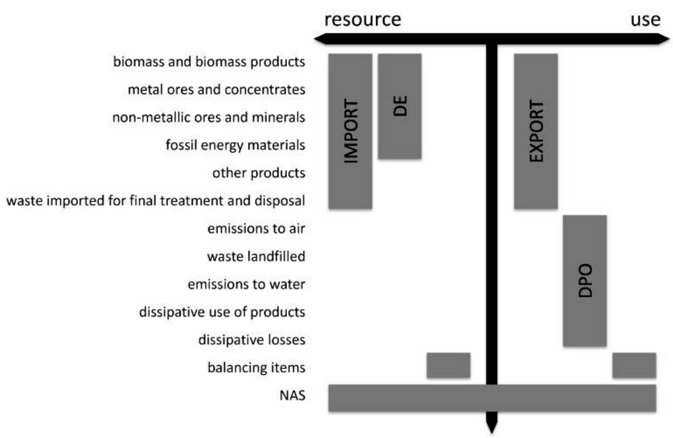

FIGURE 19: A BALANCED ECONOMY-WIDE MATERIAL FLOW ANALYSIS (EW-MFA) FRAMEWORK. THE MAIN MATERIAL CATEGORIES CAN BE FURTHER SUBDIVIDED TO INCREASE THE LEVEL OF DETAIL.

EW-MFA are compilations of data from various official statistics, most of which are regularly provided and updated by national statistical offices. DE is mainly based on data from agricultural, forestry, fishery production, mining and energy statistics. Imports and export data are taken from foreign trade statistics. The overall value of EW-MFA depends largely on its internal consistency, its international comparability and its potential to reflect a large variety of real world processes. (Eurostat, 2009)

A system of material flow accounts and balances is set up and 'sum up' to an integrated EW-MFA. Each flow account (balance) has two sides: resources and use. Flows that add to the amount of material in the economy are recorded on the resources side. On the uses side flows that reduce the amount of material in the economy are recorded. All accounts are balanced. (Eurostat, 2001)

EW-MFA is built from a series of accounts. The order of accounts is based on data availability; the material flows for which data are more likely to be available are presented first. The individual accounts are: (Eurostat, 2001)

- DMI account (account 1);
- DMC account (account 2);
- PTB account (account 3);
- DPO to nature account (account 4);
- two alternative accounts to derive NAS (account 5a and 5b);
- physical stock account (account 6);
- direct material flow balance (account 7);
- unused DE account (account 8);
- indirect flows trade balance account (account 9);
- TMR account (account 10); and
- TMC account (account 11).

TABLE 8: DIRECT MATERIAL INPUT (DMI) ACCOUNT (ACCOUNT 1).

RESOURCE	**USE**
domestic extraction *fossil fuels* *minerals* *biomass* imports	direct material input (DMI)

TABLE 9: DOMESTIC MATERIAL CONSUMPTION (DMC) ACCOUNT (ACCOUNT 2).

RESOURCE	**USE**
direct material input (DMI)	export domestic material consumption (DMC)

TABLE 10: PHYSICAL TRADE BALANCE (PTB) ACCOUNT (ACCOUNT 3).

RESOURCE	**USE**
import physical trade balance (PTB)	export physical trade balance (PTB)

TABLE 11: DOMESTIC PROCESSED OUTPUT (DPO) ACCOUNT (ACCOUNT 4).

RESOURCE	**USE**
domestic processed output (DPO)	emissions and waste *emissions to air* *waste landfilled* *emissions to water* dissipative use of products and losses

TABLE 12: NET ADDITIONS TO STOCK (NAS) ACCOUNTS (ACCOUNT 5A).

RESOURCE	USE
domestic material consumption	emissions and waste
	emissions to air
	waste landfilled
	emissions to water
	dissipative use of products and losses
memorandum items for balancing	memorandum items for balancing
	net additions to stock (NAS)

TABLE 13: NET ADDITIONS TO STOCK (NAS) ACCOUNTS (ACCOUNT 5B).

	TRANSPORT INFRASTRUCTURE	BUILDINGS	MACHINERY	OTHER DURABLES	TOTALS
+ additions					
- discard and demolition waste					
- losses due to corrosion & abrasion					
= net additions to stock (NAS)					

TABLE 14: PHYSICAL STOCK ACCOUNT (ACCOUNT 6).

	TRANSPORT INFRASTRUCTURE	BUILDINGS	MACHINERY	OTHER DURABLES	TOTALS
opening stock					
additions					
removals					
losses					
other incl. changes in classification					
tot net change (NAS)					
statistical discrepancy					
closing stock					

TABLE 15: DIRECT MATERIAL FLOW BALANCE (ACCOUNT 7).

RESOURCE	USE
domestic extraction	emissions and waste
fossil fuels	*emissions to air*
minerals	*waste landfilled*
biomass	*emissions to water*
import	dissipative use of products and losses
	export
	net additions to stock (NAS)
memorandum items for balancing	memorandum items for balancing
	statistical discrepancy

TABLE 16: UNUSED EXTRACTION ACCOUNTS (ACCOUNT 8).

RESOURCE	USE
unused domestic extraction *from mining/quarrying* *from biomass harvest* *soil excavation*	disposal of unused domestic extraction *from mining/quarrying* *from biomass harvest* *soil excavation*

TABLE 17: INDIRECT FLOWS TRADE BALANCE (ACCOUNT 9).

RESOURCE	USE
indirect flows associated to import *used (RME less the weight of imports)* *unused extraction associated to RME* indirect flows trade balance	Indirect flows associated to export *used (RME less the weight of export)* *unused extraction associated to RME* indirect flows trade balance

TABLE 18: TOTAL MATERIAL REQUIREMENT (TMR) ACCOUNT (ACCOUNT 10).

RESOURCE	USE
domestic extraction *fossil fuels* *minerals* *biomass* imports unused domestic extraction fossil fuels minerals biomass indirect flows associated to imports used (RME less the weight of imports) unused extraction associated to RME	total material requirement (TMR)

TABLE 19: TMC ACCOUNT (ACCOUNT 11).

RESOURCE	USE
total material requirement	exports indirect flows associated to export used (RME less the weight of exports) unused extraction associated to RME total material consumption (TMR)

Putting these 11 accounts together result in a general EW-MFA. The result is shown in Table 20.

TABLE 20: GENERAL ECONOMY-WIDE MATERIAL FLOW ACCOUNT.

RESOURCE	**USE**
domestic extraction (used)	emissions and wastes
fossil fuels	*emissions to air*
minerals	*waste landfilled*
biomass	*emissions to water*
	dissipative use of products and losses
	dissipative use of products
	dissipative losses
imports	exports
raw materials	*raw materials*
semi-manufactured products	*semi-manufactured products*
finished products	*finished products*
other products	*other products*
packaging material imported with products	*packaging material exported with products*
waste imported for final treatment and disposal	*waste imported for final treatment and disposal*
memorandum items for balancing	memorandum items for balancing
unused domestic extraction	disposal of unused domestic extraction
unused extraction from mining and quarrying	*unused extraction from mining and quarrying*
unused biomass from harvest	*unused biomass from harvest*
soil excavation and dredging	*soil excavation and dredging*
indirect flows associated to imports	indirect flows associated to exports
	used (RME less the weight of exports)
	unused extraction associated to RME
net additions to stock	net additions to stock

1.2.3 Indicators

Aggregated EW-MFA indicators allow to monitor the material use in national or regional economies in a comparable, transparent and comprehensible way. To identify driving forces and patterns of national material use and to further evaluate progress concerning dematerialisation and sustainable use of resources, however, detailed material flows rather than highly aggregated indicators should be examined. The same is true for a closer examination of the environmental impact of the material flows. (Weisz et al., 1998)

Examples of indicators that can be calculated from an EW-MF account are: DEU, import, export, DMI, DMC, PTB, DPO and NAS (Eurostat, 2012). See **Table 6** for a description of these indicators. To fully exploit the potential of these indicators, they can be broken down by material categories. Expressing the indicators in absolute, per capita, per area or per GDP values delivers valuable information from different perspectives. For example, the per capita expression summarizes environmental justice issues because all people should have equal rights to extract and consume resources and allows a better cross-regional comparison. However, it overlooks social inequality within the region it considers. Per GDP points is the economy’s efficiency of resource transformation into economic output and allows for assessing the intensity of material use in the economy. Expressing DMI or TMR in relation with GDP gives insight into the metabolic performance of nations and shows results on the relative decoupling of material use from economic growth.

(Behrens et al., 2007; Bringezu et al., 2003; Gonzalez-Martinez & Schandl, 2008; Kovanda et al., 2009)

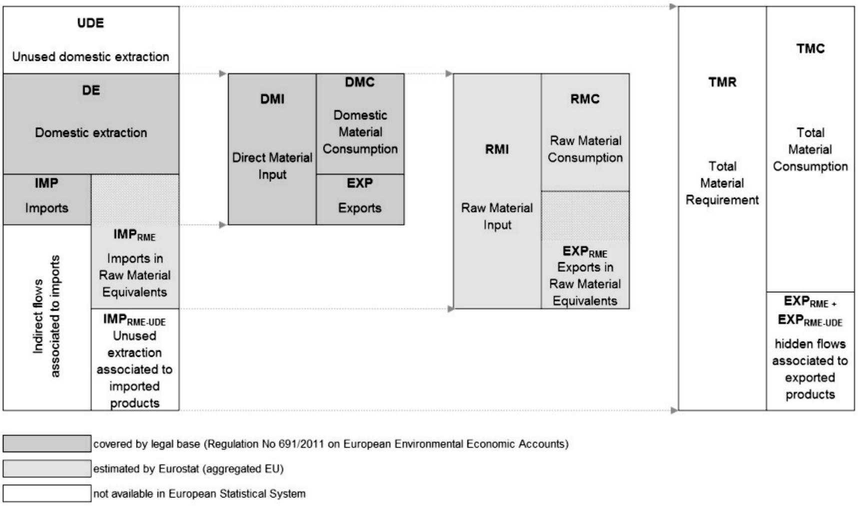

FIGURE 20: EW-MFA INDICATORS.
(SOURCE: EUROSTAT, 2015)

DE or DEU per area delivers easily interpretable results as it expresses environmental pressure per square kilometre of a given country associated with mining and production of biomass. It can be directly related to regional population and GDP to allow for inter-regional comparisons. A change in DE per capita or per GDP can be related to two effects (along with demographic changes etc.): the technology effect and the structural effect. The technology effects includes the use of new technologies with improved material and energy performance per unit of economic output. Structural changes in economies includes the growth towards service sectors characterised by less material input per unit of output[3]. (Behrens et al., 2007; Kovanda et al., 2009)

The import and export indicators define the physical quantity of all imports/exports, including raw materials, semi-manufactured products and finished products. In the case of countries, imports and exports refer to international trade while in the case of cities and regions they refer to material flows crossing the boundaries of such administrative units. Imports are an environmental pressure exerted on a spatial unit over the importing one, i.e. the pressure related to production of imports shifted from regions to the importing region. The same reasoning applies to exports, but conversely. (Kovanda et al., 2009)

The so-called efficiency or productivity indicators relate economy-wide indicators to economic output. They are a measure of the material productivity or intensity of an economy or sector: the ability to produce the same output, or to comply with the same consumption needs with less material indicates an improvement of the

[3]In this context, one has to consider the possible growth of imports. If an economy changes towards a service-based economy, the final demand does not automatically move in the same direction. To comply with domestic consumer needs, imports may increase meaning an extra pressure on the 'foreign' environment.

environmental and economic performance (and thus competitiveness). Because these indicators on the level of material groups, or even at the level of an individual material, offers the ability to identify the most important materials for an economy. Resource productivity is a "lead" macro-indicator and was selected in the RE scoreboard (Eurostat) to measure the main objective of the Roadmap. It is defined as the ratio of GDP/DMC. Also, DMC and in recent years RMC increasingly defined in other indicator sets of receivers for the green economy as a relevant indicator.

Other indicators like DE to DMC ratio, import to DMC ratio and export to DMC ratio support policies on resource and trade dependencies. The DE to DMC ratio indicates the dependence of the physical economy on domestic raw material supply, denoting the domestic resource dependency. The ratios between imports and exports to DMC indicate the physical intensity of import and export. (Weisz et al., 2006)

The EW-MFA differs from the PIOTs in the estimation of the RMC. Via the Leontief inverse the RMC can be derived from a PIOT. An extra conversion is required to derive the RMC from an EW-MFA. The RMC needs a conversion of physical imports and exports into their raw material equivalents (RME). RME-coefficients are available via Eurostat[4].

1.3 PHYSICAL SUPPLY AND USE TABLES (PSUT)

Next in line are the physical supply and use tables (PSUT). They also provide a comprehensive picture on the interaction between an economy and the natural environment. In addition to EW-MFA, they illustrate material flows within the economy. Its two tables have the same dimensions for the specification of material flows: one for the different materials observed and one for the different activities covered. They quantify (mass units) the quantities of the different materials made available and the quantities absorbed by the different activities. The tables differ in the data reported: the physical supply table (PST) shows for each activity the quantity made available per material category, while the physical use table (PUT) shows for each activity the quantities absorbed per material category. (Hernandez-Rodriguez et al., 2012; OECD, 2007)

PSUTs are based on (a part of) the definition of material flows: “Material flows are characterized by having an origin and a destination”. The supply table of a PSUT records all the ‘origins’ of material flows, while the use table records all the ‘destinations’ of material flows. The supply table shows the origin of the material flows, i.e. where do the physical quantities come from. The use table shows the destination of this same quantity, i.e. how much is received by the economy or the environment. Because every material flow has a source or a sink, the PSUTs are balanced. (Gravgård, 2009)

1.3.1 System description

The model includes three connected systems: ecological systems (environment), industrial systems (production) and societal systems (consumption). These building blocks are illustrated in **Figure 21** related to the two tables of the PSUTs.

[4]Eurostat, 2014. Estimates for Raw Material Consumption (RMC) and Raw Material Equivalents (RME) conversion factors. Available online: https://ec.europa.eu/eurostat/web/products-datasets/-/env_ac_rme

Ecological systems comprise the biosphere and provide products and services to industrial and societal systems. Industrial systems utilize ecosystem services and extract or harvest materials. Industrial wastes that cannot be re-used are deposited back into the biosphere. Societal systems consume the products, services and energy supplied by industrial systems and generate waste that is either recycled (recycling) into industrial systems or deposited back into the biosphere. They may also consume ecosystems services and resource stocks (accumulation) directly. (Fiksel, 2006)

The two tables of a PSUT include the data presented by an EW-MF account supplemented with data on material flows between actors of the domestic economy. EW-MF accounts record only material flows crossing the borders of the domestic economy, while PSUTs also record material flows within the borders of the domestic economy. An EW-MF account treats the domestic economy as a black box. In a PSUT this box is opened by including all material flows related to the economy (**Figure 21**).

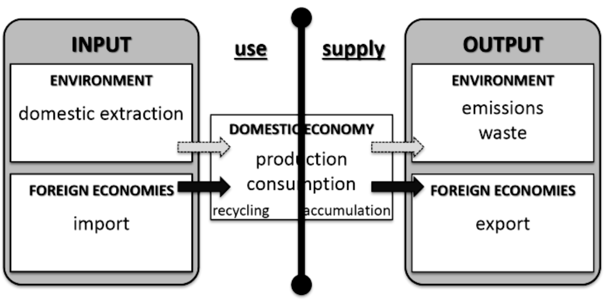

FIGURE 21: THE SCOPE OF PHYSICAL SUPPLY AND USE TABLES (PSUTS).

The treatment of semi-natural systems and the residence principle is consistent with their treatment in EW-MFA. However, it is possible to treat plants differently. Recording plants as a part of the national economy requires their uptake (CO_2, nutrients, water, etc.) as a cross-boundary flow. In contrast to EW-MFA, the valuable data on the agricultural production statistics will not be lost as they are recorded in the domestic economy.

1.3.2 Material balances and modelling

The general structure of the PST and PUT is given in **Figure 22** and **Figure 23**, respectively. The boxes represent matrices or vectors and are explained in **Table 21**. Matrices are denoted by an upper case letter and vectors are denoted by a lower case letter. Because the data they contain are in physical units (describing material flows) all matrices and vectors are denoted in bold letters. A transposed matrix or vector is denoted by an apostrophe (’).

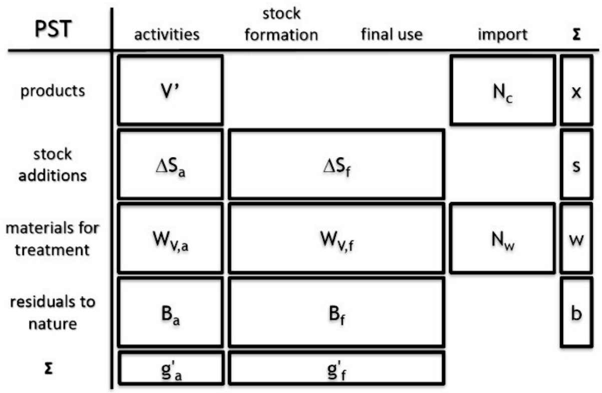

FIGURE 22: THE FRAMEWORK OF A PHYSICAL SUPPLY TABLE (PST).
(SOURCE: MERCIAI ET AL., 2011; SCHMIDT ET AL., 2012)

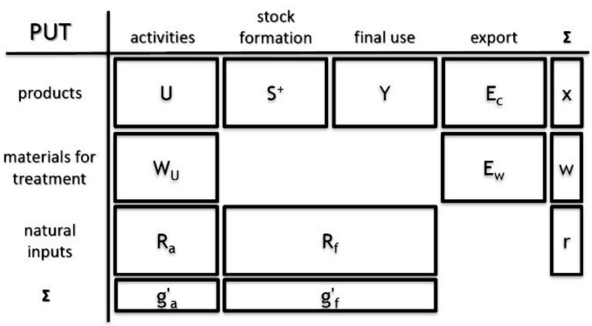

FIGURE 23: THE FRAMEWORK OF A PHYSICAL USE TABLE (PUT).
(SOURCE: MERCIAI ET AL., 2011; SCHMIDT ET AL., 2012)

The columns in **Figure 22** and **Figure 23** represent four categories: production given by activities, accumulation by stock formation, household consumption and trade flows to/from the rest of the world. Activities include all industries and can be disaggregated to increase the level of detail. Stock formation includes inventory changes, fixed assets and controlled landfills. Final uses include current material consumption and consumer durables. The trade flows can be divided according to important trade partners or trade blocks and a rest category. Expanding these four general categories will detail the information, but requires more data. The rows show the used/supplied material already subdivided in broad material categories (see section *1.1.1 Terms and definitions*). (OECD, 2007)

TABLE 21: DESCRIPTION OF MATRICES AND VECTORS IN PST AND PUT.
(ADAPTED FROM: HOEKSTRA, 2005; MERCIAI ET AL., 2011; SCHMIDT ET AL., 2012)

SYMBOL	DESCRIPTION	DIMENSION (ROWS BY COLUMNS)
ΔS_a	The additions to stocks matrix of products and materials for treatment per production activity. It shows the	products by activities

	additions to stock which have not become sold products or materials for treatment within the accounting period. $\Delta\mathbf{S_a}$ can be seen as a delayed supply. Together with $\Delta\mathbf{S_f}$ and $\mathbf{W_V}$, it is calculated as a balancing item. $\Delta\mathbf{S}$ should not be confused with $\mathbf{S^+}$ which is the change of inventories on the use side. $\Delta\mathbf{S_a}$ is the balancing item on the supply side. $$\Delta\mathbf{S_a} \cup \Delta\mathbf{S_f} = \Delta\mathbf{S}$$ $$\Delta\mathbf{S} = \Delta\mathbf{S_C} + \Delta\mathbf{S_R} + \Delta\mathbf{S_W}$$ with $\Delta\mathbf{S_C}$, $\Delta\mathbf{S_R}$ and $\Delta\mathbf{S_W}$ representing stock additions originating from inputs of products, inputs of natural resources and inputs from materials for treatment, respectively.	
$\Delta\mathbf{S_f}$	The additions to stocks matrix of products and materials for treatment from accumulation and final use categories. It accounts for products purchased by households that have not become materials for treatment within the accounting period (products with a lifetime longer than one year).	products by accumulation and final consumption categories
$\mathbf{b}$	A column vector recording the total supply of residuals to nature. $$\mathbf{B} = \mathbf{B_a} \cup \mathbf{B_f}$$ $$\mathbf{b} = \mathbf{B} \times \mathbf{i}$$[5]	emission type by one
$\mathbf{B_a}$	This emission matrix representing the output of emissions by production activities. Residuals emitted to nature do not have a market price (although they may represent a social cost), while the residuals supplied to other entities in the economy (materials for treatment) usually have a price. $$\mathbf{B} = \mathbf{B_C} + \mathbf{B_R} + \mathbf{B_W}$$ with $\mathbf{B_C}$, $\mathbf{B_R}$ and $\mathbf{B_W}$ representing emissions originating from products, natural resources and materials for treatment, respectively.	emission type by activity
$\mathbf{B_f}$	This emission matrix representing the output of emissions by accumulation and final uses categories.	emission type by accumulation and final consumption categories
$\mathbf{E_c}$	Matrix containing the exports of products per exporting region.	products by exporting regions
$\mathbf{E_w}$	Matrix containing the exports of materials for treatment aggregated per exporting region.	materials for treatment by exporting region
$\mathbf{g_a}$	The sum of the outputs in a PST or inputs in a PUT. It represents a column vector aggregated per production activities. $$\mathbf{g} = \mathbf{g_a} \cup \mathbf{g_f}$$	activity by one
$\mathbf{g_f}$	The sum of the outputs in a PST or inputs in a PUT aggregated per accumulation and final uses category.	accumulation and final consumption categories by one
$\mathbf{N_c}$	Matrix containing the imports of products aggregated per importing region.	products by importing regions
$\mathbf{N_w}$	Matrix containing the imports of materials for treatment aggregated per importing region.	materials for treatment by exporting region
$\mathbf{r}$	A column vector recording the total use of natural inputs by all human activities. $$\mathbf{R} = \mathbf{R_a} \cup \mathbf{R_f}$$ $$\mathbf{r} = \mathbf{R} \times \mathbf{i}$$	natural input types by one

[5] I and i denotes a summation matrix and vector, respectively.

$\mathbf{R_a}$	Inputs of natural resources aggregated per production activity.	natural input type by activities
$\mathbf{R_f}$	Inputs of natural resources aggregated per accumulation and final uses category.	natural input type by accumulation and final uses categories
s	Column vector recording the total additions to stocks of products and materials for treatment.	products by one
$\mathbf{S^+}$	The formation of fixed assets and the change in inventories at the end of the accounting period. S+ should not be confused with **ΔS**. $\mathbf{S^+}$ is the stock formation and change of inventories on the use side, whereas **ΔS** is a calculated balancing item on the supply side.	products by types of stock formation and change of inventories
U	Products uses aggregated per human production activity (intermediate consumption).	products by activities
V	Products supplies aggregated per human production activity (intermediate deliveries). $$\mathbf{V} = \mathbf{V_C} + \mathbf{V_R} + \mathbf{V_W}$$ with $\mathbf{V_C}$, $\mathbf{V_R}$ and $\mathbf{V_W}$ representing supplies of products originating from feedstock of products, feedstock of natural resources and feedstock from materials for treatment, respectively.	activities by products
w	Column vector recording the total materials for treatment supplies in a PST or uses in a PUT within all human activities. $$\mathbf{W_{PST}} = \mathbf{W_{V,a}} \cup \mathbf{W_{v,f}} \cup \mathbf{N_W}$$ $$\mathbf{W_{PUT}} = \mathbf{W_U} \cup \mathbf{E_W}$$ $$\mathbf{w} = \mathbf{W} \times \mathbf{i}$$	materials for treatment categories by one
$\mathbf{W_U}$	Materials for treatment used aggregated per waste treatment activity. It records the use of materials for treatment by domestic waste treatment activities.	materials for treatment categories by activity
$\mathbf{W_{V,a}}$	Materials for treatment supplied per production activities. The supply of a material for treatment represents an output flow from a human activity that remains in the technosphere, but cannot displace another principal product of an activity.	materials for treatment categories by activity
$\mathbf{W_{V,f}}$	Materials for treatment supplied aggregated per accumulation and final uses category. The distinction between $\mathbf{W_V}$ and **ΔS** is made by using product life times (which can change over time).	materials for treatment categories by accumulation and final uses categories
x	The sum of supplied products in a PST or used products in a PUT for all human activities.	products by one
Y	Products used by individual households or the community to satisfy their individual or collective needs and wants.	products by final consumption categories

The PST and its monetary counterpart (MST) differ in a number of ways. The physical matrix V only records the output of physical commodities, while the monetary counterpart includes all transaction of goods and services. The PST records residuals (in **ΔS**, **W** and **B**), whereas the monetary counterpart only records residuals which are sold on the market. (Hoekstra, 2005; Merciai et al., 2011)

The PUT and its monetary counterpart (MUT) differ in a number of ways. Similarly to the supply tables, the monetary use table contains information on all goods and services, while the physical use table only includes physical commodities. Furthermore, the non-industrial inputs are different: primary inputs (compensation of employees, net taxes on production, consumption of fixed capital, net operating surplus and taxes and subsidies) in the MUT and raw materials in the PUT. (Hoekstra, 2005)

Following formulas are used in the balancing and other general calculations with a PSUT. On the supply side:

$$\mathbf{\Delta S} = \mathbf{\Delta S_a} \cup \mathbf{\Delta S_f} \qquad \text{(eq. 7)}$$

$$\mathbf{W_V} = \mathbf{W_{V,a}} \cup \mathbf{W_{V,f}} \qquad \text{(eq. 8)}$$

$$\mathbf{B} = \mathbf{B_a} \cup \mathbf{B_f} \qquad \text{(eq. 9)}$$

$$\mathbf{g'} = \mathbf{g'_a} \cup \mathbf{g'_f} \qquad \text{(eq. 10)}$$

$$\mathbf{s} = \mathbf{\Delta S} \times \mathbf{i} \qquad \text{(eq. 11)}$$

$$\mathbf{w} = \mathbf{W_V} \times \mathbf{i} + \mathbf{N_w} \times \mathbf{i} \qquad \text{(eq. 12)}$$

$$\mathbf{b} = \mathbf{B} \times \mathbf{i} \qquad \text{(eq. 13)}$$

$$\mathbf{g} = \mathbf{V} \times \mathbf{i} + \mathbf{\Delta S'} \times \mathbf{i} + \mathbf{W'_V} \times \mathbf{i} + \mathbf{B'} \times \mathbf{i} \qquad \text{(eq. 14)}$$

$$\mathbf{x} = \mathbf{V'} \times \mathbf{i} + \mathbf{N_c} \times \mathbf{i} \qquad \text{(eq. 15)}$$

and on the use side:

$$\mathbf{R} = \mathbf{R_a} \cup \mathbf{R_f} \qquad \text{(eq. 16)}$$

$$\mathbf{g'} = \mathbf{g'_a} \cup \mathbf{g'_f} \qquad \text{(eq. 17)}$$

$$\mathbf{w} = \mathbf{W_U} \times \mathbf{i} + \mathbf{E_w} \times \mathbf{i} \qquad \text{(eq. 18)}$$

$$\mathbf{r} = \mathbf{R} \times \mathbf{i} \qquad \text{(eq. 19)}$$

$$\mathbf{g} = \mathbf{U'} \times \mathbf{i} + (\mathbf{S^+} \cup \mathbf{Y})' \times \mathbf{i} + \mathbf{W'_U} \times \mathbf{i} + \mathbf{R'} \times \mathbf{i} \qquad \text{(eq. 20)}$$

$$\mathbf{x} = \mathbf{U} \times \mathbf{i} + \mathbf{S^+} \times \mathbf{i} + \mathbf{Y} \times \mathbf{i} + \mathbf{E_c} \times \mathbf{i} \qquad \text{(eq. 21)}$$

The supply and use side are balanced, from both the products (eq. 22) and activities (eq. 23) perspectives: (Hoekstra, 2005; Merciai et al., 2011)

$$\mathbf{V'} \times \mathbf{i} + \mathbf{N_c} \times \mathbf{i} = \mathbf{q}_{\text{PST}} = \mathbf{q}_{\text{PUT}} = \mathbf{U} \times \mathbf{i} + \mathbf{S^+} \times \mathbf{i} + \mathbf{Y} \times \mathbf{i} + \mathbf{E_c} \times \mathbf{i} \qquad \text{(eq. 22)}$$

$$\mathbf{V} \times \mathbf{i} + \mathbf{\Delta S'} \times \mathbf{i} + \mathbf{W'_V} \times \mathbf{i} + \mathbf{B'} \times \mathbf{i} = \mathbf{g}_{\text{PST}} = \mathbf{g}_{\text{PUT}} = \mathbf{U'} \times \mathbf{i} + (\mathbf{S^+} \cup \mathbf{Y})' \times \mathbf{i} + \mathbf{W'_U} \times \mathbf{i} + \mathbf{R'} \times \mathbf{i} \qquad \text{(eq. 23)}$$

Equation 23 can be subdivided into an activity balance for production activities (eq. 24) and an activity balance for accumulation and final uses (eq. 25):

$$\mathbf{V} \times \mathbf{i} + \mathbf{\Delta S'_a} \times \mathbf{i} + \mathbf{W'_{V,a}} \times \mathbf{i} + \mathbf{B'_a} \times \mathbf{i} = \mathbf{g_a} = \mathbf{U'} \times \mathbf{i} + \mathbf{W'_U} \times \mathbf{i} + \mathbf{R'_a} \times \mathbf{i} \qquad \text{(eq. 24)}$$

$$\mathbf{V} \times \mathbf{i} + \mathbf{\Delta S'_f} \times \mathbf{i} + \mathbf{W'_{V,f}} \times \mathbf{i} + \mathbf{B'_f} \times \mathbf{i} = \mathbf{g_f} = (\mathbf{S^+} \cup \mathbf{Y})' \times \mathbf{i} + \mathbf{R'_f} \times \mathbf{i} \qquad \text{(eq. 25)}$$

The system of a PSUT is based on the basic principles illustrated in **Figure 10** and **Figure 24**. For any generic activity, the material inputs consisting out of products, materials for treatment and natural resources are balanced by the material outputs consisting out of products, emissions, materials for treatment and stock additions. The domestic economy of Flanders can be seen as a complex system of different (but al balanced) activities. As every individual activity is balanced, the whole system is balanced too. (Schmidt et al., 2012)

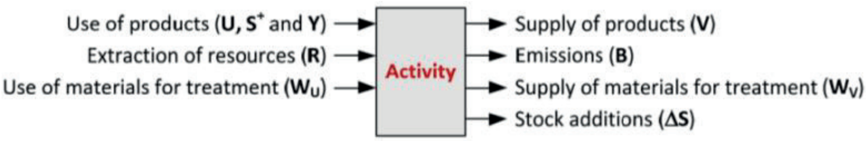

FIGURE 24: THE INPUT AND OUTPUT FLOWS FOR A GENERIC ACTIVITY.
(SOURCE: SCHMIDT ET AL., 2012)

In practice, there exists two main pathways for developing a PSUT. One is based on the price information relationship between the material flows and corresponding money flows and requires MSUT and additional information on prices per mass unit. The other one is based on a material intensity relationship and requires physical data on resources, emissions, product compositions, etc. While the first method starts from a MSUT (combined with extra data) and converts it into physical data to compile a PSUT, the second method starts from gathering physical data and builds a PSUT from scratch (**Figure 25**). Physical data should be used instead of monetary data if available. (TRITEL & CE Delft, 2013)

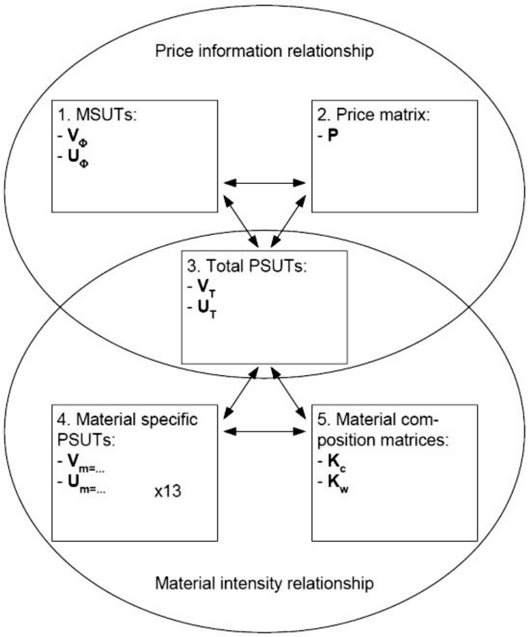

FIGURE 25: DATA SOURCES AND INTERRELATIONSHIPS BETWEEN ACCOUNTS AND MATRICES TO DEVELOP A PSUT.
(SOURCE: SCHMIDT ET AL., 2010)

Product and industry dimensions are balanced, making a PSUT a good accounting framework. Equation 22 states that the supply and use totals of production, accumulation and final use are equal. Equation 23 states that the total supply and use of industries match. To produce a balanced account, human and animal metabolism balances are included. It should be clear that the constructing of a PSUT requires data from a variety of sources: production statistics, international trade statistics, labour accounts, waste statistics, capitals accounts and consumer spending statistics. During the construction process, the balancing restrictions force comparison and adjustment of the data. (Hoekstra, 2005; Schmidt et al., 2010)

A default PSUT is based on information of the accounting period only. This implies assumptions regarding mass flows from previous and future accounting periods. For example, the supply of materials for treatment from degradation of stocks built up previous years is assumed to equal the formation of stocks in the accounting period assuming a steady state economy as no net stock **accumulation** or depreciation will occur (Δ**S**=0). However, in most economies the modelling of material flows includes an accumulation of materials (Δ**S**>0). Better estimation can be carried out by using time series data. The FORWAST project[6] (deliverable 2-3) suggests two methods for estimating current anthropogenic stocks: a direct estimation of stock increases and decreases and an estimation of stocks via commodity flows and lifetime. (Schmidt et al., 2012) (Daxbeck et al., 2009)

The technique of **balancing items** depicts the matrices Δ**S** and $\mathbf{W_V}$. These matrices are used as the balancing item in constructing a PSUT, mainly because of their limited data availability. The total amount of $\Delta\mathbf{S} + \mathbf{W_V}$ is calculated based on the mass balancing principles of a PSUT. The use of transfer coefficients enables the specification of $\Delta\mathbf{S} + \mathbf{W_V}$ in terms of the product composition (**Figure 26**). The material composition of products can be traced by using the information embodied in the transfer coefficient matrices. These matrices denote the proportion of a certain input that is present in a product and is necessary for calculating the materials for treatment and stock additions. The methodology is explained in deliverable 3-3 of FORWAST and deliverable 4-1 in CREEA[7]. Three transfer coefficient matrices are used in a balanced PSUT: a product transfer coefficient matrix, a resource transfer coefficient matrix and a materials for treatment transfer coefficient matrix. The transfer coefficient matrix specifies for each input used by an activity, how much of this is present in the products, emissions or materials for treatment plus stock additions supplied by the activity. The concept of transfer coefficients is illustrated in **Figure 26**. (G. & H., 2010; Schmidt et al., 2012; Schmidt et al., 2010)

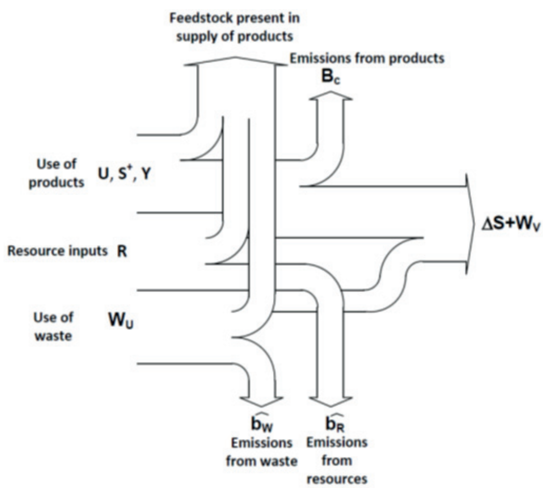

FIGURE 26: PRINCIPAL FATE OF ANY INPUT TO AN ACTIVITY DETERMINED BY TRANSFER COEFFICIENTS.
(SOURCE: SCHMIDT ET AL., 2012)

[6] http://forwast.brgm.fr/
[7] http://www.creea.eu/

1.3.3 Distinction between primary and secondary materials

Another important concept in physical accounting is the ability to distinct between virgin material resources and **secondary materials**. **Figure 27** illustrates that this distinction between virgin production and reprocessing of secondary materials modelled via a technical subdivision of the producing activity. The input to the re-processing activity are secondary materials which are generated by the waste generating activity. In some cases the generated material are of such a quality that sorting/cleaning is required before re-processing. This is modelled via service inputs to the waste generating activity from a recycling activity. (Schmidt et al., 2012)

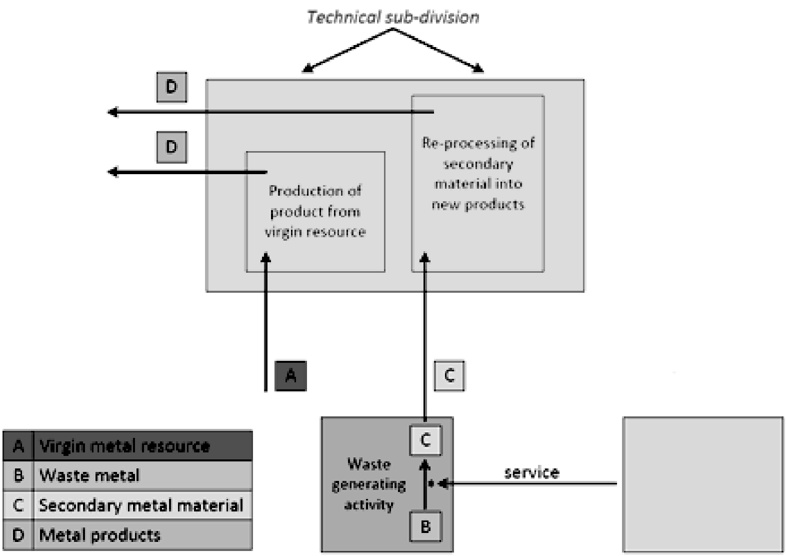

FIGURE 27: TECHNICAL SUBDIVISION TO SEPARATELY RECORD VIRGIN PRODUCTION AND PRODUCTION FORM SECONDARY MATERIALS.
(SOURCE: SCHMIDT ET AL., 2012)

This modelling requires a point of substitution: where an output of a re-processing activity can substitute a principal products of one other activity in the SUT. Only the activities before the point of substitution will be affected and need to be disaggregated (illustrated in **Figure 28**) to allow a separate and complete modelling of the recycling activity. The activity before the point of substitution is disaggregated into a production activity with virgin materials and a service activity having inputs of materials for treatment and providing the goods from recycled sources that can substitute virgin materials. (Schmidt et al., 2012)

Waste treatment activities provide services requiring inputs of materials for treatment. An intermediate waste treatment activity is defined as a waste treatment activity that supplies residuals generated from the use of residuals. A final waste treatment activity is defined as a waste treatment activity that does not supply any residuals originating from the use of residuals. In intermediate waste treatment activities there is no or limited accumulation of residuals originating from residual inputs. In final waste treatment activities there is no supply of residuals originating from residual inputs, because the residuals supplied to a final waste treatment activity remain within the activity (build-up of stocks, e.g. landfill). (Schmidt et al., 2010)

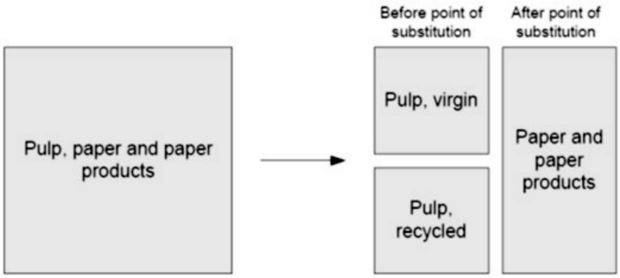

FIGURE 28: DISAGGREGATION OF ACTIVITIES BY POINT OF SUBSTITUTION TO MAKE A DISTINCTION BETWEEN VIRGIN AND SECONDARY MATERIAL INPUTS.
(SOURCE: SCHMIDT ET AL., 2012)

As in the EW-MFA **losses** can be recorded in the accounts. Losses occur at different stages of production and refer to the quantity of natural resources that have entered the economy and products that are not available for supply or use within the economy. The difference in recording losses between an EM-MF account and a PSUT is that the PSUT is able to include all losses in more detail and relating them to specific industries or products. The most common losses included are: losses during extraction/abstraction, losses during distribution/transport, losses during storage, losses during conversion/transformation and losses due to theft. In the PSUT losses are recorded as a separate category of residuals to nature. (Alfieri & Gravgård, 2009)

1.3.4 Data

Accurate data is essential for constructing any MFA-model. One measure of data (in)accuracy is the (in)consistency of mathematical models describing a system. A PSUT provides an ideal framework for ensuring consistency of data obtained from different sources and (rough) assumptions. As the model structure is known, it depends on measured data which is inherently uncertain. Data reconciliation is a technique that has been developed to improve the reliability of measurements by reducing the effect of random errors in the data. It makes explicitly use of mass balance identities and obtains estimates of the variables by adjusting measurements so that the estimates satisfy the mass balance constraints. The reconciled estimates are expected to be more accurate than the original measurements and are also consistent with the known relationship between variables as defined by the constraints. (Hernandez-Rodriguez et al., 2012)

All relevant information concerning data uncertainty can and should be incorporated in the model to estimate a consistent PSUT considering data uncertainties. Such information includes data like measured values boundaries, constraints related to product or activity totals, information on empty cells and information on measurement errors (illustrated in **Figure 29**). (Hernandez-Rodriguez et al., 2012)

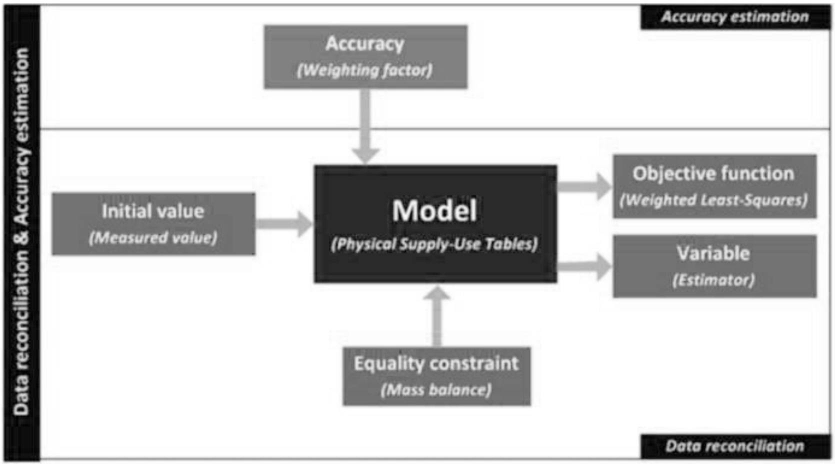

FIGURE 29: DATA SOURCES AND INTERRELATIONSHIPS BETWEEN ACCOUNTS AND MATRICES. (SOURCE: SCHMIDT ET AL., 2010)

The compilation of a PSUT is mainly driven by the availability of statistical data. It originates from different sources and is in some cases obtained from rough assumptions. The compilation requires combining several types of data. It is compiled by using mass data for products and requires process-specific data on a number of items to convert monetary data into masses to cope with missing data. All the data aforementioned are intrinsically uncertain and convey errors. (Hernandez-Rodriguez et al., 2012)

If all data sources are available or can be estimated without implausible assumptions one can start building a PSUT. Several techniques are used during the modelling and balancing of a PSUT. These techniques include accumulation, balancing items, secondary materials, waste treatment activities and losses. These techniques are explained in following paragraphs.

1.3.5 Indicators

Because of the detailed structure of a PSUT and its complete coverage, a large number of indicators or descriptive statistics can be obtained from it. Next to the EW-MFA indicators which can also be derived from a PSUT, statistics per sector and per product (group) can be calculated.

From the physical flow accounts total flows such as flows of emissions and solid waste for the economy for the whole economy, for individual industries or for households can be obtained. Descriptive statistics on the structure of different flows and stocks are obtained from the accounting structures. Because the accounting structures are complete in their coverage on economic units, shares of different variables can be derived. (United Nations et al., 2014) In contrast to indicators derived from PIOTs, it is not possible to estimate embodied impacts across value chains from PSUTs.

1.4 Physical input-output tables (PIOT)

Finally, the physical input-output tables (PIOT) are discussed. A PIOT consists of matrices describing the total material flow into, inside and out of the economy. Like EW-MFA and PSUT, the system is incorporated in a broader environmental system (L'Abbate, 2012) and all material flows between the economic system and the environment are recorded. Also, as in a PSUT, the PIOT provides a framework in which all the physical flows are recorded (Hoekstra & van den Bergh, 2006). Whereas a PSUT is better suited in an accounting perspective, it most often needs to be converted into a PIOT to address analysis on environmental issues. (Hernandez-Rodriguez et al., 2012)

The framework of a PIOT provides a comprehensive description of anthropogenic material flows following the material balance principle with the economic system embedded in the larger natural system. It describes all material flows between the economic and the natural system and opens the black box of the domestic economy illustrating the flows between the different sectors and to various types of final consumption categories within an economic system. (Giljum & Hubacek, 2009)

The PIOT registers flows of physical products, extraction of materials from nature, the supply and use of wastes and residual, emissions to nature and stock changes. Furthermore, a PIOT can use the same classification schemes for production activities as the MIOT. This makes the hybrid combination of PIOT-MIOT suitable for environmental-economic analysis. (Hoekstra, 2005; Hoekstra & van den Bergh, 2006)

Studies and research regarding the material flows between different economic sectors and from these to the biosphere become more important. Physical input-output accounting makes it possible to illustrate, model and analyse intersectoral material and energy exchanges between different economic sectors and between these sectors and the biosphere. (De Marco et al., 2009; Gravgård & de Haan, 2009)

1.4.1 System description

The input-output analysis takes on a meso-perspective to analyse the economy-environment relationship. Concerning the flows of intermediary products within the economy, PIOTs are directly comparable to MIOTs, but with the products of the intra-industry trade listed in physical units instead of monetary units. The most wide-ranging extension of PIOTs compared to MIOTs is the inclusion of the environment as a source of raw materials on the input side and as a sink for residuals on the output side of the socio-economic system. (Giljum & Hubacek, 2009)

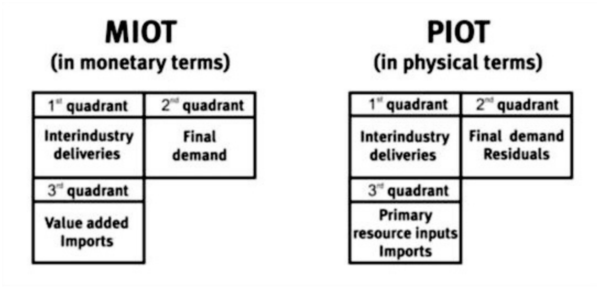

FIGURE 30: BASIC STRUCTURE OF A MONETARY INPUT-OUTPUT TABLE (MIOT) AND A PHYSICAL INPUT-OUTPUT TABLE (PIOT).
(SOURCE: HUBACEK & GILJUM, 2003)

One of the aims of a PIOT-analysis is to calculates the amount of waste and materials for treatment economic activities generate and the part emitted to the environment. There are two possibilities: (a) waste may flow directly from the economic sectors to the biosphere and (b) waste may pass through economic sectors of treatment, reuse, recycling or disposal and consequently do not flow directly or entirely to the biosphere. Analysis based on a PIOT calculate this distinction and modelling can calculate the influence of for example policy instruments on waste generation (scenario-analysis). (De Marco et al., 2009)

The primary resource inputs of a PIOT only comprise data on flows measured in physical terms. Such information is especially available in the case of raw materials withdrawn from nature like water flows, air components and solid materials. Other inputs originate from foreign economies (imports). The intermediate deliveries consist of domestic products and residuals which are recycled or treated in environmental protection facilities. The outputs consist of products for final demand and residuals. In general, the outputs of service activities comprise only residuals. As a consequence, the importance of the service sector in the whole economy is not reflected in a physical framework. The final uses consist of domestic final consumption (durables and non-durables), investments, stock changes and exports. (Giljum & Hubacek, 2009; Stahmer, 2000)

Pedersen and Deveci (2014) wrote a technical implementation report on the construction of a PIOT for Denmark. The construction process involves five steps (Figure 31):

1. initial filling in of source data to the PSUT;
2. estimation of lacking information on uses of products;
3. balancing of sub PUSTs for groups of products/materials;
4. final overall balancing of the complete PSUT; and
5. transforming the sub PSUTs and the complete PSUTs into corresponding PIOTs.

They use a detailed MSUT as the skeleton to which all the physical data is attached and aligned. In addition, it is used to estimate the physical use of products in cases where no direct information is available. This typically requires a conversion from other measurements (monetary flow, volume, pieces, etc.) to mass.

In the initial phase, all available data is filled in the framework of a PSUT. Still missing gaps remain which are completed via assumptions like ‘logical’ bookkeeping identities. The balancing step includes the balancing of material flows as well as the balancing of inputs and outputs (incl. accumulation) of all actors (industries, households, etc.). If all the sub PSUTs are balanced, one is able to construct a complete balanced PSUT which can be transformed into the PIOTs. This step requires assumptions, as a PSUT does not contain information on the link between the origin and the destination of flows. A supply table presents information only on the origin of the materials, while the use tables presents information only on the destination of the materials. In contrast, the PIOTs present information on how much the material flows from one entity (i.e. a product, industry or commodity) to another entity (Pedersen & Devici, 2014). This transformation process is further explained in the next section.

Because a PIOT is constructed from a PSUT, the description of the system of a equals to the one of a PSUT. Therefore, the treatment of semi-natural systems and the residence principle is consistent with the PSUT.

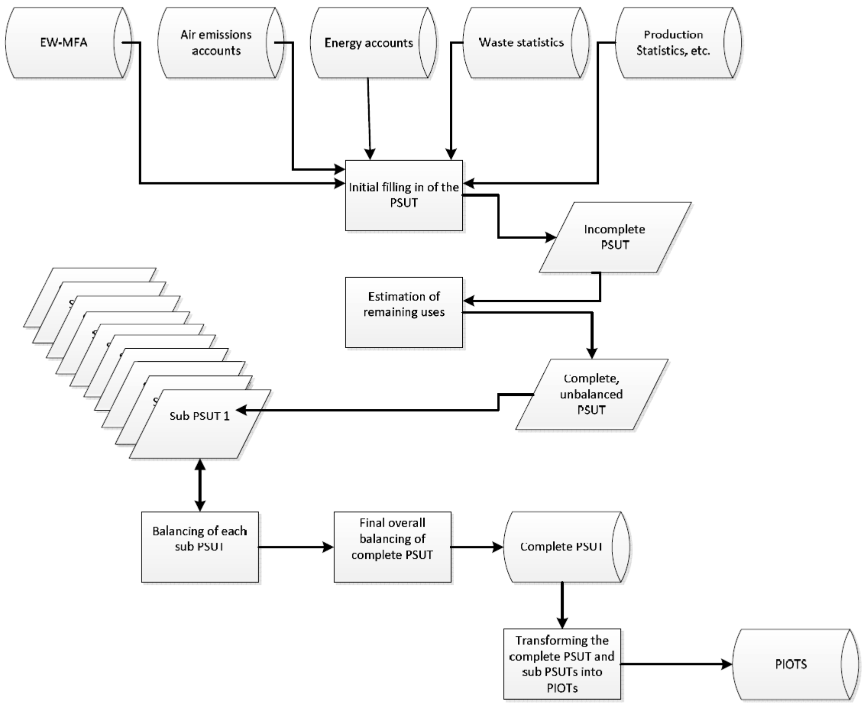

FIGURE 31: FROM ECONOMY WIDE MATERIAL FLOW ACCOUNTS (EW-MFA) TO PHYSICAL INPUT-OUTPUT TABLES (PIOT).
(SOURCE: PEDERSEN & DEVICI, 2014)

1.4.2 Material balances and modelling

Based on Konijn and Steenge (1995) and Hoekstra (2005) several methods exist for constructing symmetrical IOT from SUT. The conversion is a transformation process where SUTs are used to produce a single IOT. Hoekstra (2005) describes this process as: “Essentially, the production units in the supply table are rearranged in such a way that only values on the diagonal remain. Simultaneously, assumptions are made about the input requirements of the production units and appropriate adjustments of the use tables are made. The use matrix is thereby transformed into an IO table.”. The conversion process requires assumption on the technology or sales structure of the economy and the resulting IO table can have an industry-by-industry, commodity-by-commodity or activity-by-activity dimension. Hoekstra (2005) describes four approaches to produce symmetrical IO-tables: fixed commodity sales structure (each commodity has its own specific sales structure, irrespective of the industry by which the products is produced), fixed industry sales structure (each industry has its own specific sales structure, irrespective of the industry by which the product is produced), commodity technology (each commodity is produced in its own specific way, irrespective of the industry by which it is produced) and industry technology (each industry has its own specific way of production, irrespective of its product mix). The commodity technology and industry technology methods can be seen as transformation methods: secondary products and their (assumed) inputs are transferred from the industry that actually produces the products to the industries where the respective commodities are products as the primary product. The advantage of the commodity technology is that its assumption corresponds to the fixed coefficients assumption of the IO model. Thus, the commodity technology attaches technology to the commodities. (Hoekstra, 2005; Konijn & Steenge, 1995)

As mentioned in Hoekstra (2005) and Konijn and Steenge (1995) the leading principle in converting a SUT into an IOT is that the assumptions made in the construction of IOT is consistent with the assumptions made in the subsequent IO-analysis. An important assumption is homogeneous or heterogeneous production, especially in the way that the commodities are produced. Konijn and Steenge (1995) concluded that the IOT that will be used in traditional input-output analysis should be of the commodity-by-commodity type. But, production processes are characterised by an input structure and a set of goods (or services) produced according to that input structure. For practical use, these production processes are aggregated in activities. Thus, an activity is a set of production processes with matching structures. The input structure of an activity can be formulated in terms of commodities (describing which products are used by that activity) or in terms of activities (describing by which activities the products used by the activity are produced). (Konijn & Steenge, 1995)

A basis (P)IOT comprises three quadrants illustrated in **Figure 30**. The first quadrant shows the intermediate transactions of products between industries. Column j of this quadrant shows how many intermediate products from industry i are used by industry j. The second quadrant shows the final uses of products or residuals. This is the final output matrix. The third quadrant shows the input of primary materials and imports of the industries (except inter-industry deliveries). (Moll et al., 2006)

Schmidt et. al. (2012) described the input and output flows for a generic activity (**Figure 24**). These flows are recorded in a PIOT. The use and supply of products are recorded in the first or second quadrant if the product is used or supplied as an intermediary or as a final product, respectively. The extraction of resources and natural inputs are inputs recorded in the third quadrant. The use and supply of materials for treatment are recorded in the first quadrant. Emissions are recorded in the second quadrant. Finally, stock additions are recorded in the second quadrant (output category). Imports and exports are recorded in the third and second quadrant, respectively[8].

Direct and indirect consequences due to final demand for goods and services are analysed by the basic Leontief model. The basic Leontief model is expressed by following matrix equation: (Leontief, 1966)

$$\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1} \times \mathbf{F}\,\mathbf{i} \qquad \text{(eq. 26)}$$

With **x** the production output, $(\mathbf{I} - \mathbf{A})^{-1}$ the Leontief inverse matrix (**L**) and **F** the final demand. The Leontief inverse matrix represents the manifold and complex interactions between all industries of an economy. A column in this matrix shows how much output needs to be produced directly and indirectly by the delivering industries i to enable industry j to produce one unit of its own production output. One cell of the Leontief inverse shows how much output industry i needs to produce directly and indirectly in order to enable industry j to generate one unit of its production output. (Moll et al., 2006)

Hoekstra (2005) defines three variations of a PIOT: basic PIOT, extended PIOT and full PIOT. The basic PIOT uses a similar structure to the MIOT. In the basic PIOT production processes, final demand, primary inputs and residuals categories are defined. The extended PIOT splits the production process into two distinct parts: the structural and auxiliary production process. The full PIOT combines all aspects of material flows, such as residuals, packaging, recycling, landfilling and incineration, which are relevant to environmental accounting and policy. (Hoekstra, 2005)

While the two dimensional rectangular (product x industry) supply and use tables show separately the origin and destination of the flows, symmetric PIOTs merge this information into one single square matrix The conversion leads to an information loss since either the industry or product dimensions disappears. However, it also adds information on the connection between supply and use. The interconnected quantification of production chains presented in input-output tables serves various analytical and modelling purposes. (Gravgård & de Haan, 2009)

The framework of a PIOT presented here is based on a literature research. This research is based on PIOT studies in The Netherlands, Germany, Denmark, Italy, Finland and the EU and also from journal articles, conference proceedings and reports describing methodological or practical issues. This review covers: (De Marco et al., 2009; Dietzenbacher, 2005; Dietzenbacher et al., 2009; Eurostat, 2008; Giljum & Hubacek, 2001; Hoekstra, 2005, 2010; Hoekstra & van den Bergh, 2006; Hubacek & Giljum, 2003; Stahmer, 2000; Stahmer et al., 1996; Statistics Austria & SERI, 2011; Strassert, 2000; Weisz et al., 1998). The framework is presented in **Figure 32**.

In the PIOT, each column of production processes and final demand shows how many inputs from each industry, from imports and from the environment each industry or final use category has used. Each row of the production processes tells how much of the industry's products is used as intermediate inputs of other industries, how much is used in the final use categories and how much are exported

[8]This holds for a single-region model. In a multi-regional IO-model, inter-industry imports and exports are part of the first quadrant and final demand imports and exports are part of the second quadrant (see section 1.6 Multiregional input-output tables (MRIOT)).

and how much of its total material output had ended up as final waste or to the environment. (Mäenpää, 2004)

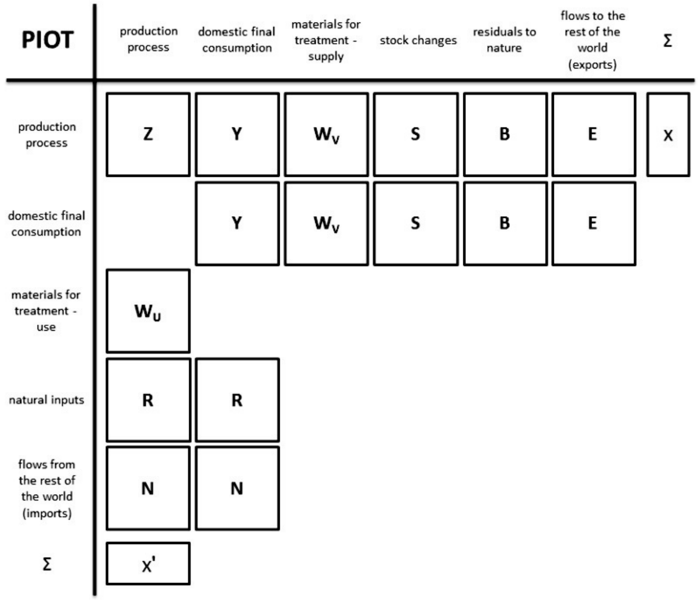

FIGURE 32: THE FRAMEWORK OF A PHYSICAL INPUT-OUTPUT TABLE (PIOT). (SOURCE: MERCIAI ET AL., 2011; SCHMIDT ET AL., 2012)

TABLE 22: DESCRIPTION OF MATRICES AND VECTORS IN A PIOT. (SOURCE: MERCIAI ET AL., 2011; SCHMIDT ET AL., 2012)

SYMBOL	DESCRIPTION	ORDER (ROWS BY COLUMNS)
$\mathbf{B_P}$, $\mathbf{B_I}$, $\mathbf{B_C}$	This emission matrix represents the output of emissions to nature by production (P), investment (I) and consumption (C) activities. Residuals emitted to nature do not have a market price (although they may represent a social cost), while the residuals supply as intermediate deliveries (materials for treatment) usually have a price. **b** is a column vector recording the total residuals to nature per category of residuals to nature. $\mathbf{b = B_P' \times i + B_I' \times i + B_C' \times i}$	Industries or final consumption categories by residuals to nature categories
$\mathbf{C_P}$	The domestic final consumption matrix $\mathbf{C_P}$ records the consumption of products per category of final consumption. It represents the use of products supplied by human production activities (products used by individual households or the community to satisfy their individual or collective needs and wants).	Industries by final consumption categories
$\mathbf{E_c}$	Matrix containing the exports of products by domestic final consumption categories per exporting region.	Domestic final consumption categories by exporting regions

$\mathbf{E_P}$	Matrix containing the exports of products by human production activities per exporting region.	Industries by exporting region
F	The investment matrix contains all purchases of durables by industries. These are auxiliary products used by human production activities to support production. It contains the formation of fixed assets.	Industries by industries
$\mathbf{N_c}$	Matrix containing the imports of products by domestic final consumption categories per importing region.	Importing regions by final consumption categories
$\mathbf{N_P}$	Matrix containing the imports of products per importing region.	Importing regions by industries
q	A column vector of the sum of supplied or used materials per human production activity. $\mathbf{x = Z'\times i + W_U'\times i + R_P'\times i + N_P'\times i = Z\times i + F\times i + C_P\times i + W_{V,P}\times i + S_P\times i + B_P\times i + E_P\times i}$	Industries by one
$\mathbf{R_C}$	Inputs of natural resources per final consumption categories.	natural input type by final consumption categories
$\mathbf{R_P}$	Inputs of natural resources per production activity.	natural input type by industries
$\mathbf{S_P}$	The change in inventories at the end of the accounting period per production activity.	Industries by one (or by stock change categories)
v	A column vector recording the total investments per industry. $\mathbf{v = F'\times i = W_{v,I}\times i + S_I\times i + B_I\times i}$	Industries by one
$\mathbf{W_U}$	Materials for treatment used per waste treatment activity. It records the use of materials for treatment by domestic activities.	materials for treatment categories by industries
$\mathbf{W_{V,C}}$, $\mathbf{W_{V,I}}$, $\mathbf{W_{V,P}}$	Materials for treatment supplied per final consumption categories, per investment industry or per human production process, respectively. The distinction between $\mathbf{W_V}$ and **S** is made by using product life times (which can change over time). $\mathbf{w = W_{V,P}'\times i + W_{V,I}'\times i + W_{V,C}'\times i = W_U\times i}$	Industries or final consumption categories by materials for treatment categories
Z	The intermediary production matrix **Z** contains all intermediary deliveries of products between human production processes.	Industries by industries

Following formulas are used in the balancing process of a PIOT:

$$\mathbf{x} = \mathbf{Z}' \times \mathbf{i} + \mathbf{W_U}' \times \mathbf{i} + \mathbf{R_P}' \times \mathbf{i} + \mathbf{N_P}' \times \mathbf{i} = \mathbf{Z} \times \mathbf{i} + \mathbf{F} \times \mathbf{i} + \mathbf{C_P} \times \mathbf{i} + \mathbf{W_{V,P}} \times \mathbf{i} + \mathbf{S_P} \times \mathbf{i} + \mathbf{B_P} \times \mathbf{i} + \mathbf{E_P} \times \mathbf{i} \quad \text{(eq. 27)}$$

$$\mathbf{w} = \mathbf{W_{V,P}}' \times \mathbf{i} + \mathbf{W_{V,I}}' \times \mathbf{i} + \mathbf{W_{V,C}}' \times \mathbf{i} = \mathbf{W_U} \times \mathbf{i} \quad \text{(eq. 28)}$$

1.4.3 Indicators

A wide variety of environmental information can be derived from a PIOT. Examples are: (Hoekstra, 2005)

- environmental pressure indicators present physical flows that are of interest to environmental policy such as GHG-emissions and waste;
- composition of products encompasses the link between macroeconomic material flows and microeconomic products providing knowledge about the composition of products which is interesting between different time periods because the substitution of inputs becomes apparent;

- element cycles in the economy providing insights into the sources, sinks and flows of certain elements;
- dematerialization indicators relating environmental flows to monetary indicators; and
- international (dependency) indicators like physical trade balances relate the domestic economy to foreign economies.

The derivable environmental information is fully dependent on the level of detail in the PIOT. (Hoekstra & van den Bergh, 2006)

Based on a PIOT, it is possible to calculate eco-profiles of sectors or product categories. Direct and indirect environmental pressure are allocated to different sectors, product categories or final demand categories. (Gerlo & Goeminne, 2005)

The combined physical and monetary accounts facilitate a composite use of physical and monetary indicators such as eco-efficiency indicators. These may be defined as output or value added generated per unit of energy or material used. A uniform application of accounting rules is an important precondition for achieving comparability and horizontal consistency between monetary and physical indicators and indicator ratio's. (Gravgård & de Haan, 2009)

Information given in a PIOT allows the connection between raw materials, energy inputs, production of goods and waste and emissions in each sector of the economy covering complex value chains. An analysis of these data helps identify priority areas to carry out strategies for natural resource management. (L'Abbate, 2012)

1.5 Monetary supply and use tables (MSUT) and monetary input-output tables

The SNA 1993 (par. 1.12) states: "The accounts of the System are designed to provide analytically useful information about the behaviour of institutional units and the activities in which they engage, such as production, consumption and the accumulation of assets. They usually do this by recording the values of the goods, services or assets involved in the transactions between institutional units that are associated with these activities rather than by trying to record or measure the physical processes directly. For example, the accounts do not record the physical consumption of goods and services by households - the eating of food or the burning of fuel within a given time period. Instead, they record the expenditures that households make on final consumption goods and services or, more generally, the values of the goods and services they acquire through transactions with other units, whether purchased or not.". Physical accounts cover a different aspect of human activities, since they record and measure the physical processes directly. A parallel can be established between this recording system and MITO to get information on e.g. material intensities per unit values. (OECD, 2007)

In contrast to its monetary counterpart, PSUTs depict different dimensions of the economy. There is a large overlap between products and residuals which have an economic value, but PSUTs also account for flows with no monetary counterpart or records the magnitude of flows when the monetary counterpart is independent of the mass of material flows (Hoekstra, 2005; Wullt, 2008). Examples are natural resources, ecosystem inputs, residuals and unused materials. Also, the value and physical flow of products is not a one-to-one relation as the prices of products can vary between different customers. Also, the waste management industry creates a uncommon situation, as (aggregated) data is difficult to interpret. The relation between the material flow is inverted in comparison to other sectors. Another unavoidable discrepancy between models is the exit of capital goods from stocks (gradual in value terms, but all-at-once in physical terms). (OECD, 2007)

Compatibility between PIOT and MIOT leads to obtain a direct relationship between indicators derived from physical flows and monetary indicators (L'Abbate, 2012). A coefficient matrix derived from a MIOT is equivalent to the one derived from a PIOT, providing that the assumption on unique sectoral prices is satisfied. However, a simple unit conversion in practice is not possible, because of the difference in construction (Sun et al., 2004).

The most important differences between monetary and physical IOT are: (Giljum & Hubacek, 2010)(Weisz & Duchin, 2006)

- the inclusion of the environment as a source of raw materials and as a sink of residuals in a PIOT, while this is only included in a MIOT via the extension tables;
- in contrary to MIOT the resource flows with no economic value are included in a PIOT;
- PIOTs are not influenced by price fluctuations improving their capabilities in time series analyses;
- domestic extraction of primary material inputs are part of the extension tables in a MIOT, but is incorporated into the factor input matrix in a PIOT; and
- the balancing identities of monetary values on the one hand and physical terms on the other hand for each of the sectors are different.

Interesting is the parallel construction of a physical and monetary IOT can improve each other's quality. Not only they both act as an integration framework for different data sources giving feedback on the quality. Also, the are based on different balancing principles, meaning they both add to the description and estimation of (partly) the same flows in the economy. (Hoekstra & van den Bergh, 2006)

Although MIOTs not directly cover all physical flows, they have application in SMM. Examples of research questions answered with the use of MIOTs are :

- What are the environmental effects of resource consumption at a subnational level? (Collins et al., 2006)
- How to build a framework for scenario analysis for sustainable food consumption? (Duchin, 2005)
- What is the potential of EE-IO models for understanding sustainable consumption and production patterns? (EEA, 2013a)
- Identification of potential focus areas (product groups and consumption domains) that might be tackled by policies in the context of resource use (material resource footprint). (EEA, 2011a)
- How to scale up material cost savings of microscale analyses of sample products to economy-wide benefits? (EMF, 2013a)
- What are the trends in resource consumption and their environmental impacts and what demonstration project about sustainable materials management need to be focussed on? (EPA, 2009)
- The development of a new resource footprint framework that combines a world IO-model with the CEENE method as exergy accounting methodology. (Huysman et al., 2014)
- The material contents of final products, and an analysis on the consequences of new technologies. (Konijn & Steenge, 1995)

- Estimate the economy-wide impacts of energy efficiency and renewable energy measures in Germany. (Lehr et al., 2012)
- Specific application of an IO-model to estimate the effect of a $20 tax per metric ton of CO2-emissions? (Perese, 2010)
- The relation between the material flows and climate impacts caused by the Finnish economy in 2002 and 2005. (Seppala et al., 2011)
- Illustration on how final consumption of goods and services in a region impacts other regions with a focus on carbon, water, land an material footprints (including a copper case). (Tukker et al., 2014)
- Identification of sectors consuming the greatest amounts of water (directly and indirectly) and analysing to what extent this resource may become a limiting factor in the growth of certain production sectors. (Velazquez, 2006)
- Quantification of the drivers for the changes in raw material consumption in terms of technology, the product structure of final demand and the volume of final demand (structural decomposition analysis). (Weinzettel & Kovanda, 2011)
- How many and which natural resources are needed to sustain modern economies? (Wiedmann et al., 2010)
- Delving beneath the top-level trends in material flow growth to investigate the structural changes in the economy that have been driving this growth. (Wood et al., 2009)

This non-exhaustive list of research questions partly indicates the potential of MIOTs in SMM. MIOTs do not have the same range in application possibilities to support SMM-policy. Some applications making use of MIOTs overlap those making use of PIOTs, but both models also have own specific application possibilities. Combining both models in hybrid accounts widens the range of applications.

1.6 Multiregional input-output tables (MRIOT)

In regional, national and international statistics, being able to trace and analyse global value chains, trade in value added and value added in trade is of great importance (Stehrer, 2012). The creation of products and services can be analysed from a worldwide perspective, while double counting is avoided in contrast to gross trade flows (OECD et al., 2013). Obviously, Flemish policy can only have an impact on the Flemish part of the value chains. Meaning, it can impact final demand by Flemish final consumers and foreign final consumption in Flanders. Besides, it can impact the Flemish agricultural, industrial and service related parts of global value chains. But to understand the Flemish contributions in internationally dispersed value chains and to know the ‘relative’ impact of policy decisions, one has to capture the whole picture including intersectoral, interregional and international trade and embedded social and environmental impacts.

De Bruyn, et al. (2004) state that the goal of an economy-wide material policy should be the relative or absolute decline of environmental impacts as a consequence of the use of materials (from cradle to grave) unrelated to the place of these impacts. So, including product specific, sector specific and country specific (economic, social and environmental) information is a necessary condition to correctly assess global value chains and related impacts. (EE-)MRIO tables, following the definition of trade in value added by OECD, WTO and

Database name	Countries	Type	Detail ($i \times p$)*	Time	Extensions	Approach
EORA	World (around 150)	MR SUT/IOT	Variable (20–500)	1990–2009	Various	Create initial estimate; gather all data in original formats; formulate constraints; detect and judge inconsistencies; let routine calculate global MR SUT/IOT
EXIOPOL	World (43 + RoW)	MR SUT	129 × 129	2000**	30 emissions, 60 IEA energy carriers, water, land, 80 resources	Create SUTs; split use into domestic and imported use; detail and harmonize SUTs; use trade shares to estimate implicit exports; confront with exports in SUT; RAS out differences; add extensions
WIOD	World (40 + RoW)	MR SUT	35 × 59	1995–2009, annually	Detailed socio-economic and environmental satellite accounts	Harmonize SUTs; create bilateral trade database for goods and services; adopt import shares to split use into domestic and imported use; trade information for RoW is used to reconcile bilateral trade shares; add extensions
GTAP-MRIO	World (129)	MR IOT	57 × 57	1990, 1992, 1995, 1997, 2001, 2004, 2007	5 (GWP), Land use (18 AEZ), energy volumes, migration	Harmonize trade; use IOTs to link trade sets; IOT balanced with trade and macro-economic data
GRAM	World (40)	MR IOT	48 × 48	2000, 2004	Various	Use harmonized OECD IOTs; neglect differences like ixi and pxp; use OECD bilateral trade database to trade link
IDE-JETRO	Asia-Pacific (8: 1975) (10: 1985–2005)	MR IOT	56 × 56 (1975) 78 × 78 (1985–1995), 76 × 76 (2000, 2005)	1975–2005	Employment matrices (2000, 2005)	Harmonize IOTs based on cross-country survey information; link via trade, manual balancing to reduce discrepancies within a certain bounds

*i = number of industries, p = number of products, **The follow-up project CREEA constructs the EE GMRIO for 2007.

TABLE 23: OVERVIEW OF MRIO-DATABASES. (SOURCE: TUKKER AND DIETZENBACHER (2013))

UNCTAD[9], capture worldwide value networks of products and services and give insights into the creation, composition[10] and destination of value added as well as to the worldwide use of material resources and environmental impacts. They provide a complete, but macro-economic, understanding on the economic impacts crucial in developing Flemish policy as well as the linkages with social and environmental impacts. (Inomata & Owen, 2014; Tukker & Dietzenbacher, 2013)

In the past, IO-tables were constructed for regions and countries serving many purposes. With the improvements in the quality and availability of data, these tables have been extended with satellite accounts including environmental and social data. In parallel, models now include a growing number of sectors and products. Globalization with higher impacts of import and export has increased interest in constructing multiregional input-output tables. Recently, these improvements have led to the development of environmentally extended multiregional input-output tables covering the whole world, meaning that many country-specific or regional IO tables are joined together and a proxy model is developed to represent the rest of the world economy (Dietzenbacher, E. et al., 2013a). Examples are: EXIOBASE[11] (Tukker, A. et al., 2009), WIOD (Dietzenbacher, E. et al., 2013b; Timmers, 2012), Eora (Lenzen et al., 2012; Lenzen et al., 2013), GTAP (Andrew & Peters, 2013; Narayanan et al., 2012), GRAM (Bruckner et al., 2012). A selection of available MRIO-databases is provided in **Table 23**.

1.7 Summary

EW-MFA and derived indicators are designed to describe the metabolic performance of economies as a basis for further analysis (Bringezu et al., 2003). EW-MFA serves as a valuable item in the toolbox of the industrial ecologist, but one should be aware of its limitation as its applications for integrated environmental-economic accounting assessments are limited. Its concept regards a national economy as a black box. EW-MFA does not provide information on material flows on the level of economic sectors, in particular on inter-industry relations, nor does it separate material inputs used for production processes from those directly delivered to final demand. It does not allow to analyse implications for resource use of structural and technological change, of changes in consumption behaviour and life-styles and of migration and urbanization (Giljum & Hubacek, 2009). However, EW-MFA and derived indicators provide a good basis for better understanding the metabolism of our economy and society focussing on current and retrospective analysis. Mainly because of: (Bringezu et al., 2003; de Bruyn et al., 2004; Eurostat, 2001; Kleijn, 2000)

- a well-developed methodology (see manuals: Eurostat, 2001, 2009, 2013);
- it provides accounts and indicators that are used in analytical exercises;

[9]Trade in value added is defined by the OECD, WTO and UNCTAD (2013) as: “a statistical approach used to estimate the sources of value (by country and industry) that is added in producing goods and services. It recognises that growing global value chains mean that a country's exports increasingly rely on significant intermediate imports and, in turn, value added by industries in upstream countries. […] The trade in value added approach traces the value added by each industry and country in the production chain and allocates the value added to these source industries and countries.” (OECD, WTO, UNCTAD, 2013, p. 9).
[10]Compensation of employees, use of fixed capital, operating surplus and taxes and subsidies (on products and production).
[11] Three versions of EXIOBASE are available (http://www.exiobase.com).

- it provides insights into the structure and change over time of the physical metabolism of economies;
- through its underlying data structure integrated with the national accounts it contributes to organise, structure and integrate available primary data and ensures their consistency;
- it is the starting point in the development of PSUTs and PIOTs;
- it provides a basic structure for the development and calculation of specific and specialized indicators;
- it traces environmental effects of consumption related to import and export and related to environment inputs and outputs; and
- it has the potential to become an instrument to integrate material flows and environmental impacts of material use into policies focussing on all phases of material use.

PSUT, and to a lesser extent EW-MFA, act as integration frameworks for different data sources. The material balance principles provide an accounting identity that forces these different data sources to be confronted. This process leads to a homogenization of classification schemes and data collection methods and may expose errors. In the process of the confrontation of data, decisions will be made about the relative quality of the data sources, which should lead to a better set of statistics. These accounts serve statistical purposes to provide an integrated framework for checking consistency and completeness of national accounts data.

A PSUT is used to assess the supplies and uses of materials and to examine changes in production and consumption patterns over time. In combination with data from monetary supply and use tables, changes in productivity and intensity in the use of natural inputs and the release of residuals can be examined. (SEEA, 2012)

PIOTs are used to identify material-intensive sectors and branches and to analyse the relationships between material use, goods produced and quantities of pollutants in various stages of production. The changes in the material intensity or material efficiency of the branches of production over time could serve as additional indicators for the development of the economy. An advantage of PIOTs is the analysis of complex value chain networks including materials flows and the indirect material burdens of production and consumption. In economic-environmental modelling the relationship between structural changes in the economy and the extraction and emissions of materials are of great importance. PIOTs and subsequent analysis render insights into the way the economic activities give rise to environmental problems and into what type of policies can alleviate them. It distinguishes between individual components of the economy, such as technology, exports, imports, consumption, stocks and investments to assess the impact of structural changes. (Hoekstra, 2005)

Building upon one another the three physical models add information from EW-MFA to PSUT to PIOT (**Figure 31** and **Figure 33**), but the investments (in time, budget and know-how) increase likewise. In general, the EW-MFA and PSUT accounts are a helpful tool for a structured gathering of information on the metabolism of an economy. The PSUT are superior to PIOT tables for accounting purposes because the data that is available to national accounts is usually provided in commodity and industry dimension. Any conversion to a symmetrical PIOT table would require adjustment of the production statistics. PSUT are further capable of recording multiple products for a single industry, while these are not directly visible in PIOT's with heterogeneous sectors. Despite the superiority of PSUT for accounting, their direct use in modelling is limited as they don't allow complete production chain analysis. The PIOT table is more attractive for modelling because of the symmetrical structure of intermediate demand, which allows the calculation of the Leontief inverse. (Hernandez-Rodriguez et al., 2012; Hoekstra, 2005; OECD, 2007)

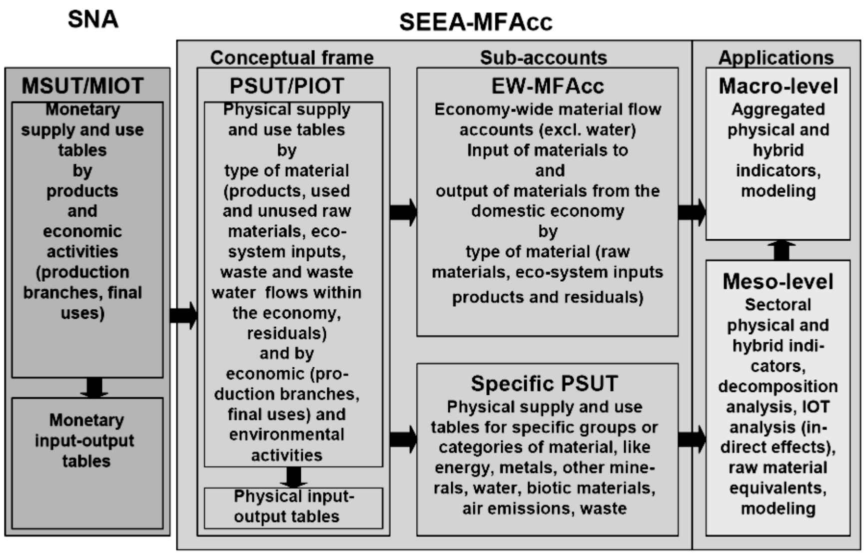

FIGURE 33: LINKING THE PHYSICAL FLOWS DESCRIBED BY SEEA TO THE MONETARY FLOWS DESCRIBED BY SNA.
(SOURCE: SCHOER AND GRAVGÅRD (2007))

Predefined pathways need to guide the data gathering process and the compilation of PSUTs and PIOTs. The goals should be clear and set in advance as one does not want to get lost into an information overload. The pathways will guide the compilation of the tables and will reduce the workload as the focus is already set. Theoretically PSUTs should include all the physical flows within the economies and the exchanges with the environment. 'Theoretically', because the idea to have complete tables is considered from the experts of UN a very ambitious target and a less stringent approach might be applied, which considers only some specific physical accounts and not all of them (Merciai et al., 2011). The principal limitation of the bottom-up approach is that it is laborious and a long time is required to obtain an overall picture of the intersectoral exchanges within the socio-economic system (De Marco et al., 2009). The time investment for building national PIOTs is estimated on 11 months FTE (first time) and 7 months FTE (routine) (TRITEL & CE Delft, 2013).

Consistent material balances for all metabolic processes in units of weight are indispensable as a database for all further studies of the physical world, but there is no quick method to produce such tables that are consistent with IO-modelling assumptions. To develop a PIOT, next steps are necessary: (Hoekstra, 2005; Stahmer, 2000)

- interregional physical material flow data on imports and exports estimated based on foreign trade statistics;

- physical supply tables based on regional PRODCOM-surveys[12], adopted foreign trade statistics, economic structure surveys and environmental statistics;
- physical use tables based on existing foreign tables and additional information of the domestic economy;
- aggregation of the supply and use table into a PIOT requiring additional economical and process knowledge;
- substance flows based on imports, production and use tables; and
- collaboration with statistical offices.

A central critique of indicators derived from physical accounts is on the interpretation of their outcome: more does not necessarily mean worse and less does not necessarily mean better. Sometimes indicators are meaningless because interpretations and results are too general. All materials that enter an economy will sooner or later become residuals, but the magnitude of material flows rarely relates linearly to the environmental impacts it causes. The critique is a consequence of the difficulties in aggregating different types of material flows to derive indicators and the weak links between MFA indicators and environmental impacts (Bringezu et al., 2003; de Bruyn et al., 2004; Giljum et al., 2006; Kleijn, 2000). The limitations of weight based aggregated indicators are: (Statistics Austria & SERI, 2011)

- large materials flows dominate derived indicators and bias interpretation of aggregated results;
- unweighted indicators do not reveal anything about environmental impacts;
- the sole focus on the reduction of aggregated resource use is a necessary but not sufficient precondition for achieving sustainability; and
- aggregation should reflect the economic usefulness of materials, while weight is not a category that reflects economic values/decisions of end-users of materials.

The relationship between mass and environmental impacts of material flows on an economy-wide basis is weak (de Bruyn et al., 2004), so one can dispute if mass-based accounts are sufficient. The answer is that for material flow analysis these accounts will provide a good basis for further analysis. However, environmental impacts related questions always require further analysis, disaggregation and conversions to other units.

1.8 Critical reflection

This dissertation will build upon input-output databases and analysis. The advantages and opportunities of using this model will be shown in the range of applications found in the literature described in Chapter 1 and 2 and shown in Chapter 3 and following of this dissertation. However, it is crucial to understand the shortcomings of the IO-model and IOA, to keep them in mind and do not make mistakes against them. A first major limitation faced by input-output analysis is that its framework uses constant technical coefficients of production (fixed production recipe). This assumption holds in a stationary economy, but implies it cannot handle large shocks or forecasting. Because large shocks (e.g. large final demand changes) would require changes in inter-industry relations, substitutions, non-linear

[12]Prodcom provides statistics on the production of manufactured goods. The term comes from the French "PRODuction COMmunautaire" (Community Production) for mining, quarrying and manufacturing: sections B and C of the Statistical Classification of Economy Activity in the European Union (NACE 2) (Eurostat, 2016).

production changes, price adjustments, etc. The rigidity of the IO-model does not reflect such phenomena.

Also, the IO-model is a macro-economic model. It is not suited for micro-economic analysis. It is a simplified model representing an economy. The available level of detail in product and sector classification is given. Applying sector or product disaggregation should be done with caution, in order not to multiply errors and increase the uncertainty of the results.

Finally, an IO-model puts emphasis on the production side of an economy with exogeneous final demand. The impact of a (small) change in final demand can be estimated, however, the model is not capable of judging the production feasibility thereof. For example: Are there sufficient resources available? Are extra investments required to increase production?

Next to the potential pitfalls of IOA, the models and accompanied methodologies described in this chapter do not always match. For example, differences in definitions and notation, different system boundaries (e.g. difference in using the territorial or the residence principle, even complicated by exceptions on these principles), etc. Therefore, one cannot cherry-pick from different methods. Recommended is to strictly follow one method and be very careful when combining methods.

CHAPTER 2

2. Policy needs to be covered by EE-IO capabilities

This chapter is redrafted from the manuscript in revision Vercalsteren A., Christis M., Geerken T., & Van der Linden A. (2016). Policy needs to be covered by EE-IO capabilities. Submitted to Economic Systems Research.

KEY MESSAGE

A lack of evidence indicating that insights based on input-output analyses have been used in political decision-making, reveals unused potential. The paper addresses the types of application of input-output analysis relevant for (environmental) policy based on scientific literature. Which applications are relevant for environmental policy? A case-study on Flanders (Belgium) building upon interviews with policy makers gives an overview of opportunities for using input-output analysis for environmental policy purpose giving insights in how to optimize the uptake of EE-IO in policy steps.

The extended literature review provides an overview of the applications of IOA supporting environment-related policies focusing on methodologies and database usage. The overview is structured in a matrix and supplemented with the interviews. These combined insights give clear steps forward on how the uptake of EE-IO in policy processes can be optimized.

The improvements and optimization in the uptake of EE-IO in policy processes is accompanied by an increased acceptance of IOA results. An increase in research questions triggered by policy demand, will help in better and increased access to data improving IO-models and IOA.

Highlights

- The paper addresses different types of application of IOA relevant for (environmental) policy based on a scientific literature review.
- Building upon interviews with policy makers, the paper gives an overview of opportunities for using IOA for environmental policy purposes, providing insights in how to optimize the uptake of EE-IO.
- The extended literature review provides an overview of the applications of IOA supporting environment-related policies focusing on methodologies and database usage.
- The paper links applications of IOA to the DPSIR framework and the different steps in the policy cycle. IOA is found to be useful in all stages of the DPSIR framework an all steps of the policy cycle, although ex-ante research question are not often addressed.

Keywords

- Environmentally extended input-output analysis
- Environmental policy application
- Policy cycle

Acknowledgments
The paper followed from a study 'Onderzoek naar beleidstoepassingen van milieu input-output modellen' [in dutch] (2015) commissioned by Flanders Environment Agency (VMM-MIRA; https://en.vmm.be/).

2.1 Abstract

In literature there exists little evidence and knowledge of the extent to which environmentally extended multiregion input-output studies actually contribute to political decision-making and (environmental) policy formulation. This paper provides a structured overview of reported applications of environmentally extended input-output tables in environmental context, either initiated by questions from policy makers or demonstrated by researchers. The applications are structured according to their scope and scale, the coverage of the DPSIR environmental policy framework (driving forces, pressures, state, impact, response), and the type of application (problem analysis/agenda setting, ex ante and ex post/monitoring). Results from interviews with policy makers (Belgium) show both their interest in input-output modelling as well as specific needs they have to make it more useful in their own context. New experimental models already allow to show applications and by doing so encourage the further development of internationally recognized input-output models, ideally based on worldwide harmonized bottom-up statistics.

2.2 Introduction

Input-output tables exist already for a long time. Since Leontief published his article on 'Quantitative input-output relations in the economic system of the United States' (Leontief, 1936), input-output analysis became an important tool for economists. Meanwhile important developments have taken place with regard to the availability of input-output tables and to their increasing variety in applications. While input-output tables were traditionally used by economists, they have emerged into a valuable tool also for other sciences, such as environmental sciences, through including other kind of information in so-called extension tables (Rose, A. & Miernyk, W., 1989). Well-known examples of extensions are emissions of greenhouse gases (GHGs) (Acquaye & Duffy, 2010; Lenzen, 1998; Wyckoff & Roop, 1994), use of natural resources (Chen & Chen, 2011; Hubacek & Giljum, 2003; Wiedmann, T. O. et al., 2015), but also employment data (Hazari & Krishnamurty, 1970; Neuwahl et al., 2008; Park & Chan, 1989), R&D expenditures (Gu et al., 2006; Hauknes & Knell, 2009; Mohnen, 1997), etc. Another development of recent years is the increasing coverage of the global scale of input-output tables. Whereas input-output tables were used for a long time to describe national or regional economies, recent developments have been focussing on a global scale which have led to several environmentally extended multiregional input-output databases (EE-MRIO) (Dietzenbacher, E. et al., 2013a; Tukker & Dietzenbacher, 2013). Examples of MRIO-tables are: Exiobase (Tukker et al., 2013; Wood et al., 2015a), WIOD (Timmers, 2012), Eora (Lenzen et al., 2012; Lenzen et al., 2013), GTAP (Andrew & Peters, 2013) and GRAM (Bruckner et al., 2012; Wiebe et al., 2012a; Wiebe et al., 2012b).

However despite the fact that much efforts have been made on the development of environmentally extended input-output tables (EE-IO) and recent developments have led to an increasing use by (environmental) scientists, there is only little evidence indicating that insights of input-output analyses have been used in political decision-making. Wiedmann and Barrett (2013) state that "To our knowledge, an account of the extent to which policy-makers are aware of this, and whether EE-MRIO studies actually contributed to political decision-making and policy formulation has not been presented yet." An exception is the UK, where consumption-based GHG-emissions accounting is adopted in statistics.

This paper, based on a non-exhaustive inventory of applications of environmental input-output analysis (IOA) described in international scientific literature, gives an overview of the applications where IOA is used in environmental policy context, reports on needs from Flemish policy makers and also formulates recommendations on how to optimize the uptake of EE-IO in environmental policy making. The work described in the article is largely based on the work commissioned by the Flemish Environment Agency who wanted to gain insight in the different possibilities of EE-IO models with regard to environmental policy in general and Flemish policy in particular, and to estimate the usefulness of the Flemish EE-IO model for Flemish policy purposes. As the Flemish Environment Agency co-financed the development of the Flemish EE-IO model, they aim to have a maximum uptake of results and use of the model by policy makers.

The research questions addressed in this article are:

- What types of application of input-output analysis relevant for (environmental) policy are described in international scientific literature?
- Which applications are relevant for environmental policy? What opportunities do (Flemish) policymakers see for using input-output analysis for environmental policy purpose?
- How can the uptake of EE-IO in policy process steps be optimized?

The first research question focusses on applications of IOA relevant for (environmental) policy that are described in international scientific literature. Answering this question allows for structuring applications and selecting them for further examination by policy makers. The unique properties of IO-models allow for different types of applications relevant for (environmental) policy. Depending on the available extensions in IO-models different themes and aspects can be covered, such as emissions (e.g. GHG emissions), resource use (e.g. water and land), added value, jobs, etc. determining the relations to policy themes. The literature review aims to create an overview of the variety of frequently used types of applications, without the aim to achieve completeness.

The second research question assesses the needs and opportunities policy makers see for using IOA for the case of Flanders. An account of the extent to which policy-makers are aware of the relevance of EE-MRIO for policy and whether EE-MRIO studies actually contribute to political decision-making and policy formulation has not been presented yet (Wiedmann & Barrett, 2013). The same reference states "It is inherently difficult to establish a cause and effect relationship between an individual analysis based on a particular research methodology and a specific policy" and contributes to the limited public knowledge in this domain by reporting on personal experiences regarding the uptake and role of results from scientific studies in specific UK policy cases. This article's contribution is based on interviews: the needs and opportunities that Flemish policy makers see for using IOA for policy purposes were inventoried.

Finally, the paper describes the role of different stakeholders and discusses how the optimal uptake of IOA in policy making can be improved. In general the publication of research on potential applications of IOA for policy making does not guarantee the uptake by policy makers. Model developers (and database developers) make choices balancing budget limitations and data availability. These choices are not always in line with the expectations of each individual policy maker, that each has different interests. Insights gathered during the literature review and from the interviews of policy makers, as well as authors' experiences in developing IO-models lead to recommendations on how policy uptake of IOA results can be improved.

2.3 APPROACH

The approach to the literature review and the interviews as well as the formulation of recommendations to improve the uptake of EE-IO in policy making is described below.

2.3.1 Literature review

The literature search looked for international literature for the period 2005 untill present, with a focus on papers and policy reports that explicitly describe the use of IO and the link to associated environmental policy or environmental impacts of other policies. All types of IO-models (regional, national, multiregional) are included in the scope of the literature review. The search on policy related topics is based on keywords like 'policy', 'government support', 'sector organisation', 'action plan' and 'administration' and/or the research question that is adressed. Studies commissioned by policy makers as well as studies performed by own research interest having policy relevance are included.

The literature review provides an non-exhaustive overview of applications of IOA supporting environment-related policies. Applications targeting environmental effects of all kinds of policies (not only environment-specific policies) as well as socio-economic effects of environment-related policies are looked at. In other words, in the context of this paper applications are relevant if they link to environment-related policies or environment-specific effects of policies. The review comprises scientific literature, conference papers, policy documents and reports. Logically, research starting from policy questions is considered. But also research questions that have a link with policy are included. This regards analyses initiated and performed by researchers, which are interesting to policy by offering new methodological possibilities and insights.

The literature search for scientific articles is mainly focussed on journals like: Economic Systems Research, Ecological Economics, Journal of Cleaner Production, Journal of Industrial Ecology and Environmental Science and Technology. Conference papers from e.g. the annual International Input-Output Conference are checked. Next, references from EE-MRIO models are scanned as these are frequently used to compare regions and countries. It was not the intention to compile a complete overview of all policy relevant applications of IOA for statistical purposes, but only to provide a robust overview of the most common types of reported applications.

In total more than 130 articles, documents and reports are inventoried of which 85 were publicly available and based on EE-IOA (meaning based not solely on IOA but also using environmental extensions). All publicly available documents were screened in detail. Appendix A lists the sources specifying the publication year and geographical scope of the analysis. Appendix B describes the research questions and the type of EE-IO model and/or other main data sources.

The reviewed literature is structured in a matrix using 6 parameters: policy cycle phase, DPSIR framework, scope, scale, focus and policy or research driven. These parameters are described below.
The reviewed literature sources are classified according to two main characterizing features of the IOA, i) the scope of the model and ii) the policy cycle phase of the analysis. The **scope** relates to the model used for the IOA and distinguishes 3 alternatives, based on Lenzen et al. (2004):

- An autonomous economy is an IO-model in which imports are assumed to be produced using the own production recipe and impacts (Lenzen et al., 2004). It is a territorially focussed model defining a domestic single region input-output model solely based on regional data. Such a model either includes impacts related to imports by assuming that these are identical to impacts related to own production, e.g. domestic technology and emission assumption (Steen-Olsen et al., 2014), or either excludes impacts related to imports and focusses merely on territorial impacts. The latter implies trade leakages as no data on the foreign production chains is included and thus neglecting impacts occurring abroad.
- In a unidirectional trade model imports are allocated to the country of origin, and these imports are assumed to be produced in that country using a domestic production recipe (the countries are modelled like the autonomous economy). Such models make use of input-output models of different economies, but the trade link is incomplete.
- In the multidirectional trade scenario all trade volumes are assumed to be produced using the production structure of the economy of origin. A globally covered model makes use of a global multiregional input-output model and as such excludes the risk of any trade leakages. Such models capture complete value networks and global impacts, relying as much as possible on country-specific data.

To estimate consumption footprints, thus including embodied impacts, an autonomous model makes use of the domestic technology assumption. Whereas a unidirectional trade model enables the calculation of footprints without relying only on the domestic technology assumption. However, the imported products are assumed to be produced in that country using a domestic production recipe. Globally covered multidirectional trade models contain all the required data to calculate footprints. However, the available multi-regional IOTs (e.g. Exiobase, WIOD) still rely on a rest of world category. This rest of world category encompasses a modelled economy representing many countries.

Another important parameter for characterizing and classifying IOA applications is the **policy cycle phase** the IOA contributes to. In general the policy cycle distinguishes 5 steps: agenda setting, policy formulation, decision making, implementation and evaluation (Howlett et al., 2015; Parsons, 1995). Decision making is a political process step where the role of EE-IO is providing information. Implementation is an operational process step, where IO-models have no role to play. Other authors (Tukker et al., 2005) describe the policy process typically in three phases: a pre-policy phase, policy formulation and policy evaluation. The pre-policy phase is often split up in “problem definition” and “agenda setting”. In this phase new issues arise because of media attention, new research work, new political priorities and, as such, the pre-policy phase benefits from IOA in which problem or hot spot analyses are performed. Once the decision is taken to either investigate the feasibility or the development of a new policy, i.e. the phase of policy formulation is entered, IOA can play a role in policy development through a so-called ex ante analysis, by estimating for example indirect effects on employment and global warming. Once policies are active and create effects they may be evaluated by an ex post analysis where IOA also can play a role, despite the disadvantage of a few years delayed data availability. An ex post analysis typically evaluates the effectiveness of one or more specific policies. Another more generic application of IO in a policy context can be described as "monitoring", where general trends in a country or region, including underlying contributing sectors, are analysed to determine underlying explanatory factors for progress (efficiency improvements, consumption levels, structural changes in the economy) as a consequence of a set of policies or as a consequence of autonomous developments. In this paper we classify the examples found in the literature in three types of IOA for policy purposes, similar to Tukker et al. (2005), across the policy cycle: (1) problem definition (including agenda setting), (2) ex ante analysis (policy formulation, decision making) and (3) ex post analysis (policy evaluation, monitoring).

Next to the two main characterising features, other parameters are used to classify the papers. The **scale** of the analysis illustrates the focus or starting point: a country or region as a whole, sectors or product groups, or final demand categories (i.e. consumption domains). The literature review shows several examples of multiple scales within one research. For example, Tukker et al. (2014) use an EE-MRIO to calculate and compare footprints of countries. Also, this report lists emission-intensities of sector products combined with final demand expenditure. Another example is the report by (EEA, 2011a) on material resource use in Europe. This report compares material resource footprints of nations, analyses material productivity of production chains and ranks consumption areas in resource intensity.

Another classification parameter is the **DPSIR framework** defined by EEA since 1995, which includes 5 aspects: Driving forces, Pressures, State , Impact and Response. For each of the assessed literature sources the DPSIR aspects included in the analysis are identified. The DPSIR framework is useful in describing the relationships between the origins and consequences of environmental problems, but to understand their dynamics it is also useful to focus on the links between DPSIR elements. For instance, the relationship between the 'Drivers' and the 'Pressures' by economic activities is a function of the eco-efficiency of the technology and related systems in use, with less 'Pressures' coming from more 'Drivers' if eco-efficiency is improving. Similarly, the relationship between the 'Impacts' on humans or eco-systems and the 'State' depends on the carrying capacities and thresholds for these systems. Whether society 'Responds' to impacts depends on how these impacts are perceived and evaluated; and the results of 'Response' on the 'Drivers' depends on the effectiveness of the Response (EEA, 1999).

The policy cycle steps describe a generic and chronological order to follow for any type of policy. The DPSIR framework, used by EEA in the context of environmental and sustainability policy, provides a better understanding of causal chains, linking environmental impacts (I) to economic driving forces (D) creating pressures (P), assessing the state (S) of the environment, and describing societal (policy) responses (R). Environmental 'problem definition' is fed by information about the state of the environment, pressures and impacts due to economic driving forces. 'Policy formulation and decision making' benefits from understanding the driving forces as well as the pressures and impacts. 'Policy evaluation' aims to observe whether the policy responses led to lower pressures and impacts and finally a better state of the environment.

Other characterizing features for each literature source included in the matrix are the **focus** (environment only or environment-economy) and whether the study addresses a **policy or research driven question**.

2.3.2 Interviews

Starting from the wide range of applications and policy areas identified in international literature, a selection is made of inspirational examples relevant for Flemish policy. This selection of inspirational examples is presented to and discussed with policy makers in bilateral semi-structured interviews. The objective of the interviews was twofold: on the one hand to make policy makers aware of the existence of IOA and its possibilities. This is covered via showing the interviewee the inspirational examples of results from IOA related to their policy domain. On the other hand, the objective was to identify and discuss relevant current policy issues and themes that may benefit from the latest state of the art of EE-IOA. In the discussion it was up to the interviewee to list questions. It was not up to the interviewee to judge the relevancy of IOA in answering these question, meaning there is no issue in a potential lack of knowledge in IOA.

The interviews had a semi-fixed structure. A PowerPoint presentation was used to guide the interview. First, the context of the study was given, together with an introduction to IOA focussing on the model and applications. The introduction was followed by the inspirational example(s) selected closely linked with the policy domain(s) of the interviewee. After this, a discussion was opened using some guiding question: "Did you already used IOA in the past?" and "Which current policy/research questions might benefit from IOA?".

The consulted policy organisations (mainly administrations) cover the different Flemish policy competences: Department of Agriculture and Fisheries, Department of Environment, Nature and Energy, Public Waste Agency of Flanders, Flemish Environment Agency, Flanders Social and Economic Council, Research Centre of the Government of Flanders, Flemish Energy Agency and Policy Research Centre on Sustainable Materials Management. The interviews focused on relevant applications, needs and opportunities for the respective Flemish (environmental) policy makers related to IOA. The potential of IOA was proven by giving specific (international) examples in the policy area of the interviewee. Relevant research and policy questions were illustrated by examples from the literature review. For example for the agriculture and food policy domain the study described in (Wiedmann et al., 2008) was presented that assesses the potential of improvement options in the meat and dairy products' value chain in terms of environmental and socioeconomic impacts. For the materials policy (EPA, 2009) was used to show the potential of IOA to identify different measures to manage materials more sustainable and start a public dialogue to create a transition towards sustainable materials management. It was discussed with the policy makers if they already applied input-output models or other macro-economic models (f.e. statistics, equilibrium models) for policy support or development. Also the question was raised which policy questions could benefit from the future use of IOA.

2.3.3. Recommendations for improvements in uptake of EE-IOA in policy making

Recommendations are based on lessons and conclusions following from the interviews and complemented by the authors' experience in building environmental extensions of the Flemish EE-IO model (Dils et al., 2012; Vercalsteren et al., 2008; Vercalsteren et al., 2011) and using EE-IO tables for policy purposes (Athanassiadis et al., 2016; Christis et al., 2016a; Christis et al., 2015; Vercalsteren et al., 2015).

2.4 Results

2.4.1 What type of applications of IOA relevant for (environmental) policy are described in international scientific literature? (Literature survey)

The matrix that structures the reviewed literature sources according to both dimensions is presented in **Table 24**. The papers are listed in *2.7 Appendix A* and *2.8 Appendix B.*

TABLE 24: THE MATRIX STRUCTURES THE REVIEWED LITERATURE SOURCES ACCORDING TO THE DIMENSIONS CATEGORY AND SCOPE (DPSIR: DRIVING FORCES, PRESSURES, STATE, IMPACT AND RESPONSE; FOCUS: ENVIRONMENT, ECONOMIC AND SOCIAL; SCALE: COUNTRY/REGION, SECTOR/PRODUCT GROUP, CONSUMPTION (FINAL DEMAND); POLICY/RESEARCH: POLICY QUESTION AND RESEARCH QUESTION).

SCALE OF ANALYSIS	SCOPE OF MODEL														
	AUTONOMOUS MODEL					**UNIDIRECTIONAL TRADE MODEL**					**MULTIDIRECTIONAL TRADE MODEL**				
	author	*DPSIR*	*focus*	*scale*	*policy/ research*	*author*	*DPSIR*	*focus*	*scale*	*policy/ research*	*author*	*DPSIR*	*focus*	*scale*	*policy/ research*
PROBLEM ANALYSIS	Alcantara and Padilla (2003)	DPR	env	s/pg	R	Collins et al. (2006)	DIR	env	fd	R	Christis et al. (2015)	DPIR	all	s/pg	R
	Choi et al. (2010)	DPIR	env-eco	s/pg	R	Dawkins et al. (2008)	DIR	env	c/r	P	Cuypers et al. (2013)	DPIR	env	c/r	P
	Dietzenbacher (2005)	DPIR	env	s/pg	R	EEA (2007)	DIR	env-eco	fd	P	Druckman and Jackson (2009)	DPR	env	fd	R
	Egilmez et al. (2013)	DPR	env-eco	s/pg	R	Huppes et al. (2006)	DIR	env	fd	R	Duchin (2005)	DPI	env	fd	R
	EPA (2009)	DPIR	env-eco	s/pg	P	Jungbluth et al. (2011)	DPIR	env	fd	P	Huysman et al. (2014)	DP	env	s/pg	R
	EPA (2013)	DPIR	env-eco	s/pg	P	Jury et al. (2013)	DPIR	env	s/pg	R	Wiebe and Yamano (2016)	DP	env	fd	R
	Jalas (2005)	D	env-eco	c/pg	R	Kerkhof et al. (2009)	DPIR	env	fd	R	Wiedmann (2009)	DPI	env	s/pg	R
	Perese (2010)	DIR	eco	s/pg	R	Nijdam et al. (2005)	DIR	env-eco	fd	P	UNEP (2015)	DPI	eco-env	c/r	P
	Tarancón and del Río (2007)	DP	env	s/pg	R	Seppala et al. (2011)	DPIR	eco	s/pg	R					
	Velazquez (2006)	DPR	env-eco	s/pg	R	Peters and Hertwich (2006)	DP	env	fd	R					
	Zbranek and Sixta (2011)	DI	eco	s/pg	R	Thomas and Azevedo (2013)	DP	env	fd	R					
						Wiedmann et al. (2006)	DI	env	fd	R					
						Weinzettel and Kovanda (2011)	DP	env	fd	R					
EX ANTE ANALYSIS	Cheong et al. (2012)	DPIR	eco-env	fd	R	EMF (2013a)	DI	eco	s/pg	R	Cui et al. (2015)	DPR	env	s/p	R
	de Souza et al. (2016)	DPI	eco-env	s/pg	R	Hoekstra and Janssen (2002)	DR	eco-env	c/r	R	Schandl et al. (2016)	DPIR	eco-env	c/r	r
	Gemechu et al. (2012)	DPIR	eco	s/pg	R	Hubacek et al. (2009)	DI	env	c/r	R	UNEP (2014)	DPIR	all	fd	P
	Hatfield-Dodds et al. (2011)	DPIR	eco-env	s/pg	R	Markaki et al. (2013)	DPR	env-soc	s/pg	P					
	Jenkins (2011)	DSI	eco	c/r	R	Martinez et al. (2013)	DPR	soc-eco	s/pg	R					
	Konijn et al. (1997)	DPI	env	c/r	R	Wilting et al. (2004)	DP	env-eco	c/r	P					
	Lenzen et al. (2013)	DP	env	c/r	R										
	Lutz and Lehr (2012)	DP	env	c/r	P										
	Su et al. (2017)	DP	eco	s/pg	R										

TABLE 25: THE MATRIX STRUCTURES THE REVIEWED LITERATURE SOURCES ACCORDING TO THE DIMENSIONS SCALE AND SCOPE (DPSIR: DRIVING FORCES, PRESSURES, STATE, IMPACT AND RESPONSE; FOCUS: ENVIRONMENT, ECONOMIC AND SOCIAL; CATEGORY: PROBLEM ANALYSIS, EX ANTE AND EX POST; POLICY/RESEARCH: POLICY QUESTION AND RESEARCH QUESTION). *(CONTINUED)*

SCALE OF ANALYSIS	SCOPE OF MODEL														
	AUTONOMOUS MODEL					UNIDIRECTIONAL TRADE MODEL					MULTIDIRECTIONAL TRADE MODEL				
	author	*DPSIR*	*focus*	*scale*	*policy/ research*	*author*	*DPSIR*	*focus*	*scale*	*policy/ research*	*author*	*DPSIR*	*focus*	*scale*	*policy/ research*
EX POST ANALYSIS	Cellura et al. (2013)	DPIR	env-eco	fd	R	EEA (2009)	DPR	env-eco	s/pg	P	Andrew et al. (2013)	DPR	env	c/r	R
	Kronenberg et al. (2012)	DIR	eco-soc	c/r	P	EEA (2011a)	DPR	env	fd	P	Arto et al. (2012a)	DPI	eco-env	c/r	R
	Lenzen et al. (2008)	DP	eco	fd	R	EEA (2011b)	DPIR	env	fd	P	Arto et al. (2012b)	DPI	eco-env	c/r	R
	Muniz (2013)	D	eco	s/pg	R	EEA (2013a)	DPR	env-eco	s/pg	P	Dietzenbacher and Serrano (2012)	DPIR	eco-env	c/r	R
	Wang, Y. F. et al. (2013)	D	env	fd	R	Michel (2013)	DIPR	env	c/r	P	Hertwich and Peters (2009)	DP	env	fd	R
	Wang et al. (2013b)	DP	env	s/pg	R	Rugani et al. (2014)	DPS	env	c/r	R	Peters and Solli (2010)	DPI	env	c/r	R
						Sissoko and Vandille (2008)	DP	env	c/r	R	Skelton et al. (2011)	DP	env	s/pg	R
						Weidema et al. (2008)	DPIR	env	fd	P	Tukker et al. (2011)	DPI	env	fd	R
						Wood et al. (2009)	DP	env	s/pg	R	Tukker et al. (2016)	DPI	env	c/r	R
											Turner et al. (2007)	DP	env	fd	R
											Wiedmann (2016)	DPI	eco-env	c/r	R
											Wiedmann et al. (2008)	DP	env	c/r	P
											Wiedmann, T. O. et al. (2015)	DP	env-eco	c/r	R
											Wiedmann and Barrett (2011)	DPI	env	fd	P
											WWF (2008)	DPI	env	fd	R

**The allocation of papers and reports in the matrix is subjected to interpretation and in case of lack of explicit information, the paper was assign to only one cell in the matrix.*

A first finding from the literature review is that most IOA are based on monetary input-output tables, only a minority uses physical input-output tables. This demonstrates that the core of most IOA is the economic structure, which shows the importance of the economic component, although this is sometimes only implicitly present. The social, e.g. employment data, and the environmental component, e.g. GHG emissions, are linked to final demand via this monetary structure. Another obvious reason for the limited use of physical input-output tables is the limited availability of physical input-output models. Only a few national models are available, e.g. Germany, Denmark, the Netherlands, Finland and Japan, and one globally covered model (Merciai & Schmidt). The recently published Exiobase v.3 also includes physical supply and use tables on a global scale (Stadler et al., 2017).

An important advantage of IO-models is their reliance on existing standards. The handbook on the System of National Accounts (SNA, 2009) covers the analytical and statistical foundation of IOA. The System of Environmental and Economic Accounts (United Nations et al., 2014) provides the conceptual framework for integrated statistics on the environment and its relationship with the economy. As a result, IO-tables have a well-described structure based on wide-spread nomenclatures which allows the combination with other statistical datasets by adding extension tables (carbon emissions, material use, etc.) or hybridization with other tools. This combination is a necessary condition in most applications. Appendix B shows that IO-models are often used in combination with other datasets. Examples of (statistical) data linked to IO-models are: LCA (e.g. Cellura et al. (2013), Duchin (2005)), energy accounts (e.g. Alcantara et al. (2013), Wang, Y. F. et al. (2013)), expenditure surveys (e.g. Thomas and Azevedo (2013), Nijdam et al. (2005)), emission data (Peters and Hertwich (2006), Hertwich and Peters (2009)), trade statistics (e.g. Jungbluth et al. (2011)), water accounts (e.g. Wang, Z. et al. (2013), EPA, 2009), deforestation data (e.g. Cuypers et al. (2013)), material extraction data (e.g. Wiedmann, T. O. et al. (2015)), employment statistics (e.g. Christis et al. (2015)), exergy (e.g. Huysman et al. (2014)) and population statistics (e.g. Wang, Y. F. et al. (2013)). Although many examples for the combination of IO-models with other datasets are found, many papers and reports don't clearly report on the model that is used for the analysis. It is recommended to authors to explicitly refer to the IO-model used, to enable others, including policy makers, to better interpret and judge the robustness of the results and conclusions.

In most of the reviewed studies a combined use of economic, social and/or environmental data was found. Often the research question addresses only one of these focus areas and conclusions focus on this area, but rarely the IOA itself is based on only one type of data. As most studies use monetary IO-models the economic core is, at least indirectly, included. If environmental and social data are relevant, they are included via extension tables. For example, Jalas (2005) analyses the energy-intensity of (changing) lifestyles. The study requires a combination of economic data on household expenditures and energy use and environmental data on sectoral energy intensities.

Different MRIO-databases are used in studies classified as using a (globally covered) multidirectional trade model (third column **Table 24**), but these are not restricted to the databases mentioned by Tukker and Dietzenbacher (2013). For example, Peters and Hertwich (2006) constructed a (globally covered) unidirectional trade model to estimate the pollution via trade for Norway. Data is collected for Norway's seven major importing partners. However, minor trading partners were given the same technology as the most similar of the major importing partners.

A widely used application of IOA is the calculation of national or regional footprints, which is followed by a more in-depth analysis of these nation-wide footprints. It helps in understanding the driving forces behind the footprints and the observed trends (e.g. by using a decomposition analysis) or in finding hot-spots in the production chains. Hot-spot analyses help in prioritizing or agenda setting. For example the study of Cuypers et al. (2013) on the global deforestation attributed (or embodied) in EU-27 consumption is linked to a.o. land-use sectors, commodities and consumption domains. Another example is found in Dawkins et al. (2008) spatializing the ecological footprint for Wales to subnational regions. The US EPA used IOA to assess trends in resource consumption and related environmental impacts to identify what demonstration projects about sustainable materials management need to be focussed on (EPA, 2009) and to identify the main drivers of environmental impacts and assess the reduction potential of specific improvement options (EPA, 2013).

Typically IOA, using the Leontief inverse, are suited to estimate embodied or indirect effects. Especially MRIO-models, which capture global value networks and impacts, allow to calculate local demand footprints with IOA. A single-region input-output model (SRIO) implies a model abstraction for foreign production chains linked to extra-regional trade (e.g. the domestic technology assumption) or, if not modelled, the exclusion of production abroad due to import and export leakages. Once a production chain requires an import or export, it is not further captured by the SRIO (e.g. Velazquez (2006)). Including the impacts of production chains of imported products (WRI & WBCSD, 2011) using EE-MRIO-models, contributes to the understanding of international value networks and allows, for example, to estimate the effects of outsourcing and globalisation (e.g. Andrew et al. (2013)). However, the researchers' attention is required to have a detailed reflection on the indicator under consideration in order to determine the optimum data model used for the estimation excercise. This will help in understanding the possible estimation errors (Christis, M. et al., 2016).

Although IOA uses static databases that do not cover the dynamic aspect when analysing impacts of, for example, taxes, applications estimating short term effects are possible and relevant. Several examples are found in the literature: Gemechu et al. (2012) studies short term price effects of the introduction of a CO2-tax, Choi et al. (2010) and Hatfield-Dodds et al. (2011) study the effect of a carbon price and Perese (2010) estimates the effect of a tax on CO2-emissions. Only few examples of dynamic IO-models are found in literature. For example, Wilting et al. (2004) assesses the effects of future technological change on Dutch production and related emissions by 2030 using a dynamic demand-driven input-output model.

Looking to applications of IOA in the context of the DPSIR classification, it is clear that the driver component is always included in IOA and often it is the starting point of the analysis. This is a logic consequence of IO-models having a monetary backbone and IOA starting from any societal production or consumption activities. As this paper focusses on environmental policy applications, either pressures or impacts are almost always included in the analysis, some studies limit to emissions only while other directly assess environmental impacts. State is rarely included in IOA, as IO-models describe flows. Nonetheless two examples were found where IO-models were used to assess the state of the environment, e.g. drought (Jenkins, 2011) and biocapacity and natural capital (Rugani et al., 2014). As the literature review focussed on policy applications, response is often addressed in the studies. As IOA are based on the Leontief inverse, demand is triggering the impacts (i.e. pressure). There are few examples where both impact and response are included.

Often authors combine different methodologies to widen the scope of the analyses and to base conclusions on. For example, Weidema et al. (2008) conduct a hybrid life cycle assessment, combining the completeness of ‘top-down’ input-output tables with the detailed modelling of ‘bottom-up’ processes from process-based life cycle assessments.

The most widely used and reported applications of IO-models refer to problem analyses. If research addresses an ex-post policy question, it more often includes monitoring than the actual impact analysis of policy. Ex-ante research questions are much less frequently reported in comparison to ex-post and problem analysis. One example of an ex-ante analysis directly related to policy is discussed in Markaki et al. (2013), where green energy investments are calculated that Greece would need to satisfy energy and environmental targets including macro-economic impacts of these green investments on production and employment in the Greek economy.

Both policy and research questions are addressed via IOA. The ratio following from the matrix in **Table 24** can’t be considered representative as the literature search specifically focused on ‘policy’ (as one of the search words). The studies addressing policy questions are often from recurring authors/commissioners like EEA, UNEP, OECD and EPA. For example a report series of EEA focusses on the potential of IOA for understanding sustainable consumption and production patterns, for identifying environmental hotspots and potential focus areas that might be tackled by resource use related policies and for analysing trends and driving forces (EEA, 2009, 2011a, 2011b, 2013a).

2.4.2 What needs and opportunities do (environmental) policy makers see for using IOA: Case of Flanders (Interviews/needs analysis)

To have a more comprehensive understanding, policy makers were interviewed to identify those applications of and analyses with EE-IO that link to current and future (Flemish) policy needs. As such an insight is gained in the needs of policy makers and subsequently opportunities are identified where IOA can answer these needs. As Flanders has specific policy domains under its authority, like waste, energy, climate, environmental monitoring, social and economic affairs, agriculture and fisheries, the competent bodies for these specific domains were inquired. Needs and opportunities are clustered according to the categories as defined in the matrix, problem analysis, ex-ante effect analysis and monitoring/ex-post analysis.

Problem analysis applications of interest to Flemish policy makers focus on analyses that link environmental, economic and social aspects, especially related to the dependence of Flanders on import. One of the interests of the Department of Agriculture and Fisheries is the import-dependence of the Flemish food industry e.g. “What would be the economic, social and environmental effect when we have to import our soya from China instead of Brazil?”. On the export side special interest was reported on the impacts from foreign policy measures that affect the Flemish production like “What could be the effect of the export ban (e.g. for apples and pears) to Russia?”. Another type of policy questions focus on the use of materials on the one hand and closing material cycles on the other. The Public Waste Agency of Flanders benefits from having information on “Which product groups and sectors are responsible for the demand of materials in the Flemish economy?”, “For which regions is this effect important?” and “Where do our recycled materials go to?”.

More general topics of interest for policy making in Flanders relate to analyses that focus on specific sectors, e.g. “Which are the most energy-intensive sectors in Flanders?” or to demand- or consumption-based assessments, e.g. “Which environmental impacts are related to consumption patterns of different types of households?”, “What is the carbon footprint and the material footprint of Flemish consumption, and are these interlinked?”. Particularly the Flemish Waste Agency and the Department of Environment, Nature and Energy are interested in this type of assessment. Flemish policy makers consider problem analysis applications to be particularly relevant for materials- and greenhouse gas-related studies. The added value of IOA is seen primarily in mapping out the level of dependence on import and providing insights into value chains, in particular the international value chains. Particularly in light of the increased attention to circular economy the additional value for policy makers also lies in the ability to do an integrated assessment linking economic aspects such as added value, with environmental aspects such as material consumption or greenhouse gas emissions, and socioeconomic aspects such as employment.

In terms of ex-ante effect analysis, Flemish policy makers consider IOA particularly relevant to assess the environmental, economic and social effects of measures on or changes to a sector, a specific consumption domain or final demand actors. For example “What is the effect of halving the output of the agriculture in terms of environmental and socio-economic impacts, on other sectors, in Flanders and abroad?” (Department of Agriculture and Fisheries), “What is the effect of an increased recycling?” (Public Waste Agency of Flanders) and “What is the effect of a change in diet?” (Department of Environment, Nature and Energy). Although relevant for policy, it is not always feasible to perform assessments related to recycling and/or secondary use of materials with IOA as the structure of most EE MRIO models doesn’t allow to focus on secondary material flows. The recent development of a hybrid MRIO model (Exiobase v.3) offers a solution as it specifically addresses recycling activities. However other topics related to the circular economy concept, e.g. the analysis of extended life times or second hand trade, are still not possible to assess with these models. Ex-ante effect analyses (of future policy) are typically interesting in those cases where an insight is required into indirect effects (throughout the preceding chain) and 2nd order effects (on other sectors of the economy), for assessing the economic as well as environmental effect of possible future policy measures.

Fewer applications, although not less interesting, that focus on monitoring and ex-post analysis were mentioned by interviewees as potentially relevant for Flemish policy. But questions like “How did the carbon footprint and material footprint of Flemish consumption evolve between 2003 and 2015?” or “What is the evolution of water consumption and water productivity in Flanders?” are still very relevant for the Flemish Environment Agency. The key themes mentioned by interviewees relate to the monitoring of greenhouse gas emissions, material consumption, greening the economy and moving to a circular economy. Although most policy targets are based on a territorial perspective, additional analyses that start from a consumption perspective give valuable insights for policy, e.g. to avoid outsourcing or to guide policy makers towards reducing the total impact of Flemish consumption (which is only an intention and not a target). Monitoring is interesting anyway, to establish the evolution of certain indicators, to investigate absolute and relative decoupling and to analyse new indicators (e.g. relating to materials or circular economy policy). Ex-post evaluation of implemented policy in a specific domain assesses whether implemented policy has led to the desired effect. Footprint calculations gain increasing interest of Flemish policy makers. They acknowledge the potential of EE-MRIO to improve the comparability of footprints between different nations. It might be more correct to compare footprints of different nations in one specific year than to monitor the evolution of footprints of a nation over different years, because the methodology behind statistics can be changed over the years. For this type of purposes the time delay of input-output models is considered a limitation, particularly for monitoring as indicators need to be available on a rather short term.

Overall the added value and thus the potential of IOA for Flemish policy formulation and decision-support mainly lies in analysing from a consumption perspective and being able to map out and investigate the global value chains in detail, delivering new additional insights by linking the environment, economy and employment. A leverage effect is achieved via a clear representation of results, for example to make use of infographics and interactive tools or indicator dashboards. As Flanders is an open economy, it is important to be able to look outside the territorial perspective and to know what Flanders imports from and exports to abroad. As well it is important to consider the effects of environmental policy in a broader context and to show the potential positive effects on both the economy and employment. Another observation that results from the interviews is that all specific policy fields would like to have a more detailed sectoral split up or new unique data to better cover the scope of the policy field (e.g. circular economy), but the question remains what policy field would cover the overall generic structure of the IO model.

2.4.3 How can the uptake of EE-IO in policy process steps be improved? (Better match policy needs and development possibilities)

Before discussing how to possibly improve the uptake of EE-IO in policy making, we provide an overview of the major actors involved and discuss the relationships between these actors. The framework presented in Figure 1 defines three actors and three relationships: (model) developers, (model) users and policy makers. Although this research question focuses on the improvement of the uptake in policy process steps (arrow 3), the uptake is influenced by all actors and relationships within this framework. The developers include the data providers (e.g. statistical offices, international research projects developing new EE-MRIO databases) and the builders of the input-output model. The (analytical) users of (EE-)IO-models combine data sources and apply methodologies (e.g. based on the Leontief inverse) to generate, analyse and interpret the results. Policy makers, both public and private, are considered to be the actors who formulate questions on problem analysis, ex ante effects of policy measures and ex post analysis/monitoring, and use the results to improve or adopt policies (uptake of results from IOA). In practice, it is possible that two or three of these actors are represented by only one person or institution.

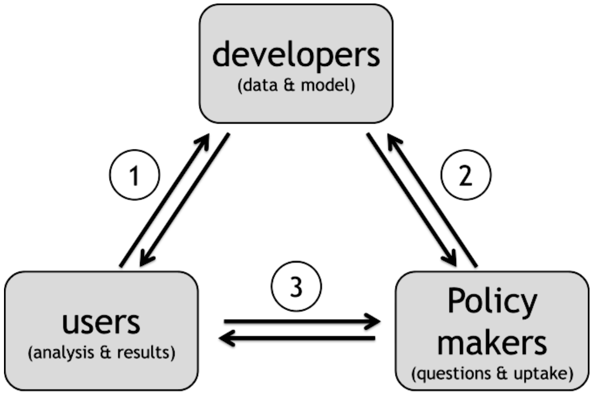

FIGURE 34: A TRIANGLE REPRESENTING THE LINKS BETWEEN DEVELOPERS, SCIENTIST AND POLICY MAKERS.

In an ideal situation three two-way feedback systems exist in this framework. The first two-way feedback system is between developers and users (arrow 1). Developers provide information on the data sources, data quality, assumptions and methodologies they apply in the construction of input-output models as these influence the interpretation of results by users. For example Eurostat, as a developer, describes in its mission statement "to provide high-quality statistical service needed to develop, implement and evaluate policies". Eurostat evidently has to serve a variety of users with different needs. Users provide feedback on model requirements to improve the usability of future input-output models.
The relation between users and policy (arrow 3) is another two-way feedback system. Users inform policy makers via the analysis and interpretation of results. Policy makers use these results to formulate, change and adopt policies. Users (can) also inform policy makers on methodological possibilities and new applications, for example, like the authors did in their interviews with Flemish policy makers.

The third two-way feedback system is the relation between policy and developers (arrow 2). Via the formulation of policy needs, policy makers inform developers on the need for policy relevant data. The development of new IO-tables by Eurostat is formalized through Regulations (EU Regulation, 2013). In turn, developers adopt and construct input-output models including new data to cover new policy needs and may keep policy makers up-to-date on the model capabilities and new model developments. Developers also consult users/policy makers on their needs prior to defining new data needs. A recent example hereof is that Eurostat as a data developer explicitly asks for feedback on current data and needs for future use from users/policy makers in the FIGARO project: "Careful checking of user needs of various European Commission's DG's for policy analyses" (Remond-Tiedrez & Rueda-Cantuche, 2016).

Several recommendations can be defined to better match policy needs and development possibilities,. First of all, in policy processes EE-IO is considered a tool and not a goal as such. To answer policy relevant research questions other models (e.g. equilibrium models) can be useful or even necessary as well. For example, post-Keynesian macro-econometric models (e.g. E3ME, GINFORS) have a core that is very similar to MRIO models, but also include variable returns to scale and non-linearities, prices and supply constraints plus time series data and baseline forecasts that allow for ex-ante analysis. They can be and are linked to bottom-up tools to assess regulations in specific sectors, in the same way that hybrid MRIO is carried out. Users can show benefits and added value from the recent development/publication of new EE-MRIO models in international research projects by adding new policy applications to the state of the art. For problem analysis the new EE-MRIO models can already be used, with a clear understanding of their limitations. Also, in the other direction, these new applications can further stimulate the development of formal consolidated internationally recognized EE-MRIO models covering the full global value chains (e.g. Exiobase v.3 was developed in an EU FP7 project fo develop and apply an optimal set of indicators to monitor European progression towards resource-efficiency). Also, developers can invest in building formal and consolidated EE-MRIO models from bottom-up statistics after consultation of users or as a result of a regulation. In a globalizing world a good international coverage is needed as well. An issue often identified as problematic is the time delay of IO-tables, in this context all efforts to reduce the time delay for publication of IO-data are very important, allowing users and policy makers to more closely follow-up the effects of policy and to fulfil monitoring purposes. Finally, policy makers could inform themselves about IO-methodologies, databases and applications and encourage it's use in research for policy purposes. Also they could consider EE-MRIO models to be part of the toolbox for impact assessment of policies.

2.5 SUMMARY

Building an EE-IO model is finding a balance between the ability to serve many different (potential) users and making the model very context specific. The literature review shows a great variety in applications that combine EE-IO models with other data models to answer context specific policy questions. The typical economic matrix structure of IO models allows an easy linking of IO models to other (environmental) datasets, which increases the range of economic, social and environmental applications. EE-IO models were found to be useful in all stages of the DPSIR environmental policy framework (driving forces, pressures, state, impact, response), even in the stage of state, despite the fact that an IO model is a flow model described by a monetary backbone in a given year.

In the interviews with Flemish policy makers from different (environmental) policy fields a variety of new needs were identified that would require further detailing, disaggregating and extending EE-IO models. Disaggregation increases the sector or product detail, which allows a more detailed analysis results on the condition that data is available for the disaggregation. Also adding more extensions (like primary material use, eutrophication and acidification gas emissions, etc.) allows a wider range of applications. Also, this is related to the advantage of using regional IO-models, as a regional IO-model can be detailed or extended depending on the regional policy focus. Still, the capability to capture complex and globalized value chains and related direct and indirect effects, is recognized as a key feature of IOA. In principle this is possible, however the challenge remains to link local datasets with international input-output databases. Only after coupling local IO-models with international IO-models, it is possible to visualise full value chains and estimate, for example, economic dependencies and footprints.

Official internationally recognized EE-IO data models, based on worldwide harmonized bottom-up statistics, often lag behind in time and level of detail compared to more experimental databases. The experimental data models already serve well for the early policy phase of problem analysis and agenda setting as their use shows the policy relevance of new issues. At the same time their use proves the importance to strengthen the international collaboration to develop harmonized worldwide statistics allowing internationally accepted EE-IO models to be developed, that increases the accuracy required especially for ex ante analysis.

The list of topics addressed in the selected international publications absolutely suggests a potential relevance for IOA in policy making. Also, given the increase in available EE-MRIO models during the last years, it can be expected that more analyses will use these models and the need to develop an additional model for a specific application will decrease. Besides the increasing availability of EE-MRIO models, several methodologies exist to link local or national statistics to these EE-MRIO models (e.g. Christis, M. et al. (2016) and Edens et al. (2015); see Chapter 3) to increase local policy acceptance. However, policy makers need scientific advice as they are not always aware of the latest methodological or database developments. Therefore, it is key to regularly inform about database updates, methodological changes and improved applications to a non-expert audience.

Given the relatively recent developments and publications of EE-IO databases and the academic need to publish, it is no surprise that in the literature review, applications of EE-IO for policy purposes are more driven by researchers than by specific requests from policy makers. The results from the interviews across Flemish policy makers also showed that to increase policy demand of IOA, having relevant international concrete policy applications at hand is more helpful than explaining the method itself. A leverage effect can be achieved by putting efforts in the clear and attractive visualisation of results (e.g. infographics).

2.6 Outlook based on Chapter 1 and 2

On basis of our analysis it is recommended that Flanders would develop a regular year-to-year EW-MFA account, following the EU-regulation No. 691/2011. It takes (based on defined framework and compilation procedure) only a limited time-investment to compile. The time lag for EW-MFA accounts to be completed would be some 4-6 months for preliminary data and some 13 months for final data from the end of the year in question. The derived indicators indicate trends and identify areas for further investments. Note that the number of stakeholders involved increases with increasing levels of aggregation and it becomes unclear who is responsible for taking action.

Not recommended for Flanders is a yearly investment in PSUTs and PIOTS as too much details in PSUTs and PIOTS hide overall trends. Furthermore, they are most useful for detailed analysis answering questions related to specific materials or impacts related to sector use and consumption patterns (Eurostat, 2001). Also at this moment, a five-yearly compilation of PSUTs and PIOTs is not recommended. First, the high data requirements and the high level of detail obstruct a wide acceptance because of data validation uncertainty and experts need to use them (Binder et al., 2009). Certainly the bottom-up and frequently compiled PSUTs and PIOTs have value in policy support, by mapping and analysing material flows. Nevertheless, the time investment is high, both in data gathering and compilation. Also, experiences in Denmark and Germany which compiled PIOTs, show that their high cost with limited use in policy did not foster further development (TRITEL & CE Delft, 2013). Finally, as Flanders is a small and open economy, import and export flows are too important. Without a physical multiregion input-output model, it is impossible to analyse material flows in globalized production networks. A Flemish PIOTs would only reveal a very small piece in the complex puzzle.

This dissertation will build upon the existing Flemish input-output tables. It will develop a new methodology to link local IO-tables to existing EE-MRIO tables and maximise the application thereof in SMM for Flanders. To extend applications in material use, it will compile Flemish EW-MFA to derive material flow indicators, but not invest in compiling PSUTs and PIOTs for Flanders. The recent developments in raw material equivalents by Eurostat will be picked up in the dissertation to include embedded primary material use (see Chapter 6). Also, this dissertation will develop a methodology of which the results can support policies on SMM.

Based on the analysis, the following conclusions and proposals can be formulated:

- ✓ **The investment in Flemish physical supply, use and input-output tables is, at this moment, not opportune, since it cannot be embedded in an existing globally covered database to include production chains of import and export flows. As long as no physical multi-region input-output database is available, the investment cost does not outweigh the benefits.**
- ✓ **The dissertation will support the construction[13] of Flemish economy-wide material flows accounts and interpretation of the results.** (see Chapter 6)
- ✓ **The dissertation will develop a methodology to embed the Flemish regional input-output model in globally covering input-output models enabling the analysis of globally spread value networks from a Flemish perspective.** (see Chapter 3)
- ✓ **The dissertation will develop applications to support sustainable materials management in Flanders building upon existing environmentally extended monetary input-output models for Flanders.** (see Chapter 5)
- ✓ **Detailing and extending the EE-IO model to apply to policy needs, especially the linkage to EE-MRIO models.** (see Chapter 3)
- ✓ **Support both the development of experimental data-models and international harmonized statistics.**
- ✓ **Create a leverage effect via supporting creative visualisation of results.**

[13]Methodologic interpretation and indicator development. The data gathering and indicator calculation is funded by the Flemish department LNE (2016) 'Indicatoren voor een groene economie. Update van datafiche en Exceltabellen DMC en RMC'.

2.7 APPENDIX A

Author	Country/ Region	Title	Year	Journal (Volume)	Pages
Alcantara V., Padilla E.	Spain	"Key" sectors in final energy consumption: an input–output application to the Spanish case	2003	Energy Policy 31 (2003)	1673–1678
Andrew R.M, Davis S.J., Peters G.P.	global	Climate policy and dependence on traded carbon	2013	Environ. Res. Lett. 8 (2013)	1–7
Arto, I., Genty, A., Rueda-Cantuche, J.M., Villanueva A., Andreoni V.	global	Global Resources Use and Pollution, Volume 1 / Production, Consumption and Trade (1995-2008)	2012		
Arto, I., Genty, A., Rueda-Cantuche, J.M., Villanueva A., Andreoni V.	global	Global Resources Use and Pollution, Volume 2 / Country Factsheets	2012		
Cellura M., Di Gangi A., Longo S., Orioli A.	Italy	An Italian input-output model for the assessment of energy and environmental benefits arising from retrofit actions of buildings	2013	Energy and Buildings 62 (2013)	97–106
Cheong B., Legoff G., Neo L., Nimpradit N., Willard L.	Australia	Input-Output tables and household effects of pricing carbon in Australia	2012	Conference proceedings: International Input Output Conference 2012	
Choi J., Bakshi Bhavik R., Haab T.	USA	Effects of a carbon price in the U.S. on economic sectors, resource use and emissions: an input-output approach	2010	Energy Policy (38)	3527–3536
Christis M. Geerken T., Vercalsteren A., Vrancken K.C.	Flanders (Belgium)	Value in sustainable materials management strategies for open economies case of Flanders (Belgium)	2015	Resources, Conservation and Recycling (103)	110–124
Collins A., Flynn C., Wiedmann T., Barrett J.	Cardiff (UK)	The environmental impacts of consumption at a subnational level: The ecological footprint of Cardiff	2006	Journal of Industrial Ecology (10)	9–24
Cui L. B., Peng P., Zhu L.	China	Embodied energy, export policy adjustment and China's sustainable development: A multi-regional input-output analysis	2015	Energy (82)	457–467

Cuypers D., Geerken T., Gorissen L., Lust A., Peters G., Karstensen J., Prieler S., Fisher G., Hizsnyik E., Van Velthuizen H.	EU27	The impact of EU consumption on deforestation: Comprehensive analysis of the impact of EU consumption on deforestation	2013	DG ENV Technical Report Technical Report - 2013 - 063	
Dawkins E., Paul A., Barrett J., Minx J., Scott K.	Wales (UK)	Wales' Ecological Footprint - Scenarios to 2020	2008		
de Souza, K., Ribeiro, L., Perobelli, F.	Brazil	Reducing Brazilian greenhouse gas emissions: scenario simulations of targets and policies	2016	Economic Systems Research (28)	482-496
Dietzenbacher E.	Germany	Waste treatment in physical input–output analysis	2005	Ecological Economics (55)	11–23
Dietzenbacher E., Serrano M.	annex B countries Kyoto protocol	How much would the Kyoto Protocol cost to consumers	2012	Conference proceedings: International Input Output Conference 2012, Bratislava	
Druckman A., Jackson T.	UK	The carbon footprint of UK households 1990–2004: A socio-economically disaggregated, quasi-multi-regional input–output model	2009	Ecological Economics (68)	2066–2077
Duchin F.	USA	Sustainable Consumption of Food , A Framework for Analyzing Scenarios about Changes in Diets	2005	Journal of Industrial Ecology (9)	99–114
EEA	EU25	Environmental Pressures from European Consumption and Production	2009	EEA, ETC working paper	
EEA	EU27	Key messages on material resource use and efficiency in Europe: Insights from environmentally extended input-output analysis and material flow accounts	2011a	ETC/SCP working paper 3/2011	
EEA	EU27	Progress in Sustainable Consumption and Production in Europe - Indicator-based report	2011b	ETC/SCP working paper 1/2011	
EEA	8 EU member states	Environmental input-output analyses based on NAMEA data: A comparative European study on environmental pressures arising from consumption and production patterns	2007	ETC/RWM working paper 2007/2	
EEA		Environmental Pressures from European Consumption and Production 2013	2013	EEA Technical report No 2/2013	

Egilmez G., Kucukvar M., Tatari O.	US	Sustainability assessment of U.S. manufacturing sectors: an economic input output-based frontier approach	2013	Journal of Cleaner Production (53)	91-102
Ellen MacArthur Foundation	EU27	Towards the Circular Economy: Economic and Business rationale for an accelerated transition	2013		
EPA	US	Sustainable materials management : the road ahead	2009	EPA publication	
EPA	US	Analysis of the life cycle impacts and potential for avoided impacts associated with single family homes	2013	EPA publication	
Garcia Muñiz A.S.	Spain	Input-output research in structural equivalence: Extracting paths and similarities	2013	Economic Modelling (31)	796-803
Gemechu E.D., Butnar I., Llop M., Amores Barrero M.J., Castells F.	Spain	The price impacts of an environmental tax on production of goods in the Spanish economy	2012	Conference proceedings: International Input Output Conference 2012	
Hatfield-Dodds, S., Feeney, S., Shepherd, L., Stephens, J., Garcia, C., Proctor W.	Australia	The carbon price and the cost of living: assessing the impacts on consumer prices and households	2011	Report to the Climate Institute prepared by CSIRO and AECOM	
Herreras Martinez, S., van Eijck J., Pereira da Cunha M., Guilhoto J.J.M., Walter A., Faaij A.	Northeast Brazil	Analysis of socio-economic impacts of sustainable sugarcane–ethanol production by means of inter-regional Input–Output analysis: Demonstrated for Northeast Brazil	2013	Renewable and sustainable energy reviews (28)	290-316
Hertwich E.G., Peters G.P.	global	Carbon footprint of nations: a global, trade-linked analysis	2009	Environmental Science Technology (43)	6414-6420
Hoekstra R., Janssen M.A.	two fictive countries	Environmental responsibility and policy in a two country dynamic input-output model	2002	Tingbergen Institute discussion paper	
Hubacek K., Guan D., Barret J., Wiedmann T.	China	Environmental implications of urbanization and lifestyle change in China: Ecological and water footprints	2009	Journal of Cleaner Production (17)	1241-1248
Huppes G., de Koning A., Suh S., Heijungs R., van Oers L., Nielsen P., Guinée J.	EU25	Environmental Impacts of Consumption in the European Union High-Resolution Input-Output Tables with Detailed Environmental Extensions	2006	Journal of Industrial Ecology (10)	129-146

Huysman S., Schaubroeck T., Dewulf J.	global	Quantification of Spatially Differentiated Resource Footprints for Products and Services through a Macro-Economic and Thermodynamic Approach	2014	Environmental Science, Technology (48)	9709−9716
Jalas M.	Finland	The everyday life context of increasing energy demands	2005	Journal of Industrial Ecology (9)	129-145
Jenkins K.	Spain	Modelling the Economic and Social Consequences of Drought under Future Projections of Climate Change	2011	dissertation	
Jungbluth N., Nathani C., Stucki M., Leuenberger M.	Switzerland	Environmental impacts of Swiss consumption and production. A combination of IO-analysis with LCA	2011	Publication of Federal Office for the Environment, Environmental studies, no. 1111	
Jury C., Rugani B., Hild P., May M., Benetto E.	Luxembourg	Analysis of complementary methodologies to assess the environmental impact of Luxembourg's net consumption	2013	Environmental Science and Policy (27)	68-80
Kerkhof A. C., Nonhebel S., Moll H. C.	The Netherlands	Relating the environmental impacts of household expenditures: An input-output analysis	2009	Ecological Economics (68)	1160-1170
Konijn P., de Boer S., van Dalen J.	The Netherlands	Input-output analysis of material flows with application to iron, steel and zinc	1997	Structural change and economic dynamics	129-153
Kronenberg T., W. Kuckshinrichs, Hansen P.	Germany	Macroeconomic Effects of the German Government's Building Rehabilitation Program	2012	Conference proceedings: International Input Output Conference 2012, Bratislava	
Lenzen M., Murray S. A., Korte B., Dey C.J.	Australia	Environmental impact assessment including indirect effects – a case study using input-output analysis	2003	Environmental Impact Assessment Review (23)	263 - 282
Lenzen, M., Wood, R., Foran, B.	Australia	Direct versus embodied energy – the need for urban lifestyle transitions (chapter 4)	2008	Urban Energy Transition	91-120
Lutz C., Lehr U., Pehnt M.	Germany	Economic impacts of energy efficiency and renewable energy in Germany	2012	20th International Input-Output Conference	
Markaki M, Belegri-Roboli A., Michaelides P., Mirasgedis S., Lalas D.P.	Greece	The impact of clean energy investments on the Greek economy: an input output analysis	2013	Energy Policy (57)	263 - 275
Michel B.	Belgium	Is offshoring driven by air emissions? Testing the pollution haven effect for imports of intermediates	2013	Federal Planning Bureau	
Nijdam D., Wilting H., Goedkoop M., Madsen J.	The Netherlands	Environmental load from Dutch private consumption: How much damage takes place abroad?	2005	Journal of Industrial Ecology (9)	147-168

Perese K.	US	Input-output model analyses: pricing carbon dioxide emissions	2010	Working paper Tax Analysis Division, Congressional Budget Office	
Peters G.P., Hertwich, E.G.	Norway	The importance of imports for household environmental impacts	2006	Journal of Industrial Ecology (10)	89-109
Peters, G.P., Solli, C.	Nordic countries	Global carbon footprints. Methods and import/export corrected results from the Nordic countries in global carbon footprint studies	2010		
Rugani B., Roviani D., Hild P., Schmitt B., Benetto E.	Luxembourg	Ecological deficit and use of natural capital in Luxembourg from 1995 to 2009	2014	Science of the Total Environment (468-469)	292-301
Schandl H., Hatfield-Dodds S., Wiedmann T., Geschke A., Chai Y., West J., Newth D., Baynes T., Lenzen M., Owen A.,	global	Decoupling global environmental pressure and economic growth: scenarios for energy use, materials use and carbon emissions	2016	Journal of Cleaner Production (132)	45-56
Seppala J., Mäenpää I. Sirkka K., Tuomas M., Ari N., Juha-Matti K., Tiina H., Marja-Riitta K., Merja S., Yrjö V.	Finland	An assessment of greenhouse gas emissions and material flows caused by the Finnish economy using the ENVIMAT model	2011	Journal of Cleaner Production (19)	1833-1841
Sissoko A.A., Vandille G.	Belgium	Quantifying environmental leakage for Belgium	2008		
Skelton A., Guan D., Peters G., Crawford-Brown D.	global	Mapping flows of embodied emissions in the global production system	2011	Environmental Science, Technology (45)	10516-10523
Su, Y.W., Yang, H.Y., Lin, C.H.	Taiwan	Increase of electricity price and energy efficiency: analysis using the macroeconomic interindustry model of Taiwan	2017	Economic Systems Research (29)	430-451
Tarancón M., del Río, P.	Spain	A combined input–output and sensitivity analysis approach to analyse sector linkages and CO_2 emissions	2006	Energy Economics	578-597

Thomas B.A., Azevedo I.L.	US	Estimating direct and indirect rebound effects for US households with input-output analysis (part 2)	2013	Ecological Economics	188-198
Tukker A., Bouwmeester M., Oosterhaven J., de Koning, A., Heijungs R.	EU27	Policy impact assessment – resources, products and imports and exports	2011	Exiopol – Technical report – Deliverable IV.2.b	
Tukker A., Bulavskaya T., Giljum S., de Koning A., Lutter S., Simas M., Stadler K., Wood R.	global	The global resource footprint of nations	2014		
Turner K., Lenzen M., Wiedmann T., Barrett J.	global	Examining the global environmental impacts of regional consumption activities – Part 1: A technical note on combining input-output and ecological footprint analysis	2007	Ecological Economics (62)	37-44
UNEP	global	Decoupling 2: technologies, opportunities and policy options	2014	A Report of the WG on Decoupling to the IRP	
UNEP	global	International trade in resources – a biophysical assessment	2015	A report produced for the UNEP-hosted IRP	
Velazquez E.	Andalusia	An input-output model of water consumption: analysing intersectoral water relationship in Andalusia	2006	Ecological Economics (56)	226-240
Wang Y., Zhao H., Li L., Liu Z., Liang S.	Beijing	Carbon dioxide emission drivers for a typical metropolis using input-output structural decomposition analysis	2013a	Energy Policy (58)	312-318
Wang Z., Huang K., Yang S., Yu Y.	Beijing	An input-output approach to evaluate the water footprint and virtual water trade of Beijing, China	2013b	Journal of Cleaner Production (42)	172-179
Weidema B.P., Wesnæs M., Hermansen J., Kristensen T., Halberg N.	EU27	Environmental improvement potential of meat and dairy products	2008	JRC	
Weinzettel J., Kovanda J.	Czech Republic	Structural decomposition analysis of raw material consumption. The case of the Czech Republic	2011	Journal of Industrial Ecology (15)	893-907
Wiebe K. and Yamano N.	global	Estimating CO2 emissions embodied in final demand and trade using the OECD ICIO 2015: Methodology and results	2016	OECD Science, Technology and Industry Working Papers, 2016/05, OECD publishing, Paris	
Wiebe K.S.	Europe	The impact of renewable energy diffusion on European consumption-based emissions	2016	Economic Systems Research	133-150

Wiedmann T.	United Kingdom	A first empirical comparison of energy Footprints embodied in trade -MRIO versus PLUM	2009	Ecological Economics (68)	1975-1990
Wiedmann, T;	global	Impacts embodied in global trade flows	2016	R. Clift, A. Druckmann. Taking Stocs of Industrial Ecology.	159-180
Wiedmann T., Barret J.	United Kingdom	A greenhouse gas footprint analysis of UK central Government, 1990-2008	2011	Environmental Science, Policy (14)	1041-1051
Wiedmann T., Minx J., Barret J., Wackernagel M.	United Kingdom	Allocating ecological footprints to final consumption categories with input-output analysis	2006	Ecological Economics (56)	28-48
Wiedmann T., Schandl H., Lenzen M., Moran D., Suh S., West J., Kanemoto K.	Global	The material footprint of nations	2015	PNAS (112)	6271-6276
Wiedmann T., Wood R., Lenzen M., Minx J., Guan D., Barrett J.	United Kingdom	Development of an Embedded Carbon Emissions Indicator – Producing A Time Series of Input-Output Tables and Embedded Carbon Dioxide Emissions for the UK by Using a MRIO Data Optimisation System	2008		
Wilting H., Faber A., Idenburg A.	The Netherlands	Exploring Technology Scenarios with an Input-Output Model	2004	Conference paper for International Conference on Input-Output and General Equilibrium: Data, Modelling and Policy Analysis, September 2-4, 2004, Brussels, Belgium	
Wood R., Lenzen M., Foran B.	Australia	A material history of Australia: Evolution of material intensity and drivers of change	2009	Journal of Industrial Ecology (13)	
WWF WWF's Trade and Investment Programme & Industrail Ecology Programme	EU	EU consumption, global pollution	2008		
Zbranek J., Sixta J.	Czech Republic	Analysis of the labour inputs in the input-output framework	2011	Conference paper International Input Output Conference 2012, Bratislava	847-862

2.8 Appendix B

Problem analysis

Author	Research question(s)	Data
Alcantara et al. (2003)	Which are the key sectors for energy policy	Spanish IO table (1995) and energy balance
Choi et al. (2010)	How to integrate short-term policy-induced consumer demand changes into the input–output framework to analyse the environmental and economic repercussions of a policy?	The U.S. Bureau of Economic Analysis (BEA) publishes data at three levels of aggregation; Type I (detailed level), Type II (summary level), and Type III (sector level), consisting of around 500, 100, and 15 sectors, respectively. This study combines one Type I, twelve Type II and thirteen Type III levels of aggregated sectors to balance out issues related to accuracy and comprehensiveness
Christis et al. (2015)	What are the potential losses in current GDP (and GHG-emissions and employment) due to intensifying SMM-strategies and determining the budget for new SMM-strategies?	Flemish EE-RIO-tables, EXIOBASE 1 and WIOD
Collins et al. (2006)	What are the environmental effects of resource consumption at a subnational level (by Cardiff, the capital city of Wales)?	National Footprint Accounts combined with monetary input–output analysis (SUT, no IOT) to establish a link with detailed national expenditure data and to disaggregate by economic sector and reallocate to final demand
Cuypers et al. (2013)	How much of deforestation in the world can be attributed to EU-27 consumption	GTAP-MRIO and FAO's 'Global Forest Resources Assessment 2010' (FRA 2010) on deforestation and FAOSTAT
Dawkins et al. (2008)	Recalculate the ecological footprint for Wales', for the six Spatial Plan areas in Wales, and for each of the 22 local authorities.	IO model 2003 Wales - domestic economy
Dietzenbacher (2005)	How to include waste in Physical Input-Output Tables.	PIOT Germany 1990
Druckman (2009)	How much CO_2 emissions (in UK or abroad) are associated to peoples high level functional needs	QMRIO and Local Area Resource Analysis Model and GTAP
Duchin F. (2005)	How to build a framework for scenario analysis for sustainable food consumption	World Trade Model and LCA

EEA (2007)	Investigate production and consumption patterns and four associated environmental pressures (namely, Global Warming Potential, Acidification Potential, Tropospheric, Ozone Forming Potential, and Direct Material Input) in 8 EU Member States	Monetary input-output tables Eurostat and NAMEA-type tables for air emissions and MFA from countries (domestic production technology approach)
Egilmez et al. (2013)	How eco-efficient are US manufacturing industries	EIO-LCA and Data Envelopment Analysis (DEA)
EPA (2009)	What are the trends in resource consumption and their environmental impacts, what demonstration projects about SMM need to be focussed on	U.S. Bureau of Economic Analysis (BEA) 1998 input/output (I/O) tables, WRI MFA data, U.S. Geological Survey for water
EPA (2013)	What are the main drivers of environmental impacts and how much can potential improvement options reduce them	BEA I/O tables, WRI MFA, US DOE, LCA
Huppes et al (2006)	How can we approach integrated product policy (IPP) from an empirical angle? As environmental effects are ultimately driven by consumption, more sophisticated policies, as well as private actions, aiming at sustainability require better insight into what is contributing to this total. How far can we go and how far should we go in modelling for IPP?	CEDA 3.0 adapted and extended to EEIOA for EU25, called the Comprehensive Environmental Data Archive—EU25 (CEDAEU25).
Huysman et al (2014)	The development of a new resource footprint framework that combines a world IO-model instead of a national IO-model with the CEENE method as exergy accounting methodology.	Exiobase
Jalas (2005)	Do lifestyles become more energy-intensive? What are the effects of these changing lifestyles?	To link time use survey data and household expenditures with corresponding use of energy in the economy, the study makes use of the national input-output tables from 1995 and the sectoral energy intensities of the financial output [MJ/FIM] of the national Finnish economy.
Jungbluth et al. (2011)	What are the environmental impacts in Switzerland that arise from consumption and production and which are their most important driving forces?	Swiss IO-table 2005, combined with Swiss trade statistics and LCA-data for environmental impacts related to import and export.
Jury et al. (2013)	Which methodological framework is recommended to support policy makers in the evaluation and choice of environmental impact mitigation strategies?	IOT for Luxembourg (only monetary data), combined with EE-IOT for the Netherlands and EU27 (for environmental extensions)
Kerkhof et al. (2009)	Aim to examine the relationship between Dutch household expenditures and multiple environmental impacts, including climate change, acidification, eutrophication and smog formation.	SU+IO-tables of the Netherlands; SU+IO-tables for competitive imports; emissions data (sector and product); household expenditures data

Nijdam et al. (2005)	What are the most important elements in the environmental load of Dutch private consumption, focusing on the impacts generated abroad?	IOT for the Netherlands for 1995, combined with data on environmental intensities for OECD and non OECD countries and household expenditures
Perese K. (2010)	This paper provides a general overview of IO models and a specific application of an IO model to estimate the effect of a $20 tax per metric ton of CO2 emissions. The model presented here, holds the price of most imported commodities fixed while subjecting imported petroleum, natural gas, and coal to the tax, and makes adjustments for the non-combusted uses of fossil fuels.	Make and use tables and input-output tables of the US with adjustments for imports (Bureau of Economic Analysis)
Peters et al. (2006)	Study focusing on Norwegian households to emphasize the importance of considering pollution embodied in imports and show the value in studying the environmental implications of international production networks focuses on indirect environmental impacts associated with production.	IO-table Norway and input-output and emissions data were collected for Norway's seven main importing trade partners. The imports from the minor importing countries were then allocated to one of the seven major importing countries based on technology similarities.
Schandl et al. (2016)	Can Well-designed policies reduce global material and energy use, and carbon emissions, with only minimal impacts on improvements in living standards.	3 separate global models in sequential order, using outputs from one model as inputs to another in an iterative fashion.: GIAM, MEFISTO an MRIO modelling for future years (2010 – 2050). For past years (1990 – 2010) EORA is used.
Seppala et al. (2011)	The research analyses the relation between the material flows and climate impacts caused by the Finnish economy in 2002 and 2005.	ENVIMAT model
Tarancón et al. (2006)	This paper provides a methodology which allows the identification and assessment of the sources of CO2 emissions, applied to the Spanish economy.	Use an input–output methodology, combined with sensitivity analysis and lineal programming (symmetrical Spanish input–output table and CO_2 emissions vector)
Thomas et al. (2013)	Simulate direct and indirect rebound effects for the average U.S. household.	Environmentally-extended input–output model and the Consumer Expenditure Survey
Velazquez E. (2006)	To identify which sectors consume the greatest amounts of water, both directly and indirectly, and to analyse to what extent this resource may become a limiting factor in the growth of certain production sectors	EE-RIO model for Andalusia (water use is included in the tables)
Wiebe K.S.	What is the impact of renewable power generation technology diffusion on consumption-based carbon emission in the EU?	EU consumption-based emissions are calculated using a combination of a multi-regional input-output system and a dynamic macro-economic input-output model, which is used to project the MRIO.

Ex ante analysis

Author	Research question(s)	Data
Cheong et al. (2012)	What is the effect of carbon pricing on industry and household prices throughout the economy	Australian Price Revenue Incidence Simulation Model (PRISMOD) and the Static Incomes Model (STINMOD)
Cui et al. (2015)	Trend and distribution of national embodied energy flows in the international trade of China and evaluation of energy-intensive industry restrictive export policy of China.	GTAP-databases (version 6.0, 7.1 and 8.0)
de Souza et al. (2016)	Evaluation of the economic impacts of greenhouse gas emission reduction on the Brazilian economy.	Integrated input-output linear programming model, based on supply and use tables and emission data.
EMF (2013)	How to scale up material cost savings of microscale analyses of a sample products to economy-wide benefits	Eurostat EU input-output tables
Gemechu et al. (2012)	What are the short term price effects of the introduction of a CO_2 tax.	Spanish Supply and Use tables and Atmospheric Emissions Accounts
Hatfield-Dodds et al. (2011)	The main goals of the report are: - to provide an independent analysis of the economic impacts of the introduction of a carbon price; - to outline the methods and assumptions used in the analysis; - to bring together estimates of price impacts and announced government assistance to households; and - to put the projected impacts into historical context, so that readers are able to better evaluate their significance.	Australian National Accounts: input-output tables (ABS Input-output Tables) and Household Expenditure Survey
Herrerras Martinez et al. (2013)	Research aims to demonstrate a methodology that quantifies key socio-economic impacts of the production of bioethanol in the NE, in particular the impact on GDP, imports and employment.	Extended interregional IO-model for Brazil.
Hoekstra et al. (2002)	This paper illustrates the problems associated with structural changes, and the effects that policy measures may play in shifting the burden of environmental emissions between countries. This paper furthermore explores the different policies that arise from different ethical viewpoints of the environmental responsibility that nation states hold. The following questions are investigated: - how do tax regimes, based on different viewpoints of environmental responsibility, lead to differences in economic growth and environmental performance?	A dynamic two-sector two-country input-output model that includes technological progress, technology spillovers, economic growth, trade and environmental emissions (SIMBIOSES: Spatial Industrial Metabolism and Behaviour of Input/Output Structures in an Economic System)

	- how do the dynamics technology, policy and trade pan affect economic and environmental performance in a hypothetical two country dynamic model? What implications are there for the economic and environmental criteria, both on the national and global scale?	
Hubacek et al. (2009)	Analyse the effect of current trajectories and future scenarios (until 2020) for the development of China and Beijing, e.g. population growth, per capita income growth, urbanization and lifestyles changes, as well as structural economic changes, technical change and changes in resource efficiency. The effects of these changes are analysed and measured in terms of Ecological Footprint (EF) and Water Footprint (WF).	National input-output tables and input–output tables for Beijing in 1997 with aggregation level of 40 by 40 economic sectors, (industry by industry tables)
Jenkins (2011)	What are the indirect economic effects of drought damages under future climate change? (research question based on IO)	Adaptive Regional Input-Output model (ARIO), using I-O tables for Spain from Eurostat for 2005
Konijn et al. (1997)	The material contents of the final products are calculated, and an analysis is made of the consequences of new technologies.	PIOT and MIOT for the Netherlands
Lenzen et al. (2003)	We describe a method that uses input–output analysis to calculate the indirect effects of a development proposal in terms of several indicator variables	hybrid EIA approach combining static input-output analysis (Australian IO table with additional conversion factor for energy and greenhouse gas emissions obtained from energy statistics) with a conventional EIS
Lutz et al. (2012)	The paper presents recent results of economy-wide impact of energy efficiency and renewable energy measures in Germany.	PANTA RHEI is an environmentally extended version of the econometric simulation and forecasting model INFORGE, which includes a time series of input-output tables for Germany.
Markaki et al. (2013)	The aim of this paper is to calculate the ‘‘green’’ energy investments, by industrial sector, that Greece would need in order to satisfy a number of energy and environmental targets adopted in the context of the European Commission’s energy and climate change package; and second, to calculate the macro-economic impacts of these ‘‘green’’ investments on production and employment in the Greek economy.	Eurostat EU input-output tables
Su et al. (2017)	Does higher electricity prices negatively affect Taiwan’s economy?	MEIT (macroeconomic interindustry model of Taiwan)
UNEP (2014)	The report highlights technological possibilities and opportunies to accelerate decoupling and reap environmental and economic benefits of increased resource productivity. It examines the policy options that have proved to be successful to improve resource productivity in different countries.	Results from other studies are compiled to derive conclusions (most reference is made to ICIO (intercountry IO tables) of OECD and GTAP)

UNEP (2015)	How important is trade for supplying countries with resources? How is trade dependency distributed and how does it change over time? What roles do countries occupy in international trade, where are the centres of use and demand, and where are the locations of international supply of resources? What factors determine this distribution? What are the upstream resource requirements, in terms of materials, water and land, of traded commodities? What can be concluded about the contribution of trade to the efficiency of global resource use?	Results from different studies are compiled to derive conclusions (e.g. based on EORA and Exiobase).
Weinzettel et al. (2011)	Quantify the drivers for the changes in raw material consumption in terms of technology, the product structure of final demand and the volume of final demand.	Hybrid LCA-EEIOA data for Czech Republic
Wiedmann (2009)	What is the energy footprint embodied in UK trade?	UK-MRIO1
Wiedmann et al. (2006)	Disaggregate the national Ecological Footprints by economic sector, detailed final demand category, sub-national area or socio-economic group.	National Footprint Accounts combined with monetary input–output analysis (SUT, no IOT) to establish a link with detailed national expenditure data
Wilting et al. (2004)	What are the effects of future technological change on Dutch production and emissions (2030)?	Dynamic demand-driven input-output model DIMITRI
Zbranek J. et al (2011)	Research analyzes the labour intensity development, as a measure for labour productivity, connected with production of products according to commodity classification using the system of input-output tables in the Czech Republic.	Symmetric IOT published for the Czech economy

Ex post analysis

Author	Research question(s)	Data
Andrew et al. (2013)	How growing trade in embodied carbon impacts effects of domestic climate policy	GTAP-MRIO
Arto et al. (2012a)	A series of indictors describing the evolution of the use of natural resources and the emissions of air pollutants around the world, in relation to production, consumption, and trade activities.	WIOD
Arto et al. (2012b)	Development of a comprehensive dataset of reliable and comparable economic an environmental information that contributes to a better understanding of the complexity of issues like natural resource use and the level of pollution, and to supporting evidence-based policymaking.	WIDO

Cellura (2013)	How much energetic and environmental benefits will occur as a consequence of Italian policy on energy saving measures in buildings.	Italian Input-output model combined with LCA
Dietzenbacher et al. (2012)	How much would the Kyoto Protocol cost to consumers ?	WIOD, (price input-output model)
EEA (2009)	What is the potential of EE-IO models for understanding sustainable consumption and production patterns	NAMEA symmetrical IO tables (6 EU countries)
EEA (2011a)	Identification of potential focus areas (product groups and consumption domains) that might be tackled by policies in the context of resource use (material resource footprint).	Eurostat EU input-output tables
EEA (2011b)	Calculation and analysis of SCP indicators and historic trends. Analysis of driving forces starting from products, sectors and consumption domains.	Eurostat EU input-output tables (only for consumption based indicators)
EEA (2013)	What is the potential of EE-IO models for answering key SCP policy questions, what are the environmental hotspots in European consumption and production and what are weaknesses and potential for improvement of the IO tool.	NAMEA symmetrical IO tables (9 EU countries) for consumption perspective, NAMEA air emissions for production perspective , EW-MFA
Garcia Muñiz (2013)	The aim is to outline a new approach to clustering sectors based on similarities between sector linkages profiles. The obtained set of structurally equivalent sectors defines a reduced model which provides additional information about the main paths of influence and the degree of complexity.	The information used as a starting point is supplied by the input–output tables in Spain in 2000 (IOT-00) and in 2005 (IOT-05) with a 25 desegregation level.
Hertwich et al. (2009)	To analyzes and compares the carbon footprint of different countries. They quantify greenhouse gas emissions associated with the final consumption of goods and services for 73 nations and 14 aggregate world regions. They analyze the contribution of 8 categories: construction, shelter, food, clothing, mobility, manufactured products, services, and trade.	GTAP version 6 supplemented with greenhouse gas emission intensity data
Kronenberg, et al. (2012)	The aim of the paper is to contribute to a fact-based discussion of the costs and benefits of the building rehabilitation program. We develop an extended input-output model (STEIN) to estimate the macroeconomic effects of the rehabilitation measures that received funding and how they affect the public deficit, focusing on the revenue from income taxes and social security contributions (SSC) as well as taxes on products and production	STEIN-model for Germany (STEIN, a static open input-output quantity model)
Lenzen et al. (2008)	What is embodied energy and how is this put in an international perspective?	Australian input-output tables, energy statistics, household budget surveys

Michel (2013)	The pollution haven effect reflects the idea that stricter environmental policies foster the relocation of polluting activities and imports of pollution-intensive products. This paper develops a new approach for testing this effect for imported intermediate materials. It adds to the existing literature on pollution havens through this specific focus on imports of intermediates, which is of particular interest in view of the rise of offshoring within global value chains.	Belgian input output tables
Peters and Solli (2010)	- What are the global greenhouse gas emissions to produce the products and services entering final consumption in the Nordic countries? - What are the trade-adjusted emission inventories in the Nordic countries? a) What are the territorial greenhouse emissions in the Nordic countries to produce products and services which are exported? b) What are the territorial greenhouse emissions outside of the Nordic countries to produce products and services which are imported into the Nordic countries?	GTAP database
Rugani, et al. (2014)	i) to calculate EF and SED of the Luxembourg's consumptions over a timeframe of 15 years, ii) to estimate the biocapacity and the natural capital of the country over the same period, iii) to estimate the ecological deficit and the use of natural capital, and, iv) to discuss the added value and lingering limitations, from a technical perspective, of the modelling and methodological framework	Integration between environmentally extended input–output tables (EE-IOT) for domestic production and input–output-based hybrid tables for imports over time-series
Sissoko et al. (2008)	Illustrate the deficiency of the production approach as a tool to measure a country's responsibility for international environmental impacts. A use approach is presented as a more suitable tool.	Two datasets for Belgium for the period 1995-2002: supply and use tables (SUTs) and the NAMEA-Air.
Skelton et al. (2011)	(i) how to examine a large number of supply chains linking sectors at different stages in the production system; (ii) how to show the relative importance of different supply chains in regard to GHG emissions; and, (iii) how to account for the majority of supply chains that each constitute negligibly small emissions sources, but that collectively make up a considerable share of total emissions within an economy	GTAP version 7 (converted into an MRIO table through the proportional allocation of bilateral trade data across interindustry requirements and final consumption of imported products)
Tukker et al. (2011)	Life cycle impacts of final consumption for the EU27. It further indicates how much of these impacts take place outside Europe, and how impacts are embodied in Europe's exports. Also, to analyse the improvements of using an MR EE IO approach compared to other approaches of	EXIOBASE version 1.

	assessing pollution embodied in imports, most notably the 'domestic technology assumption'.	
Tukker et al. (2014)	Illustrate how final consumption of goods and services in a region impacts other regions. This has been shown for four kinds of aggregated footprint: carbon, water, land and material. For material extraction, global production and consumption of copper ore is highlighted as an example for single products.	Exiobase version 2
Turner et al. (2007)	To provide an account of the analytical method by which Ecological Footprints should ideally be estimated in an international input-output framework.	This paper has argued that adopting a multi-region input–output accounting approach is the most appropriate method of calculating Ecological Footprints.
Wang et al. (2013a)	Study contributes mainly to the analysis of the driving forces of the change in CO2 emissions in Beijing during the time period 1997–2010 using the IO-SDA model.	MIOTs for Beijing, population data and energy consumption.
Wang et al. (2013b)	The objective of this paper is to quantify and map the agricultural and industrial water footprint intensity, gross water footprint and grey water footprint of Beijing by applying a modified IO model. The evaluation also considers virtual water flows and national gross water savings as a result of trade.	IO tables for Beijing in 2002 and 2007 and gross water consumption and use from other statistical sources.
Weidema et al. (2008)	The study first estimates and compares the environmental impacts of meat and dairy products consumed in EU-27, taking into account the entire value chain (life cycle) of these products. It then identifies and analyses the potentials of improvement options for the processes in the value chains that contribute most to the environmental impacts, focusing on options with proven technological feasibility and short to medium-term implementation horizon. Finally, it assesses the socioeconomic impacts of the improvement options, their relations to autonomous developments and current policies, and their feasibility of implementation. Targets and measures for the implementation of the improvements are suggested.	Hybrid life cycle assessment method (combines the completeness of 'top-down' input-output matrices with the detailed modelling of 'bottom-up' processes from process-based life cycle assessments) based on the EU-27 NAMEA matrices.
Wiedmann (2016)	What are the latest empirical finding on global change instigated by trade, new methodological developments and reflections on the sustainability of globalised production and consumption?	literature research
Wiedmann et al. (2008)	Develop a model to calculate a time series of direct and indirect carbon dioxide emissions associated with UK economic activities, in particular emissions that are embedded in imports to and exports from the UK.	UK-MRIO1 using a SUT data framework (including 3 trade regions: OECD Europe, OECD non-Europe and non-OECD countries

Wiedmann et al. (2011)	What are the scope 1, 2 and 3 GHG emissions associated with UK Central Government activities from 1990 to 2008?	MRIO model (2 regions: UK and Rest of World)
Wiedmann et al. (2015)	How many and which natural resources are needed to sustain modern economies?	Global MRIO database Eora, complemented with physical unit data on the DE of raw materials from a global reference database
Wood et al. (2009)	The purpose of this work is to delve beneath the top-level trends in material flow growth to investigate the structural changes in the economy that have been driving this growth.	Structural decomposition, using input–output analysis (IOA) at a sector level of 344 industries
WWF (2008)	What makes up the carbon footprint of EU consumption?	GTAP, Greenhouse gas viewer (EEA), Statistical Review of World Energy (BP)

CHAPTER 3

3. Linking regional input-output tables to multiregional input-output tables

The literature review in chapter 2 shows a great variety in applications that combine EE-IO models with other data models to answer context specific policy questions. The typical economic matrix structure of IO models allows an easy linking of IO models to other (environmental) datasets, which increases the range of economic, social and environmental applications. Also, the interviews with Flemish policy makers from different (environmental) policy fields showed a variety of needs that require further detailing and extending EE-IO models. In principle this detailing and extending is possible, however the challenge remains to harmonize databases internationally to capture global value chains. Still, the list of topics addressed in the selected international publications suggest a potential relevance for IOA in policy making. Also, given the increase in available EE-MRIO models during the last years, it can be expected that more analyses will use these existing models, decreasing the need to develop an additional model for specific applications. However, a lack of insights based on input-output analyses that have been used in political decision-making reveals unused potential.

To increase at least local policy acceptance of IOA, this chapter develops a methodology to link local or national statistics to EE-MRIO models. Especially in Flanders, which has an open economy, the trade linkages are a key feature in both developing policy making and understanding its effects. It is crucial to investigate and understand the role of local sectors and consumption in global value networks.

Before the methodology is described, this chapters gives an introduction on the Flemish economy with a focus on the open economy and the general economic structure. The more open an economy is, the more it depends on import and export, the more relevant is the application of this methodology. This chapters concludes with a discussion on the different errors that arise from IO calculations using three different models:

- Using local models implies a model abstraction for foreign production chains linked to extra-regional trade or, if not modelled, the exclusion of production abroad due to import and export leakages. Once a production chain requires an import or export, it is not further captured by the model, i.e. import or export leakage.
- Using an EE-MRIO model, implying that regional specific data is not included.
- Using a linked EE-RIO and EE-MRIO model.

This last option is based on the application of the described methodology. It is shown that a combined EE-RIO and EE-MRIO model results in the best local footprint estimation possible, as this estimation is based on all data available.

3.1 THE FLEMISH OPEN ECONOMY IN A GLOBAL CONTEXT

The economy in Flanders is open (Flanders Investment & Trade, 2013). But, what means an open economy, how open is de Flemish economy and what are the implications and consequences thereof?

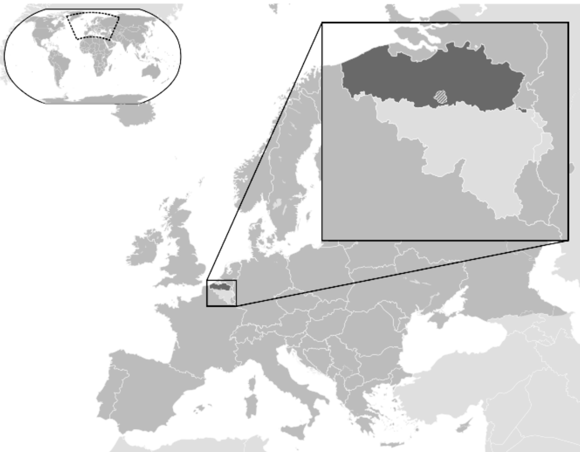

FIGURE 35: GEOGRAPHIC LOCATION OF FLANDERS (DARK GREEN).

An open economy can be defines as (www.businessdictionary.com): “Market-economy mostly free from trade barriers and where exports and imports form a large percentage of the GDP. No economy is totally open or closed in terms of trade restrictions, and all governments have varying degrees of control over movements of capital and labour. Degree of openness of an economy determines a government's freedom to pursue economic policies of its choice, and the susceptibility of the country to international economic cycles”. The definition not only focusses on the flows of import and export, but also on consequences to governmental freedom and susceptibility to international economic cycles.

Several indicators estimate the openness of economies. For example, the (trade) openness index (Leamer, 1988) shows the percentage of trade compared with GDP by taking the sum of import and export divided by the total GDP. Belgium has one of the highest index of all countries worldwide with an index of 167 in 2015 with an increasing trend (data from the World Bank, trade (% of GDP) index). The index for Flanders, excluding interregional trade, was 168 in 2014. The interregional trade of Flanders is around 25% of total trade (interregional + international), resulting in an even higher index for Flanders.

Other ways to estimate and illustrate the openness, using input-output methodology, are based on the trade in value added (Stehrer, 2012). The trade in value added is expressed via two indicators: own value added in exports and foreign value added in local final consumption. The own value added in export (%TiVA_X) is the value added created by local economies in production chains serving final demand abroad divided by total value added created in the local economy. It is the ratio of locally created value added directly or indirectly exported in the total value added created locally. The foreign value added in own final consumption (%TiVA_M) is the ratio of foreign value added in local consumption divided by the total final demand.

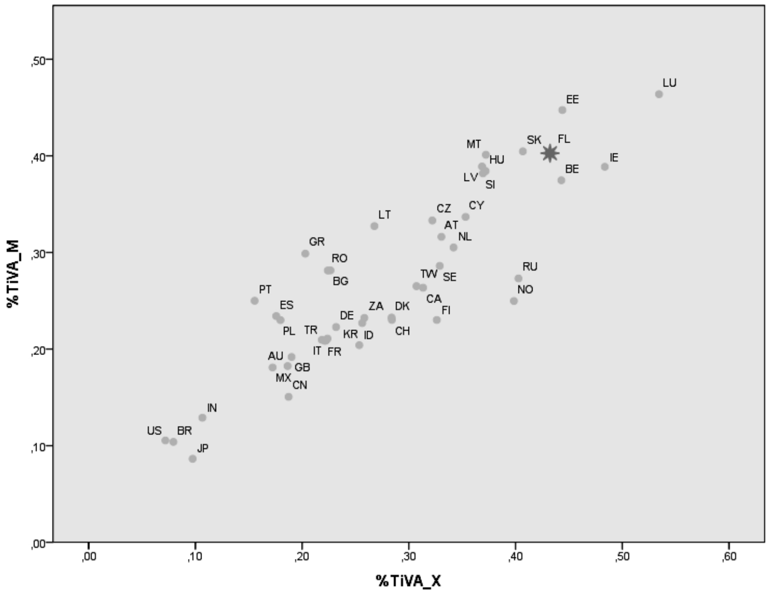

FIGURE 36: TRADE IN VALUE ADDED MEASURED BY LOCAL VALUE ADDED IN EXPORT (%TIVA_X) AND FOREIGN VALUE ADDED IN LOCAL FINAL CONSUMPTION (%TIVA_M). COUNTRY CODES FROM EXIOBASE 1 (SEE *APPENDIX 6: EXIOBASE 1 COUNTRY/REGION CLASSIFICATION*). SOURCE: OWN CALCULATION BASED ON EXIOBASE 1 AND FLEMISH RIOT 2007.

Figure 36 displays the trade in value added of Flanders (red cross) and the 43 countries included in EXIOBASE 1[14]. Flanders is located in the right-upper corner with both a high share of locally created value added serving final demand abroad and a high share of value added created abroad in Flemish final demand.

This indicator can also be expressed in domestic extraction used (DEU). The trade in DEU is expressed via own DEU in export and foreign DEU in local final demand. The own DEU in export (%TiDEU_X) is the share of total DEU used in the supply chains of exported products, while the foreign DEU in local final demand (%TiDEU_M) is the share of foreign DEU in the total DEU used in the supply chains of products in local final consumption. The comparison of Flanders to other countries is presented in **Figure 37**. Flanders has the highest share of foreign DEU in local final demand of all listed countries.

The trade in value added indicator is visualised in **Figure 38**. On the left side, the locally generated value added is divided into value added generated in production chains of locally consumed products (local final demand) and products consumed abroad (foreign final demand). On the right side, the foreign value added embedded in imports is divided into value added generated in production chains of products consumed locally and products consumed abroad. At the centre, the consumption perspective is illustrated, compiled from value added form local activities and abroad activities. The difference between the territorial and consumption perspective illustrate that Flanders is a net importer of value added.

[14]See *Appendix 6: EXIOBASE 1 Country/region classification*, excluding the rest of world region.

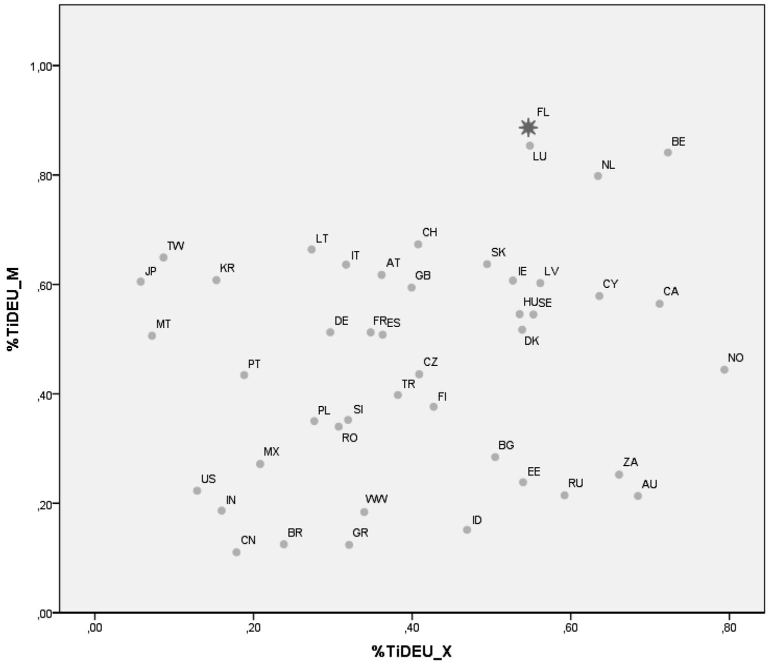

FIGURE 37: PRIMARY MATERIAL USE, IN DOMESTIC EXTRACTION USED, IN TRADE MEASURED BY LOCAL EXTRACTION IN EXPORT (%TIDEU_X) AND FOREIGN EXTRACTION IN LOCAL FINAL CONSUMPTION (%TIDEU_M). COUNTRY CODES FROM EXIOBASE 1 (SEE *APPENDIX 6: EXIOBASE 1 COUNTRY/REGION CLASSIFICATION*).
SOURCE: OWN CALCULATION BASED ON EXIOBASE 1 AND FLEMISH RIOT 2007.

The same applies to primary material use shown in **Figure 39**. Based on the several indicators listed above, the statement that Flanders has an open economy can be confirmed. Flanders depends on imported products to fulfil its demand and to maintain the export oriented production. Its dependency on non-domestically extracted or produced primary materials is high: only 10% (weight based share) of the primary materials required to produce product for final demand originate from Flanders. Therefore, the international aspect in policy development in Flanders cannot be underestimated. This leads to the recommendation that research supporting policies in open economies should include the international aspects.

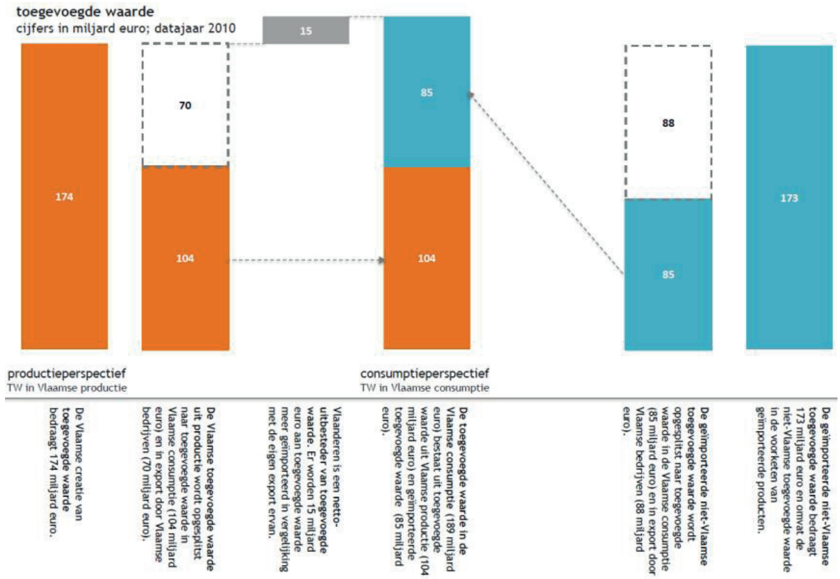

FIGURE 38: THE IMPORT AND EXPORT DEPENDENCY OF FLANDERS IN VALUE ADDED (2010) [IN DUTCH].
SOURCE: FIGURE CONSTRUCTED IN PROJECT FUNDED BY VMM-MIRA (2016) 'CARBON FOOTPRINT VAN VLAAMSE CONSUMPTIE'.

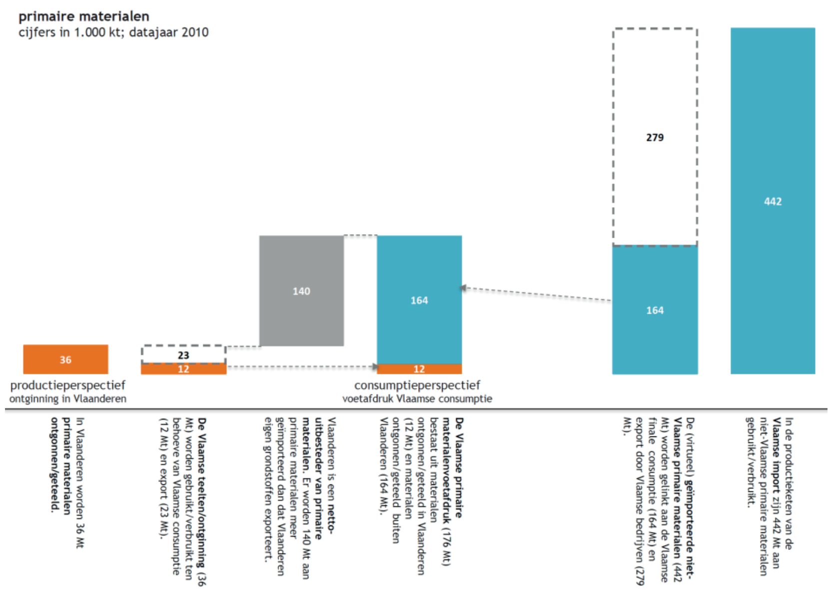

FIGURE 39: THE IMPORT AND EXPORT DEPENDENCY OF FLANDERS ON DIRECT AND INDIRECT PRIMARY MATERIAL USE (2010) [IN DUTCH].
SOURCE: FIGURE CONSTRUCTED IN PROJECT FUNDED BY OVAM (2018) 'SECUNDAIRE MATERIALEN IN DE IO-TABEL'.

3.2 Linking regional input-output tables to multiregional input-output tables

Section 3.2.1 Methodology is appendix A in Christis et al. (2016) and section 3.2.2 Case of Flanders is redrafted from appendix B in Christis et al. (2016) and supplemented with other model characteristics.

3.2.1 Methodology

The goal of linking a RIOT (local input-output table) to a MRIOT (multiregional input-output table) is to analyse local specific problems embedded in the networks of globalised value chains. This model is fully consistent with local accounts and environmental data, but is included in an MRIOT via its trade links: the building blocks (matrices Z, F, K, E and x) of the MRIOT are equal, but include one extra region. To keep a balanced model, part of the national imports and exports are reallocated to local imports and exports. The idea behind is closely related to the single-country national accounts consistent (SNAC) footprint developed by Edens et al. (2015). They replace the basic data behind the MRIOT with detailed country and sectorial level data and micro-data to estimate the value of imports and exports that remains unaltered during the reconciliation procedure (Edens et al., 2015). Bachmann et al. (2015) also focus on the inclusion of a sub-region in an MRIOT. Both methodologies use local data and result in one balanced MRIOT (Bachmann et al., 2015). However, an important conceptual difference is the replacement of a country in an MRIOT by Edens et al. (2015) and Bachmann et al. (2015), while this methodology adds a local region to the MRIOT. The building process is illustrated below.

As a starting point, we have the two building blocks: a RIOT and a MRIOT. We assume that the local region R is not presented in the MRIOT, but the nation of which R is part of is included in the MRIOT. Consider a RIOT of R with (illustrated in **Figure 40**):

- $s_1, s_2, \ldots, s_i$ sectors;
- $f_1, f_2, \ldots, f_k$ final demand categories;
- $k_1, k_2, \ldots, k_m$ elements in the factor input matrix;
- $e_1, e_2, \ldots, e_o$ elements in the extension tables; and
- $r_1, r_2, \ldots, r_q$ product groups in the import matrices.

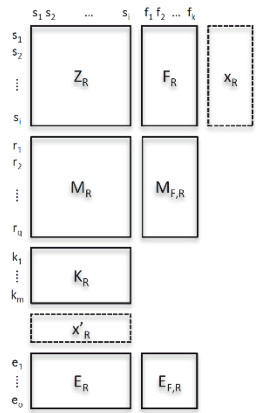

FIGURE 40: THE FRAMEWORK OF A LOCAL INPUT-OUTPUT TABLE.

Consider a MRIOT with (illustrated **Figure 41**):

- $s_1, s_2, \ldots, s_j$ sectors;
- $r_1, r_2, \ldots, r_r$ regions in the model;
- $f_1, f_2, \ldots, f_l$ final demand categories;
- $k_1, k_2, \ldots, k_n$ elements in the factor input tables; and
- $e_1, e_2, \ldots, e_p$ elements in the extension tables.

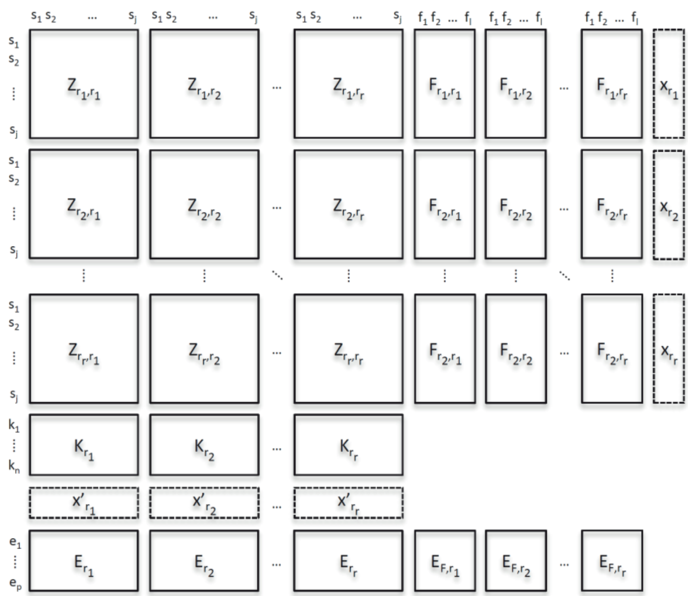

FIGURE 41: THE FRAMEWORK OF A MULTIREGIONAL INPUT-OUTPUT TABLE.

These tables are linked into one model (illustrated in **Figure 42**). The non-shaded matrices are directly taken from the RIOT or the MRIOT. The dimensions of these matrices are equal to the dimensions of the original tables. The lay-out of this framework allows varying (dis)aggregation levels between the RIOT and MRIOT for sectors, value added elements, final demand categories. Also, a different number and type of elements in the extension tables is possible. This is a prerequisite for building the model at the highest disaggregation level possible. Often, the local sector disaggregation level substantially differs from the sector disaggregation level in MRIOTs, as RIOTs focus on local economic characteristics. For example, in Flanders the chemical industry[15] is an economically important sector resulting in a highly disaggregated chemical industry of six different sectors in the RIOT compared to five sectors in the EXIOBASE 2 MRIOT and only one sector in the EXIOBASE 1 and WIOD MRIOTs.

The output vectors (x) equal their output equivalents in the RIOT and MRIOT. The import and export flows from the MRIOT to the RIOT are estimated via other sources (preferably local trade statistics), but their totals equal the import and export flows in the RIOT. So, the building process does not change the input-output balance neither the totals.

The value added matrices and extension tables are added in their original format. To build a square matrix K and E, zero-matrices are added (indicated by empty matrices in **Figure 42**).

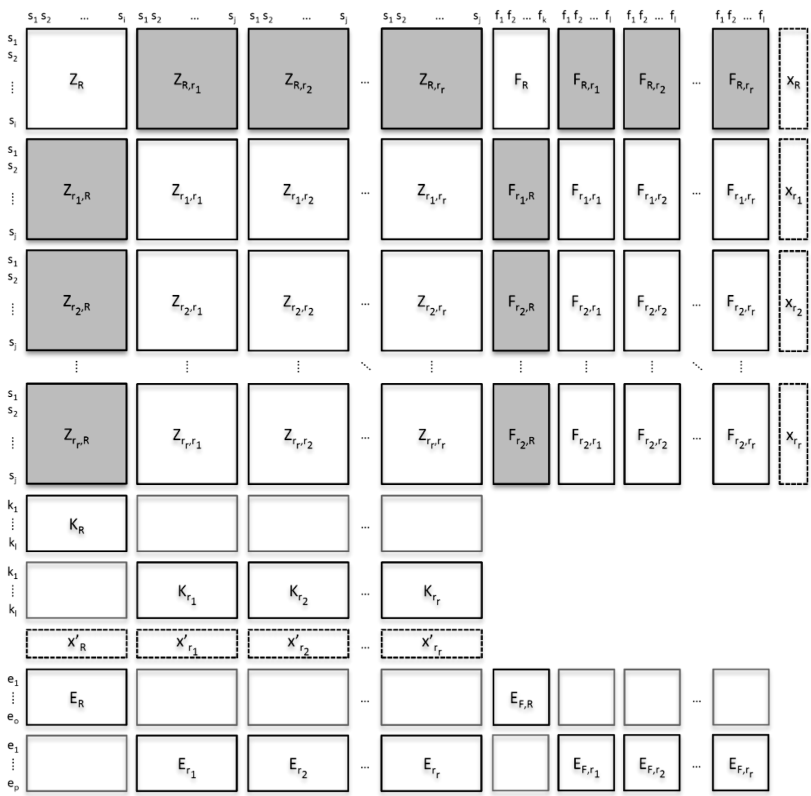

FIGURE 42: THE FRAMEWORK OF A LINKED LOCAL INPUT-OUTPUT TABLE TO A MULTIREGIONAL INPUT-OUTPUT TABLE.

[15]NACE Rev. 1: 24 and NACE Rev. 2: 20+21

The import matrices M_R and $M_{F,R}$ (**Figure 40**) presents all intermediary and final demand import flows (in product group detail) from other regions to sectors of region R. The framework of the RIOT makes a distinction between intermediary and final demand imports. Matrix M_R presents intermediary imports and matrix $M_{F,R}$ presents import by final demand. Both intermediary and final demand imports need to be allocated to their geographical origin at the level of regions/countries of the MRIOT. Both matrices provide product group detail (use table) which should be reallocated to their origin: (1) the sector and (2) the region/country of the MRIOT. This is a two-step procedure:

- First, the product group classification of the RIOT is converted into products of sectors compliant to the MRIOT sector classification. If both tables are based on harmonized classification systems (e.g. product groups in Statistical Classification of Products by Activity in the European Economic Community 'CPA' and sectors in Statistical Classification of Economic Activities in the European Community 'NACE'), then Eurostat provides correspondence tables via their reference and management of nomenclature metadata server (RAMON) (Eurostat, 2016). The sectoral linkage must be developed for the classification system to interact. The linkage is based on a normalised concordance matrix. For more details see: (Bachmann et al., 2015; Lenzen et al., 2012; Lindner et al., 2012).
- Second, each sector product is subdivided and allocated to their geographical origin based on local import statistics. Note, these statistics in general make no distinction between imports for intermediary use and final demand. Another option is to allocate proportionally to the national intermediary and final demand import allocation available in the MRIOT making use of a trade coefficient matrix (Bachmann et al., 2015).

This procedure results in r intermediary import matrices with dimension (j x i) and r final demand import matrices with dimension (j x k).

In the RIOT, exports are one or multiple vectors of the final demand matrix (F_R). They present all exported products by local sectors. The framework of the RIOT makes no distinction between exports for intermediary use or use by final demand. The export needs to be allocated to the importing sector or final demand category and to their geographical destination at the level of regions/countries of the MRIOT. This is a three-step procedure:

- First, the export of products by local sectors are divided into exports for intermediary use and export for final demand. If there is no data available on this division, an option is to allocate proportionally to the national division available in the MRIOT.
- Second, the export for intermediary use is allocated to a specific sector and the export for final use is allocated to a specific final demand category. As the export in the RIOT is provided via vectors, there is no data available on the user. Only the supplier is given. An option is to allocate proportionally to the national division available in the MRIOT.
- Third, each export flow is allocated to its geographical destination based on local export statistics. Note, these statistics in general make no distinction between export for intermediary use and final demand. Another option is to allocate proportionally to the national intermediary and final demand export allocation available in the MRIOT.

The last two steps can be combined via the use of a trade coefficient matrix. This procedure results in r intermediary export matrices with dimensions (i x j) and r final demand export matrices with dimensions (i x l). To keep the required balance, the import and export of the local region are subtracted in matrix Z from the national import and export. In fact, part of the national intermediary imports and exports are reallocated to imports and exports of the local region. The same can be done for final demand imports and exports in matrix F to avoid double counting of final consumption in the local region and the nation. However, this was no necessary step in this paper as we solely focus on final demand by the local region.

3.2.2 Case of Flanders

Based on the methodology described in *3.2.1 Methodology* and in cooperation with Katrien Boonen (VITO) a Flemish EE-MRIO database is built (project funded by VMM-MIRA (2016) 'Carbon footprint van Vlaamse consumptie'). The database consists out of:

- Flemish EE-MRIOT 2003 (EXIO) compiled from the Flemish EE-RIOT 2003 and EXIOBASE 1 MRIOT (2000 data);
- Flemish EE-MRIOT 2007 (EXIO) compiled from the Flemish EE-RIOT 2007 and EXIOBASE 2 (2007 data);
- Flemish EE-MRIOT 2007 (WIOD) compiled from the Flemish EE-RIOT 2007 and the WIOD 2007 MRIOT; and
- Flemish EE-MRIOT 2010 (EXIO) compiled from the Flemish EE-RIOT 2010 and EXIOBASE 2 (2007 data).

Below, the process is elaborated for the construction of the Flemish E-MRIOT 2003 using EXIOBASE 1. The other models have a similar construction process. Only the database descriptions and diverting specifications are given.

The Flemish EE-MRIOT 2003 (EXIO)
The Flemish RIOT of the year 2003 consists out of[16]:

- i=1, …, 119 119 sectors;
- k=1, …, 9 9 final demand categories;
- m=1, …, 6 6 elements in the primary input matrix;
- o=1, …, 137 137 elements in the extension tables; and
- q=1, …, 119 119 product groups in the import matrices.

A simplified 3-sector[17] RIOT of Flanders is given in **Figure 43**.

The import matrices and export vectors are subdivided into rest of Belgium (RoB), rest of Europe (REU) and rest of world (RoW). In the Flemish RIOT of 2003 REU is defined as EU-15, the 15 member states of the European Union in 2003 (Avonds & Vandille, 2008): Germany, France, Italy, the Netherlands, Luxembourg, Denmark, Ireland, United Kingdom, Greece, Spain, Portugal, Austria, Finland and Sweden. Belgium was a member of the EU-15 in 2003, but is excluded from REU.

The EXIOBASE 1 MRIOT (Tukker et al., 2013) consist out of[18]:

- j=1, …, 129 129 sectors;
- r=1, …, 44 43 countries and one RoW-region
- l=1, …, 7 7 final demand categories;
- n=1, …, 17 17 elements in the primary input matrix; and
- p=1, …, 386 386 elements in the extension tables.

The allocation of Flemish export to the different countries and sectors of the MRIOT starts with the division of Flemish export in export for intermediary use and export

[16]See *Appendix 1: Flemish RIOT 2003 sector* classification.
[17]Primary sector: NACE Rev. 1 01A1-14A1; secondary sector: NACE Rev. 1 15A1-45E1; tertiary sector: NACE Rev. 1 50A1-95A4.
[18]See *Appendix 4: EXIOBASE 1 sector classifications.*

for final use. To our knowledge there is no Flemish data available to underpin this division. Therefore, we allocate proportionally to the Belgian division available in the MRIOT. This requires a conversion between the Flemish sector classification in the RIOT and the sector classification of the MRIOT. Both the Flemish RIOT and the EXIOBASE 2 MRIOT are based on the NACE classifications. These normalised concordance matrices allow a coupling between models with different sector aggregations. The link will always be carried out from the viewpoint of one Flemish sector, implying that only one-to-one and one-to-many relations are possible. This way, we avoid complex many-to-many relations.

The above described allocation is done proportionally to the Belgian division available in the MRIOT. This has an impact on the quality of the model, as the regional model is build using strong assumptions that trade coefficients are derived from the national model. The impact on the quality is mainly related to import flows: import by Flanders might be misallocated to another country or region. As a result, the estimation of footprints results in errors. The error is related to a misallocation of an imported product to another country or region. However, the impact on the quality of the model is limited. The import volume and the mix of imported products (in fact product groups) is not subjected to this potential error, and, international import by Flanders represents already 83% of total import by Belgium (based on 2017 international trade statistics by NBB, national concept).

	FL pri	FL sec	FL ter	int. supply	P.31/ S.14	P.31/ S.15	P.31/ S.13	P.32/ S.13	P.51	P.52	P.6/ S.21	P.6/ S.22	P.6/ RoB	final demand	x
FL pri	109	3.158	214	**3.481**	546	0	0	0	21	17	848	98	218	**1.749**	**5.230**
FL sec	1.381	29.879	14.345	**45.605**	9.499	2	163	0	14.705	-672	58.478	13.570	6.427	**102.172**	**147.777**
FL ter	815	24.189	43.897	**68.901**	44.941	1.128	19.162	10.278	5.462	72	22.369	8.672	6.154	**118.236**	**187.137**
int. use	**2.305**	**57.225**	**58.456**	**117.987**	**54.986**	**1.129**	**19.325**	**10.278**	**20.189**	**-583**	**81.695**	**22.340**	**12.799**	**222.157**	**340.144**
RoB pri	6	234	10	**250**	14	0	0	0	2	0	0	0	0	**16**	**266**
RoB sec	68	1.803	1.003	**2.874**	1.004	0	45	0	301	-20	0	0	0	**1.330**	**4.204**
RoB ter	141	2.126	6.408	**8.675**	6.459	344	1.350	3.733	228	1	0	0	0	**12.115**	**20.790**
import RoB	**215**	**4.163**	**7.421**	**11.799**	**7.477**	**345**	**1.395**	**3.733**	**530**	**-18**	**0**	**0**	**0**	**13.461**	**25.261**
REU pri	133	3.966	275	**4.374**	624	0	0	0	36	15	823	1.573	0	**3.070**	**7.444**
REU sec	272	28.456	5.757	**34.485**	10.018	4	366	0	5.968	924	21.525	4.943	0	**43.748**	**78.233**
REU ter	66	2.891	8.723	**11.680**	513	0	0	0	255	0	215	43	0	**1.025**	**12.705**
import REU	**471**	**35.312**	**14.755**	**50.538**	**11.155**	**4**	**366**	**0**	**6.259**	**939**	**22.562**	**6.559**	**0**	**47.843**	**98.382**
RoW pri	42	1.924	142	**2.108**	239	0	0	0	5	11	492	1.805	0	**2.552**	**4.660**
RoW sec	76	6.796	1.780	**8.652**	2.741	2	224	0	1.681	199	7.100	3.401	0	**15.347**	**23.999**
RoW ter	24	1.102	3.380	**4.506**	142	0	0	0	93	0	61	12	0	**308**	**4.814**
import RoW	**142**	**9.821**	**5.303**	**15.266**	**3.122**	**2**	**224**	**0**	**1.778**	**210**	**7.653**	**5.218**	**0**	**18.208**	**33.474**
D.21-D.31	57	306	3.560	**3.923**											
D.1	419	25.295	53.927	**79.642**											
D.29	20	632	2.392	**3.044**											
D.39	-22	-223	-1.074	**-1.319**											
B.2N	1.047	7.589	26.360	**34.996**											
K.1	575	7.657	16.036	**24.268**											
primary input	**2.097**	**41.255**	**101.202**	**144.554**											
x'	**5.230**	**147.777**	**187.137**	**340.144**	**76.740**	**1.480**	**21.311**	**14.010**	**28.757**	**547**	**111.909**	**34.117**	**12.799**	**301.670**	

FIGURE 43: THE FLEMISH 3-SECTOR REGIONAL INPUT-OUTPUT TABLE (RIOT) FOR 2003.

Per Belgian sector three fractions are calculated representing the intermediary deliveries in total deliveries (one for national deliveries, one for REU deliveries and RoW deliveries) via the formulas:

$$\text{fraction } s_i^{BE\rightarrow BE} = \sum_{x=1}^{129} Z_{s_i\rightarrow s_x}^{BE\rightarrow BE} \Big/ \left(\sum_{x=1}^{129} Z_{s_i\rightarrow s_x}^{BE\rightarrow BE} + \sum_{x=1}^{7} F_{s_i\rightarrow f_x}^{BE\rightarrow BE} \right) \quad \text{(eq. 29)}$$

$$\text{fraction } s_i^{BE\rightarrow REU} = \sum_{x=1}^{129} Z_{s_i\rightarrow s_x}^{BE\rightarrow REU} \Big/ \left(\sum_{x=1}^{129} Z_{s_i\rightarrow s_x}^{BE\rightarrow REU} + \sum_{x=1}^{7} F_{s_i\rightarrow f_x}^{BE\rightarrow REU} \right) \quad \text{(eq. 30)}$$

$$\text{fraction } s_i^{BE\rightarrow RoW} = \sum_{x=1}^{129} Z_{s_i\rightarrow s_x}^{BE\rightarrow RoW} \Big/ \left(\sum_{x=1}^{129} Z_{s_i\rightarrow s_x}^{BE\rightarrow RoW} + \sum_{x=1}^{7} F_{s_i\rightarrow f_x}^{BE\rightarrow RoW} \right) \quad \text{(eq. 31)}$$

$\sum_{x=1}^{j} Z_{s_i\rightarrow s_x}^{BE\rightarrow BE}$ (in eq. 29) and its equivalents in eq. 30 and 31 are not readily available in the MRIOT as this summation is based on the Flemish sector classification. Therefore, the normalised concordance matrix is behind this formula.

Negative values in F (due to negative changes in inventories) cause fractions to be negative if $\sum_{x=1}^{129} Z_{s_i \to s_x}^{BE \to REU;RoW} < \left|\sum_{x=1}^{7} F_{s_i \to f_x}^{BE \to REU;RoW}\right|$ or larger than one if $\sum_{x=1}^{129} Z_{s_i \to s_x}^{BE \to REU;RoW} > \left|\sum_{x=1}^{7} F_{s_i \to f_x}^{BE \to REU;RoW}\right|$. Therefore, the fractions $s_i^{BE \to REU}$ and $s_i^{BE \to RoW}$ are calculated excluding the categories changes inventories and changes in valuables in final demand. The fractions $s_i^{BE \to BE}$ result in only one negative faction (s_{58}: processing of nuclear fuel). We assume this fraction is equal to one, meaning we assume all deliveries by the Belgian sector 'processing of nuclear fuel' are intermediary deliveries.

Multiplying the interregional export vector (P.6/regional) with fractions $s_i^{BE \to BE}$ and $1 - s_i^{BE \to BE}$ results in two vectors: Flemish intermediary export to sectors in RoB and Flemish export to final demand in RoB, respectively. To subdivide the vector of exports to EU-27 (P.6/S.21) into exports for intermediary use and final demand use in the REU, we multiply these vectors with $s_i^{BE \to REU}$ and $1 - s_i^{BE \to REU}$ (from eq. 30). To subdivide the vector of exports to non-EU-27 (P.6/S.22) into exports for intermediary use and final demand use in the RoW, we multiply these vectors with $s_i^{BE \to RoW}$ and $1 - s_i^{BE \to RoW}$ (from eq. 31). The aggregated 3-sector level results are provided in **Table 26**. The columns 'Z+F' refer to the original values in **Figure 43**. The columns 'Z' and 'F' present the calculated values.

TABLE 26: DIVISION OF THE FLEMISH EXPORT INTO EXPORT FOR INTERMEDIARY USE AND EXPORT FOR FINAL DEMAND USE. 'ROB': REGIONAL EXPORTS; 'S.21': EXPORTS TO EU-27; 'S.22': EXPORTS TO NON-EU-27.

	RoB Z+F	S.21 Z+F	S.22 Z+F	RoB Z	S.21 Z	S.22 Z	RoB F	S.21 F	S.22 F
primary	218	848	98	179	446	70	39	402	28
secondary	6.427	58.478	13.570	3.813	35.489	8.106	2.614	22.989	5.463
tertiary	6.154	22.369	8.672	4.316	17.923	5.761	1.837	4.445	2.911

Next, the export by Flemish sectors are allocated to the user and the geographic location of this user via a trade coefficient matrix. This combines the last two steps of the three-step procedure in *3.2.1 Methodology*. Intermediary export is allocated to a sector and final demand export is allocated to a final demand category. Trade coefficient matrix is derived from the Belgian allocation, as, to our knowledge, no specific Flemish data is available. It assumes that the use of Flemish exports in RoB is proportionally to the intra-national (Belgian) use of products. The formulas for export to intermediary users are:

$$Z_{s_i \to s_j}^{FL \to RoB} = Z_{s_i \to s}^{FL \to RoB} * \left(Z_{s_i \to s_j}^{BE \to BE} / \sum_{x=1}^{129} Z_{s_i \to s_x}^{BE \to BE} \right) \quad \text{(eq. 32)}$$

$$Z_{s_i \to s_j}^{FL \to REU_r} = Z_{s_i \to s}^{FL \to REU} * \left(Z_{s_i \to s_j}^{BE \to REU_r} / \sum_{y=1}^{129} \sum_{x=1}^{\#REU} Z_{s_i \to s_y}^{BE \to REU_x} \right) \quad \text{(eq. 33)}$$

$$Z_{s_i \to s_j}^{FL \to RoW_r} = Z_{s_i \to s}^{FL \to RoW} * \left(Z_{s_i \to s_j}^{BE \to RoW_r} / \sum_{y=1}^{129} \sum_{x=1}^{\#RoW} Z_{s_i \to s_y}^{BE \to RoW_x} \right) \quad \text{(eq. 34)}$$

with #REU and #RoW the number of REU-regions and RoW-regions in the EXIOBASE 1 MRIOT. The formulas for export to final demand are:

$$F_{s_i \to f_l}^{FL \to RoB} = F_{s_i \to f}^{FL \to RoB} * \left(F_{s_i \to f_l}^{BE \to BE} / \sum_{x=1}^{7} Z_{s_i \to f_x}^{BE \to BE} \right) \quad \text{(eq. 35)}$$

$$F_{s_i \to f_l}^{FL \to REU_r} = F_{s_i \to f}^{FL \to REU} * \left(F_{s_i \to f_l}^{BE \to REU_r} / \sum_{y=1}^{7} \sum_{x=1}^{\#REU} F_{s_i \to f_y}^{BE \to REU_x} \right) \quad \text{(eq. 36)}$$

$$F_{s_i \to f_l}^{FL \to RoW_r} = F_{s_i \to f}^{FL \to RoW} * \left(F_{s_i \to f_l}^{BE \to RoW_r} / \sum_{y=1}^{7} \sum_{x=1}^{\#RoW} F_{s_i \to f_y}^{BE \to RoW_x} \right) \quad \text{(eq. 37)}$$

The equations 35 to 37 result in Flemish export matrices for intermediary use in RoB, REU and RoW with dimensions (119 x 129), (119 x 1935) and (119 x 3612), respectively and Flemish export matrices for final demand use in RoB, REU and RoW with dimensions (119 x 7), (119 x 105) and (119 x 196), respectively.

The next step is linking the Flemish imports to the sector and country of origin. The imports from RoB are converted via correspondence tables to the EXIOBASE MRIOT classification (VMM-MIRA (2016) 'Carbon footprint van Vlaamse consumptie'). The formulas to link intermediary imports from REU and RoW to the country of origin for intermediary use are:

$$Z_{s_j \to s_i}^{REU_r \to FL} = Z_{s_j \to s_i}^{REU \to FL} * \left(Z_{s_j \to s_i}^{REU_r \to BE} / \sum_{x=1}^{\#REU} Z_{s_j \to s_i}^{REU_x \to BE} \right) \quad \text{(eq. 38)}$$

$$Z_{s_j \to s_i}^{RoW_r \to FL} = Z_{s_j \to s_i}^{RoW \to FL} * \left(Z_{s_j \to s_i}^{RoW_r \to BE} / \sum_{x=1}^{\#RoW} Z_{s_j \to s_i}^{RoW_x \to BE} \right) \quad \text{(eq. 39)}$$

The formulas to link final demand imports from REU and RoW to the country of origin are:

$$F_{s_j \to f_k}^{REU_r \to FL} = F_{s_j \to f_k}^{REU \to FL} * \left(F_{s_j \to f_k}^{REU_r \to BE} / \sum_{x=1}^{\#REU} F_{s_j \to f_k}^{REU_x \to BE} \right) \quad \text{(eq. 40)}$$

$$F_{s_j \to f_k}^{RoW_r \to FL} = F_{s_j \to f_k}^{RoW \to FL} * \left(F_{s_j \to f_k}^{RoW_r \to BE} / \sum_{x=1}^{\#RoW} F_{s_j \to f_k}^{RoW_x \to BE} \right) \quad \text{(eq. 41)}$$

The equations 40 and 41 result in Flemish import matrices for intermediary use in REU and RoW with dimensions (129 x 119), (1935 x 119) and (3612 x 119), respectively and Flemish import matrices for final demand use in RoB, REU and RoW with dimensions (129 x 9), (1935 x 9) and (3612 x 9), respectively.

<u>The Flemish EE-MRIOT 2007 (EXIO and WIOD)</u>

The Flemish RIOT of the year 2007 consists out of:

- i=1, …, 122 122 sectors;
- k=1, …, 9 9 final demand categories;
- m=1, …, 6 6 elements in the primary input matrix;
- o=1, …, 447 447 elements in the extension tables; and
- q=1, …, 122 122 product groups in the import matrices.

A simplified 3-sector RIOT of Flanders is given in **Figure 44**.

The import matrices and export vectors are subdivided into rest of Belgium (RoB), rest of Europe (REU) and rest of world (RoW). In the Flemish RIOT of 2007 REU is defined as EU-27, the 27 member states of the European Union in 2007 (Avonds & Vandille, 2008): Austria, Bulgaria, Cyprus, Czech Republic, Germany, Denmark, Estonia, Spain, Finland, France, Greece, Hungary, Ireland, Italy, Lithuania, Luxembourg, Latvia, Malta, Netherlands, Poland, Portugal, Romania, Sweden, Slovenia, Slovakia and United Kingdom. Belgium was a member of EU-27 in 2007, but is excluded from REU.

	FL pri	FL sec	FL ter	int. supply	P.31/ S.14	P.31/ S.15	P.31/ S.13	P.32/ S.13	P.51	P.52	P.6/ S.21	P.6/ S.22	P.6/ RoB	final demand	x
FL pri	188	2.393	408	**2.989**	942	0	0	0	44	15	996	153	371	**2.522**	**5.512**
FL sec	1.499	44.254	14.303	**60.055**	11.287	1	220	0	21.923	1.405	74.842	17.981	7.525	**135.185**	**195.240**
FL ter	821	28.264	57.732	**86.816**	54.610	1.511	22.996	11.623	6.573	490	28.997	13.268	9.383	**149.449**	**236.266**
int. use	**2.508**	**74.910**	**72.443**	**149.860**	**66.840**	**1.511**	**23.215**	**11.623**	**28.540**	**1.910**	**104.835**	**31.403**	**17.280**	**287.157**	**437.017**
RoB pri	9	194	15	**219**	6	0	0	0	2	1	0	0	0	**8**	**227**
RoB sec	76	2.080	1.133	**3.289**	1.094	0	57	0	230	39	0	0	0	**1.420**	**4.709**
RoB ter	112	2.056	6.544	**8.712**	8.718	558	2.303	4.426	208	8	0	0	0	**16.221**	**24.933**
import RoB	**197**	**4.331**	**7.693**	**12.221**	**9.818**	**558**	**2.360**	**4.426**	**440**	**47**	**0**	**0**	**0**	**17.649**	**29.869**
REU pri	46	8.004	276	**8.325**	464	0	0	0	62	-47	782	1.041	0	**2.302**	**10.628**
REU sec	274	41.999	7.806	**50.079**	9.259	1	424	0	7.976	471	25.483	6.755	0	**50.369**	**100.448**
REU ter	83	3.610	12.250	**15.943**	574	0	0	0	494	0	189	62	0	**1.319**	**17.262**
import REU	**403**	**53.612**	**20.332**	**74.347**	**10.298**	**1**	**424**	**0**	**8.533**	**424**	**26.453**	**7.858**	**0**	**53.991**	**128.338**
RoW pri	33	2.615	97	**2.745**	225	0	0	0	5	10	634	2.161	0	**3.034**	**5.779**
RoW sec	66	10.195	2.169	**12.430**	2.736	0	100	0	2.215	151	8.214	4.480	0	**17.897**	**30.327**
RoW ter	33	1.589	5.394	**7.017**	203	0	0	0	193	0	53	29	0	**479**	**7.496**
import RoW	**131**	**14.400**	**7.661**	**22.192**	**3.164**	**0**	**100**	**0**	**2.412**	**161**	**8.901**	**6.670**	**0**	**21.410**	**43.602**
D.21-D.31	315	725	4.251	**5.291**	11.254	1	140	0	4.740	-10	364	52	0	**16.541**	
D.1	497	27.769	66.588	**94.854**											
D.29	9	562	2.491	**3.062**											
D.39	-398	-796	-1.790	**-2.984**											
B.2N	1.210	10.596	35.036	**46.842**											
K.1	639	9.133	21.561	**31.332**											
primary input	**2.272**	**47.988**	**128.137**	**178.398**											
x'	**5.512**	**195.241**	**236.265**	**437.018**	**101.373**	**2.072**	**26.239**	**16.048**	**44.667**	**2.532**	**140.552**	**45.983**	**17.280**	**396.747**	

FIGURE 44: THE FLEMISH 3-SECTOR REGIONAL INPUT-OUTPUT TABLE (RIOT) FOR 2007.

The EXIOBASE 2 MRIOT (Tukker et al., 2013; Wood et al., 2015a) consist out of[19]:

- j=1, …, 163 — 163 sectors;
- r=1, …, 48 — 43 countries and 5 RoW-region
- l=1, …, 7 — 7 final demand categories;
- n=1, …, 19 — 19 elements in the primary input matrix; and
- p=1, …, 469 — 469 elements in the extension tables.

The WIOD Release 2013 consist out of:

- j=1, …, 35 — 35 sectors;
- r=1, …, 41 — 40 countries and 1 RoW-region
- l=1, …, 5 — 5 final demand categories;

[19]See *Appendix 3: Flemish RIOT 2010 sector classification*.

- n=1, …, 5 5 elements in the primary input matrix; and
- p=1, …, 148 148 elements in the extension tables.

The construction of the Flemish EE-MRIOT 2007 is similar to the construction process of the Flemish EE-MRIOT 2003 explained above.

<u>The Flemish EE-MRIOT 2010 (EXIO)</u>
The Flemish RIOT of the year 2007 consists out of:

- i=1, …, 124 124 sectors;
- k=1, …, 9 9 final demand categories;
- m=1, …, 7 7 elements in the primary input matrix;
- o=1, …, 51 51 elements in the extension tables; and
- q=1, …, 124 124 product groups in the import matrices.

A simplified 3-sector RIOT of Flanders is given in **Figure 45**.

The import matrices and export vectors differ from the 2003 and 2007 RIO-models. The Flemish RIOT is part of an interregional model which, next to Flanders, contains Brussels Capital Region, Walloon and extra regional areas of Belgium (e.g. embassies). Import matrices and export vectors from and to regions outside Belgium (except the extra regional areas of Belgium) are given for rest of Europe (REU) and rest of world (RoW). In the Flemish RIOT of 2010 REU is defined as EU-28, the 28 member states of the European Union in 2010 (Luc Avonds, 2008; L. Avonds & Vandille, 2008): Austria, Bulgaria, Croatia, Cyprus, Czech Republic, Germany, Denmark, Estonia, Spain, Finland, France, Greece, Hungary, Ireland, Italy, Lithuania, Luxembourg, Latvia, Malta, Netherlands, Poland, Portugal, Romania, Sweden, Slovenia, Slovakia and United Kingdom. Belgium was a member of the EU-28 in 2010, but is excluded from REU.

	FL pri	FL sec	FL ter	**int. supply**	P.31/ S.14	P.31/ S.15	P.31/ S.13	P.32/ S.13	P.51	P.52	P.61	P.62	P.6/ RoB	**final demand**	**x**
FL pri	382	2.743	567	**3.692**	471	0	0	0	55	9	1.273	27	1.004	**2.840**	**6.532**
FL sec	2.011	43.154	13.022	**58.186**	8.996	0	142	137	24.126	510	73.476	4.594	23.449	**135.431**	**193.617**
FL ter	1.200	18.051	55.980	**75.231**	55.890	1.683	27.751	13.489	4.596	101	17.068	34.945	21.743	**177.267**	**252.498**
int. use	**3.593**	**63.947**	**69.569**	**137.109**	**65.358**	**1.683**	**27.893**	**13.626**	**28.777**	**620**	**91.817**	**39.566**	**46.197**	**315.537**	**452.646**
RoB pri	47	925	174	**1.146**	33	0	0	0	15	14	235	5	0	**301**	**1.447**
RoB sec	235	6.802	2.635	**9.672**	2.328	0	23	42	947	116	8.620	70	0	**12.146**	**21.818**
RoB ter	139	4.786	13.631	**18.555**	8.155	571	3.067	3.843	718	26	2.543	24	0	**18.947**	**37.502**
import RoB	**421**	**12.513**	**16.440**	**29.373**	**10.515**	**571**	**3.089**	**3.885**	**1.680**	**156**	**11.398**	**99**	**0**	**31.394**	**60.767**
REU pri	78	8.839	368	**9.285**	701	0	0	0	46	20	3.654	15	0	**4.437**	**13.722**
REU sec	174	40.128	6.758	**47.059**	11.998	1	539	0	7.454	440	28.365	369	0	**49.166**	**96.226**
REU ter	44	4.496	14.429	**18.969**	3.594	0	0	0	257	0	115	5	0	**3.972**	**22.941**
import REU	**296**	**53.463**	**21.555**	**75.314**	**16.294**	**1**	**539**	**0**	**7.758**	**460**	**32.133**	**390**	**0**	**57.575**	**132.888**
RoW pri	20	2.856	101	**2.977**	308	0	0	0	2	31	5.710	7	0	**6.058**	**9.035**
RoW sec	42	10.583	1.891	**12.516**	3.190	1	152	0	1.821	110	12.051	92	0	**17.416**	**29.932**
RoW ter	16	2.152	6.466	**8.634**	913	0	0	0	69	0	19	1	0	**1.002**	**9.636**
import RoW	**78**	**15.591**	**8.458**	**24.127**	**4.411**	**1**	**152**	**0**	**1.892**	**141**	**17.780**	**100**	**0**	**24.476**	**48.603**
D.21-D.31	231	928	3.798	**4.957**	11.962	1	228	0	4.570	-47	101	491	0	**17.305**	
D.1	376	29.022	73.246	**102.643**											
D.29	45	723	2.984	**3.752**											
D.39	-352	-1.688	-2.603	**-4.643**											
B.2N	1.313	8.509	34.114	**43.935**											
K.1	532	10.611	24.937	**36.080**											
primary input	**2.144**	**48.104**	**136.475**	**186.723**											
x'	**6.532**	**193.618**	**252.497**	**452.646**	**108.540**	**2.257**	**31.902**	**17.511**	**44.677**	**1.330**	**153.230**	**40.644**	**46.197**	**446.287**	

FIGURE 45: THE FLEMISH 3-SECTOR REGIONAL INPUT-OUTPUT TABLE (RIOT) FOR 2010.

In the RIOT the international export vector does not distinguish between export to EU-27 and export to non-EU-27, but between export of goods (P.61) and export of services (P.62). Therefore, the subdivision is based on the Belgian shares of sectoral exports.

The construction of the Flemish EE-MRIOT 2010 is similar to the construction process of the Flemish EE-MRIOT 2003 explained above.

3.3 IMPROVING FOOTPRINT CALCULATIONS OF SMALL OPEN ECONOMIES: COMBINING LOCAL WITH MULTI-REGIONAL INPUT-OUTPUT TABLES

This section is redrafted from Christis M., Geerken T., Vercalsteren A. & Vrancken K. (2016). Improving footprint calculations of small open economies: combining local with multi-regional input-output tables. Economic Systems Research. doi:10.1080/09535314.2016.1245653

Key message

A combined environmentally extended local input-output (EE-RIO) and environmentally extended multi-region input-output (EE-MRIO) model results in the best local footprint estimation possible, as this estimation is based on all data available. The domestic technology assumption and using national data to represent a local area results in substantial specification errors leading to unreliable indicator estimations (**Table 26**). Researchers should reflect on the indicator being studied before choosing the optimum model: Is the indicator determined by mainly domestic or foreign economic/environmental characteristics? Does import play an important role in the estimation of the indicator? Is the footprint influenced by large country and/or sector differences? Are the underlying coefficients stable over time or subject to trends?

From a local perspective when facing the task of aligning local data with data in an (EE-) MRIO model, the preferable option is to use a combined or linked EE-RIO and EE-MRIO model with the highest available resolution, otherwise specification errors would become unacceptably large in a globalized world, due to the assumption of domestic technology and price levels abroad. By combining a EE-RIO and a EE-MRIO model, the analysis is based on all the local data available, adapted to the local economic characteristics, and includes global sectoral use/creation/impacts. For open economies, such as Flanders, most indicators are determined both by local and global specific characteristics, resulting in large specification errors if not all country-specific data is included in the model. Indicators mainly determined by domestic characteristics require at least the use of an EE-RIO model; indicators mainly determined by foreign characteristics require at least the use of an EE-MRIO model.

From the footprints tested in this paper, we can conclude that aggregation of non-neighbouring countries (i.e. aggregating no major trading partners) leads to small errors. All the indicators tested benefit from secondary sector disaggregation. Only some indicators benefit from primary sector disaggregation, for example the water and material footprint, as these indicators are largely determined by primary sector coefficients. Using data based on a different year is only a valuable option in estimations for indicators if coefficients tend to be stable over time. Trends could have only a small impact on coefficients and multipliers, however, the consistent over- or underestimation of coefficients and multipliers certainly results in deviated footprint estimations. A detailed reflection on the indicator under consideration to determine the optimum model helps to understand the possible estimation errors in final footprint estimations. The key is to find the optimal balance between investments in model adoption and/or extension and the reliability of estimation results.

Highlights

- For every estimation of an indicator the reflection on the data model is key.
- Combining local and multi-regional input-output models are essential for open economies.
- The developed methodology of linking regional with multi-regional input-output tables allows for varying sector classification between regions, allowing sector classifications adapted to the local economic characteristics.

Keywords

- regional input-output tables
- multi-regional input-output tables
- specification errors

- aggregation errors
- time errors

Citation: Christis M., Geerken T., Vercalsteren A. & Vrancken K. (2016). Improving footprint calculations of small open economies: combining local with multi-regional input-output tables. Economic Systems Research. doi: 10.1080/09535314.2016.1245653

3.3.1 Abstract

In a small, open and resource-poor economy, import and export dependency has an ever-growing impact on local policy decisions, which makes local (environmental) policy makers increasingly depend on global data. This increases the interest in models that link local production and consumption data to global production, trade and environmental data. The recent increase in availability of global environmentally extended multiregional input-output tables (EE-MRIO tables) provides an opportunity to link them with existing local environmentally extended input-output tables (EE-RIO tables). These combined tables make it possible (1) to analyse the links between local and global production and consumption and (2) to study global value chains, material use and environmental impacts simultaneously. However, estimations using input-output analyses contain errors due to imperfect databases. In this article, using as a case study the linking of the local Flanders IO table with relevant EE-MRIO tables, the magnitude of specification, aggregation and time errors is estimated and compared. The results show the need to combine local datasets with multiregional ones and the limitation of the domestic technology assumption for open economies. The results also show that both highest detailed (country and sector level) as well as time series of global EE-MRIO tables and EE-RIO tables are the way forward for using IO analyses in local policy making and analysis in social and environmental topics, especially for open economies. It is up to the user to determine the required level of detail, since this can differ for each topic. A detailed reflection on the indicator being studied is recommended, to determine the choices for the optimum model, as it helps the user to understand the possible errors in footprint estimations in advance of building the model. The paper provides guidance on trading off investments in model adoption and/or extension and the reliability of estimation results.

3.3.2. Introduction

The production of goods and services for society is the goal of the economy (Parsons & Smelser, 1984, p. 20). Today, goods and services are produced by global value chains to meet local societies' demand. The economic contribution of a firm, sector or country to a product it produces is captured by the total value added it generates. A value chain is the full range of activities (design, production, marketing, logistics and distribution) that firms engage in to bring a product to the market, from conception to final use. Both social and environmental impacts are closely linked to these value chains and are influenced by their volume and changes within them, but can also influence value chains through, for example, restrictions and scarcity. In local, national and international statistics it is of great importance to trace and analyse global value chains, trade in value added and value added in trade (Stehrer, 2012). The creation of products can be analysed from a worldwide perspective, while double counting is avoided in contrast to gross trade flows (OECD, 2013).

Local policies mainly impact the parts of value chains that include actors in their own region. In other words, policies can influence final demand in their own region and can impact the local agricultural, industrial and service-related parts of global value chains. To understand their contributions in internationally-dispersed value chains and to determine the 'relative' impact of local policy decisions and possible rebound effects, one has to look at the whole picture, including intersectoral, interregional and international trade and embodied social and environmental impacts. Using environmentally extended multiregional input-output tables (EE-MRIO tables) and following the definition of trade in value added given by the OECD, WTO and UNCTAD[20], it would be possible to ascertain worldwide value networks of goods and services and provide insights into the creation, composition[21] and destination of value added, as well as into the worldwide use of material resources, social consequences and environmental impacts related to local final demand. IO tables provide a complete macro-economic understanding on the economic impacts that are crucial in developing policies, as well as the links with social and environmental impacts (OECD et al., 2013). By linking environmentally extended local input-output tables (EE-RIO tables) to EE-MRIO tables, we both obtain structured local data and determine a complete picture of the world economy, including economic data as well as social and environmental extensions (Tukker & Dietzenbacher, 2013) (Inomata & Owen, 2014).

In the past, IO tables were constructed for regions and countries serving many purposes. With the improvements in the quality and availability of data, these tables have been extended with satellite accounts including environmental and social data. In parallel, models now include a growing number of sectors and products. Globalization with higher impacts of import and export has increased interest in constructing multiregional input-output tables. Recently, these improvements have led to the development of environmentally extended multiregional input-output tables covering the whole world, meaning that many country-specific or regional IO tables are joined together and a proxy model is developed to represent the rest of the world economy (Dietzenbacher, E. et al., 2013a). Examples are: EXIOBASE (Tukker, Arnold et al., 2009), WIOD (Dietzenbacher, E. et al., 2013b; Timmer, 2012), Eora (Lenzen et al., 2012; Lenzen et al., 2013), GTAP (Andrew & Peters, 2013; Narayanan et al., 2012), GRAM (Bruckner et al., 2012). As long as it is impossible to create a *complete* EE-MRIO covering all regions, states, provinces, counties or neighbourhoods, detailing many hundreds of sectors and products and including all possible extensions, all based on consistent and reliable time series data, researchers will have to live with models that try to simulate reality by using, adopting and extending existing models so as to be suitable for their applications.

If we assume that the *complete* model would generate the results closest to reality, then existing models generate results deviating from reality, thus including errors. Moran and Wood concluded that their results show substantial quantitative variation between models, even after harmonising the extension tables. In consumer-based account results, there are differences of up to 10-20% for major

[20]Trade in value added is defined by the OECD, WTO and UNCTAD (2013) as: "a statistical approach used to estimate the sources of value (by country and industry) that is added in producing goods and services. It recognises that growing global value chains mean that a country's exports increasingly rely on significant intermediate imports and, in turn, value added by industries in upstream countries. […] The trade in value added approach traces the value added by each industry and country in the production chain and allocates the value added to these source industries and countries."(OECD et al., 2013).

[21]Compensation of employees, use of fixed capital, operating surplus and taxes and subsidies on products and production.

economies. The degree of differences varies by country and depending on which models are compared (Moran & Wood, 2014). Hoekstra et al. conclude that sensitivity of carbon footprints is large for some countries, especially for small open economies (Hoekstra et al.). It is relevant to gain an idea of the extent to which empirical results are influenced by different databases and the extent to which they may lead to differing policy interpretations and different conclusions for decision making.

Three overarching errors related to the lay-out of an EE-(M)RIO table are: (1) specification errors due to limited data on foreign regions or countries regarding the technologies and extensions, (2) aggregation errors due to limited detail in domestic and/or foreign sectoral data or mismatching between sources and (3) time errors due to incomplete data sets or imperfect matches due to different base years. Another possible source of errors, which is not covered by this paper, is the uncertainty underlying the data and calculation procedures of a (global) IOT (Lenzen et al., 2010). **Table 27** specifies the options that currently exist in regional IO analyses and the possible errors to expect. Option 1 is an IO-analysis (Miller & Blair, 2009) using an EE-RIO model. This type of analysis implies a model abstraction for foreign production chains linked to extra-regional trade or, if not modelled, the exclusion of production abroad due to import and export leakages. Once a production chain requires an import or export, it is not further captured by the model, i.e. import or export leakage. Option 2 is an IO-analysis using an EE-MRIO model, implying that regional specific data is not included. Option 3 is an IO-analysis using a linked EE-RIO/EE-MRIO model. Mismatches between those models complicate the analysis. From a practitioners point of view, it is possible that the sector or product classification as well as the model base year do not correspond to policy needs, resulting for all options in aggregation and time errors, respectively.

TABLE 27: OPTIONS AND EXPECTED ERRORS IN ANALYSING LOCAL PRODUCTION AND CONSUMPTION VIA IO ANALYSIS. AE: AGGREGATION ERROR; SE: SPECIFICATION ERROR; TE: TIME ERROR

	model	**error**	**(sub)optimal solution (non-exhaustive)**
option 1	EE-RIO	aggregation error (sector), specification error (extra-regional trade) and time error	AE: disaggregation based on national IO data or other sources SE: use (price corrected[22]) domestic coefficients for imports TE: correct for price changes
option 2	EE-MRIO	aggregation error (sector), specification error (region; rest of world model) and time error	AE: disaggregate based on local IO data or other source SE: use regional extension coefficients TE: correct for price changes
option 3	EE-RIO+EE-MRIO	aggregation (sector and region), specification error (rest of world model) and time error	AE(sector): disaggregate based on national IO data or other sources TE: correct for price changes

[22](See for example: Tukker et al., 2012)

Specification errors always occur in calculations with IO tables that do not cover the entire world. Even IO models covering the entire world, but using a proxy model to represent the rest of the world, are subject to specification errors. Specification errors result from the assumption that all imports from trading partners not included in the model are produced with the same interindustry and environmental coefficients as a region/country included in the model. A specification error arises in the calculation results influenced by foreign inputs based on an IO-model that incorrectly specifies foreign data, for example by using the domestic technology assumption. The error is the difference between the same calculation based on a model correctly specifying foreign data and a model incorrectly specifying foreign data. As stated by Bouwmeester and Oosterhaven (2013, p. 308): “This domestic technology and emission assumption enables the use of single-country data to estimate emissions embodied in both its imports and exports. When technologies or emission coefficients differ, these assumptions create specification errors.” The total specification error can be broken down into a domestic technology error and a domestic emission error. In their study on embodied CO_2 emissions and water use footprints, Bouwmeester and Oosterhaven (2013) found that the total specification errors can grow to unacceptable proportions. Furthermore, Andrew et al. (2009) conclude in their paper on carbon footprints that the domestic technology assumption introduces significant errors and means that careful validation is required before using these results. However, the assumption results in better estimates than ignoring imports (Andrew et al., 2009). Watson and Moll (2008) stress the importance of considering specification errors. They state that “accurately assessing the pressures released along global value chains of consumed goods would require harmonisation and linking of NAMEAs[23], both for the EU but also all the major importers to EU countries.” (Watson & Moll, 2008).

Aggregation errors cover both sector and spatial aggregation errors. Typically, firms are grouped into sectors based on similarity of outputs and processes and regions are added based on data availability and their importance in the world economy. Adding data to disaggregate sectors or regions increases both the accuracy (Steen-Olsen et al., 2014) and the costs of constructing the IO model. In theory, disaggregation will eventually lead to a model based on firm-level data. In practice, however, disaggregation will end after a few tens or hundreds of sectors and a few tens of regions are included in the model due to either budget limits, confidentiality or limited availability of data. Next, many diverse firms are grouped into only a few sectors in IO models. Firm-level differences in economic inputs, value added coefficients, emissions, material use, etc. make the aggregated sector heterogeneous. Of course, aggregation bias is more severe when aggregated industries have very different structures. The characteristics of sectors are represented by the weighted averages of the characteristic of the firms aggregated within them (Steen-Olsen et al., 2014). Disaggregation is likely to increase the accuracy of the model in many ways. Aggregation errors arises in the calculation results based on an IO-model with aggregated sectors and/or countries. The error is the difference between the same calculation based on a model with disaggregated sector and country data and a model with aggregated data. Steen-Olsen et al. (2014), focussing on CO_2 multipliers, conclude that the additional information provided by the extra sector detail may warrant the additional costs of compilation due to the heterogeneous nature of economic sectors in terms of their environmental characteristic. Su et al. (2010) conclude in their paper on the effects of sector aggregation on CO_2 emissions embodied in trade that levels around 40 sectors appear to be sufficient to capture the overall share of emissions embodied

[23]National Accounting Matrix including Environmental Accounts

in a country's exports. Of course, these results depend on how 40 sectors are (dis)aggregated (Su et al., 2010). Su & Ang (2010) studied the effects of spatial aggregation on CO_2-emissions embodied in trade. The paper presents a numerical example using data for China subdivided into eight regions. They found that the results are highly dependent on spatial (dis)aggregation (Su & Ang, 2010). These results indicate the possible impact of aggregation errors and the need for considering both sectoral and spatial disaggregation.

The process of linking an existing EE-RIO table to an existing EE-MRIO table requires aggregation or disaggregation of sectors due to imperfect matches between these tables or to work with different sector level detail, as for example in the Eora database. Disaggregation of environmental and economic data, even with increased uncertainty about the validity of the final data set, is preferable to aggregation, because aggregation implies an undesirable loss of detail (Bouwmeester & Oosterhaven, 2013; Lenzen, 2011; Su et al., 2010). One problem that occurs frequently, however, is that the product/sector classification of RIO tables is especially adapted to the local economic structure, which can differ substantially from the product/sector classification used in MRIO tables. Based on time and cost limitations, disaggregating sectors (one sector into more than one subsectors) in RIO tables using national data from MRIO tables or local/national data from other sources is preferable, whereas disaggregating MRIO tables is much less so. Methodologies of disaggregation is explained in the literature, e.g. (Lindner et al., 2012; Wenz et al., 2015; Wolsky, 1984). By way of example, the EE-RIO tables of Flanders (*adj.: Flemish*) subdivide the chemical sector into six sectors, while this distinction is not present in, for example, the EXIOBASE 1 and WIOD databases. The opposite is the case for the mining industry, which is represented on an aggregated level in Flemish EE-RIO tables and WIOD, but disaggregated in EXIOBASE 1 (Dils et al., 2012).

When coupling a local EE-IO table to an EE-MRIO table with different base years or when IO-tables are not available for a certain year in line with policy needs, time errors arise in the calculation results from it. The error is the difference between the same calculation based on a model of a certain year complying to policy needs and (part of) a model of a year not complying to policy needs. Any dataset can suffer from a mismatch between the data year and the policy needs, but especially detailed IO-tables are only compiled every few years. The costs of compiling IO tables are high, and as a consequence these tables are currently only available either yearly at a highly aggregated sector and/or spatial level, with varying sectoral detail per region and per time period, or on an *ad hoc* basis with a highly disaggregated sector and/or spatial level. There is a wide variety of methods for updating matrices, with pure survey-based methods at one end of the spectrum, pure mathematical or automatic methods at the other end, and various combinations of the two in between (Rørmose, 2011). Nonetheless, the UN emphasises that no purely mathematical or automatic method would be able to replace updating coefficients in supply and use tables or IOT by survey based or similar statistical methods. (Rørmose, 2011; UN, 1999).

To investigate the added value of combining local and global IO tables in local analysis and to provide an indication and comparison of the different errors, Flanders is introduced as a case study. Flanders (the northern part in Belgium) is a geographically-small region at the centre of Europe with an open economy that is due to its low accessibility to material resources and high labour costs[24]. Considering the relatively high volume of imports by the Flemish economy and society and the high dependence on foreign demand (exports), linking Flemish EE-IO tables (currently data for 2003, 2007 and 2010) with EE-MRIO data so as to fully incorporate and understand the entire value chains of Flemish goods and services (both intermediate and finished goods and services) is necessary to provide support for Flemish policy decisions. None of the existing MRIO tables contain Flanders as a separate region, although Belgium is included in MRIO tables. The economic differences (e.g. access to harbours and economic composition in sectors) between the three regions in Belgium (Wallonia, Brussels and Flanders) mean that Belgium, as included in EE-MRIO tables, is not representative of Flanders and not useful in local policy analysis.

In this paper we calculate, map and discuss the different errors that arise from IO calculations using the three options mentioned in **Table 27**, including implementation of the suboptimal solutions. The calculations are based on the Leontief inverse using straightforward economic and non-economic indicators. All analyses are performed from the Flemish perspective. As in the paper written by Miller and Shao, the term ‘error’ suggests that the most disaggregated model is most accurate. All calculations based on less detailed models create deviating results in which the deviation is described as an ‘error’. As there is in the literature no common agreement on this term, it is possible to describe the work in this paper as an investigation into the sensitivity of (EE-)RIO/MRIO models (Miller & Shao, 1990).

3.3.3 Approach and Method

‘The sum of foreign and domestic value added equates to gross exports’ (OECD et al., 2013), which states that the market value of exports is equal to a country’s own value creation plus the value created in the foreign supply chain/network via imports of these exported products. In our globalized economy, it is hard to describe a product value chain exactly, especially if one goes beyond the immediate supply chain partners, as networks become both internationally and sectorally more dispersed over time. Nonetheless, the market value of goods and services is equal to the sum of taxes less subsidies on products, international trade margins and gross value added. As global MRIO are a reflection of the economy, they describe this as:

$$\sum \mathrm{F_{global}} = \sum \mathrm{VA_{global}} \qquad \text{(eq. 42)}$$

which states that the value (e.g. in Euros) of the global final demand (F) equals to global value added (VA) creation. In a local or national IO table, this is expressed as:

$$\sum \mathrm{F_{region/nation}} = \sum \mathrm{VA_{domestic}} + \sum \mathrm{VA_{foreign}^{net}} \qquad \text{(eq. 43)}$$

which states that the final demand of a region or nation is equal to total domestic value added plus total value added in imports minus total value added in exports.

[24] 98% of Flemish primary resource uses are satisfied by imports (in monetary values); 42% of total intermediary inputs (i.e. the consumption of goods and services by companies) are imported; 24% of Flemish final consumption is import. 54% of Flemish output and 72% of Flemish GDP is generated in the tertiary economy (tertiary economy: NACE rev. 1 division 50 – 90); 45% of output and 27% of GDP is generated in the secondary economy (secondary economy: NACE rev. 1 division 15 – 45); only 1% output and 1% GDP is generated in the primary economy (primary economy: NACE rev. 1 division 01 – 14).

In other words, this is equal to the sum of value added generated by all the firms participating in value chains of products in this final demand. A straightforward MRIO analysis (Miller & Blair, 2009) is capable of approximating this complete network of value chains. The value added creation and composition is described by:

$$\mathrm{VA} = \hat{\mathrm{k}}_{\mathrm{coef}} \times \mathrm{L} \times \hat{\mathrm{f}} \qquad \text{(eq. 44)}$$

with:

- $\hat{\mathrm{k}}_{\mathrm{coef}}$: diagonalized vector of total value added coefficient by sectors: $\mathrm{k}_{\mathrm{coef}} = (\mathrm{K} \times \mathrm{i}) \times \hat{\mathrm{q}}^{-1}$, with K the value added matrix, i the corresponding summation vector and q the output vector;
- L: Leontief-inverse $\mathrm{L} = (\mathrm{I} - \mathrm{A})^{-1}$ with $\mathrm{A} = \mathrm{Z} \times \hat{\mathrm{q}}^{-1}$, Z the matrix containing the interindustry deliveries and I an identity matrix;
- $\hat{\mathrm{f}}$: diagonalized final demand vector; and
- VA: resulting value added[25] matrix.

The sum of matrix VA from eq. 44 is the total value added as a result of final demand. The row total of matrix VA is the total value added by an industry in a country. A row vector from matrix VA reveals the contribution, expressed in value added, that a sector makes in all value chains worldwide (industry perspective). A column total of matrix VA is the total final demand for a product or service of an industry in a country A column vector from matrix VA it reveals the value added composition of the market value of that product or service (product perspective).

The above methodology can also be applied to social or environmental extensions to calculate both the industry contributions (industry perspective) and the impacts due to final demand (consumption perspective). The general formula is:

$$\mathrm{E} = \hat{\mathrm{e}}_{\mathrm{coef}} \times \mathrm{L} \times \hat{\mathrm{f}} \qquad \text{(eq. 45)}$$

with:

- $\hat{\mathrm{e}}_{\mathrm{coef}}$: diagonalized extension vector with summed coefficients derived from the extension matrix E; and
- E: resulting extension matrix.

The interpretation of matrix E in eq. 45 is equal to that of VA in eq. 44, except that interpretation of E is linked to the social or environmental extension and the row vector containing all column totals of E is no longer equal to the final demand vector. The column totals contain global value chain impacts linked to the production of that product or service expressed in the unit of the extension.

The value added multiplier ($\mathrm{m}^{\mathrm{VA}} = \hat{\mathrm{k}}_{\mathrm{coef}} \times \mathrm{L}$) and extension multiplier ($\mathrm{m}^{\mathrm{e}} = \hat{\mathrm{e}}_{\mathrm{coef}} \times \mathrm{L}$) provide a better understanding of the underlying sector-specific error, independent of final demand volumes (Steen-Olsen et al., 2014). Footprint results weight multipliers by regional consumption volumes, meaning that the footprint results (matrix VA) are the product of sector-based multipliers weighed by consumption volumes.

Based on eq. 44 for economic impacts and eq. 45 for social and environmental impacts, one can perform a general IO calculation using different IO datasets. We assume that calculations with the most complete IO dataset available will provide

[25] Here, value added is defined as the sum of taxes less subsidies on products, international trade margins and gross value added at basic prices.

the result closest to reality (Miller & Shao, 1990). The same calculation with a less complete IO dataset gives a result containing errors. By comparing these results, one can calculate the magnitude of the errors made using this incomplete IO dataset compared to the better alternative available. By carefully adjusting the incomplete dataset, we can estimate specification, aggregation and time errors separately from one another.

Two types of IO analysis are performed to estimate calculation errors: IO analysis focussing on economic results using matrix K (technical coefficients) and IO analysis focussing on non-economic results using the extension vectors E (social or environmental coefficients). The difference between these types of IO analysis can be contributed to the relationship between coefficient matrix K and the Leontief inverse: changes in the share of value added in output results in changes of the share of intermediates and therefore in changes in both A and L matrices. This direct relationship between coefficient matrix K and A does not exist between the coefficient vectors of E and A: changes in vector E, all other things being equal, have an impact on the coefficients of vector E but do not result in changes in matrices K, A or L. Steen-Olsen et al. (2014) state that the impact of sector aggregation may be larger in environmental IO analysis than in economic IO analysis for two reasons: (1) there are technological limits to the variation in economic inputs and value-added coefficients between industries, where emission intensities can easily differ by order of magnitude from one industry to the next, and (2) aggregated sectors that appear similar may in fact be very different in studying non-monetary factors like labour and environmental interventions.

In this paper we use generic economic and non-economic indicators that can be derived from IO analysis, based on the Leontief inverse. The indicators used in this paper are listed in **Table 28**.

TABLE 28: THE LIST OF INDICATORS USED IN THIS PAPER WITH THEIR FOCUS AND A BRIEF DESCRIPTION.

indicator	focus	description
domestic value added footprint	economic (estimated using eq. 44)	domestically generated value added linked to products consumed by local final demand (excl. export)
service content in export	economic (estimated using eq. 44)	globally generated value added by the tertiary sector linked to products exported by the local economy
material value footprint	economic (estimated using eq. 44)	globally generated value added by the primary sector linked to products consumed by local final demand (excl. export)
compensation footprint	economic (estimated using eq. 44)	the compensation of employees (globally) linked to products consumed by local final demand (excl. export)
employment footprint	social (estimated using eq. 45)	the number of persons engaged in the production process of products consumed by local final demand (excl. export)
carbon footprint	environment (estimated using eq. 45)	global GHG-emissions[26] emitted in value chains linked to product consumed by local final demand (excl. export)

[26] GWP is calculated as GHG emissions including carbon dioxide (impact factor 1), methane (impact factor 21) and nitrous oxide (impact factor 310).

material footprint	environment (estimated using eq. 45)	global primary material use in the production processes of products consumed by local final demand
energy footprint	environment (estimated using eq. 45)	global energy use in the production processes of products consumed by local final demand
water footprint	environment (estimated using eq. 45)	global water use in the production processes of products consumed by local final demand

All indicators described in **Table 28** look from different perspectives at the industry contributions/use/impact in the global production chains linked to final consumption. The domestic value added footprint is little influenced by foreign data quality as the weight of this indicator is largely determined by the domestic economy. The service content in exports and the material value footprint look at the global value added creation in the tertiary and primary sectors respectively. For Flanders, these economic indicators depend to a large extent on foreign data. The difference between the economic indicator on compensation of employees and the non-economic indicator on the number of persons engaged is significant. While the compensation is mainly determined by high-income activities and countries, the number of persons engaged in production is largely determined by low-income activities and countries. The other non-economic indicators cover the carbon, material, energy and water footprint. Each indicator is estimated using several IO models to estimate specification, aggregation and time errors in regional analysis. These models are explained in the next section.

3.3.4 Combining the Flemish Input-Output Database with Global Multiregional Input-Output Databases

The Flemish EE-RIO table (2007 data) contains 122 sectors (of which 116 have a non-zero output), 9 final use categories, three import regions: RoB (rest of Belgium), REU (rest of Europe) and RoW (rest of world), and 6 value added categories (OVAM, 2007). Environmental data in the extension tables comprises around 400 items. Social data is added via extensions and supplemented with sector-aggregated annual accounts of companies provided by the National Bank of Belgium.

WIOD (1995-2011 data) is a global EE-MRIO database constructed by a project of the 7th Framework Programme. The database covers 35 sectors for 40 countries and 1 rest-of-world region, and contains more than 100 items in the extension tables. Flanders is indirectly included in the WIOD database via Belgium. (Timmer, 2012; Timmer et al., 2015)

EXIOBASE 2 (2007 data) is a global EE-MRIO database produced in the context of the project ‘Compiling and Refining of Economic and Environmental Accounts’ (CREEA). The database covers 200 products and 163 industries for 43 countries and 5 rest-of-world regions. The extension tables contain 15 land use types, employment broken down by three skill levels, 48 types of raw materials and 172 types of water use. Flanders is indirectly included in the EXIOBASE 2 database via Belgium. (Tukker et al., 2013; Wood et al., 2015b).

The Flemish EE-RIO table is extended with data on foreign trade and country-specific extensions from a MRIOT (e.g. WIOD or EXIOBASE 2). The basic structure is illustrated in **Figure 46**. The methodology is explained in *3.2.1 Methodology* and is closely related to the multi-scale multi-region input-output model by Bachmann et al. (2015). The difference is this methodology adds a sub-region to an existing MRIO, while Bachmann et al. replace a nation with its sub-regions. A similarity is the accounting for different sectoral representations. In *3.2.2 Case of Flanders* the specific case of Flanders is explained.

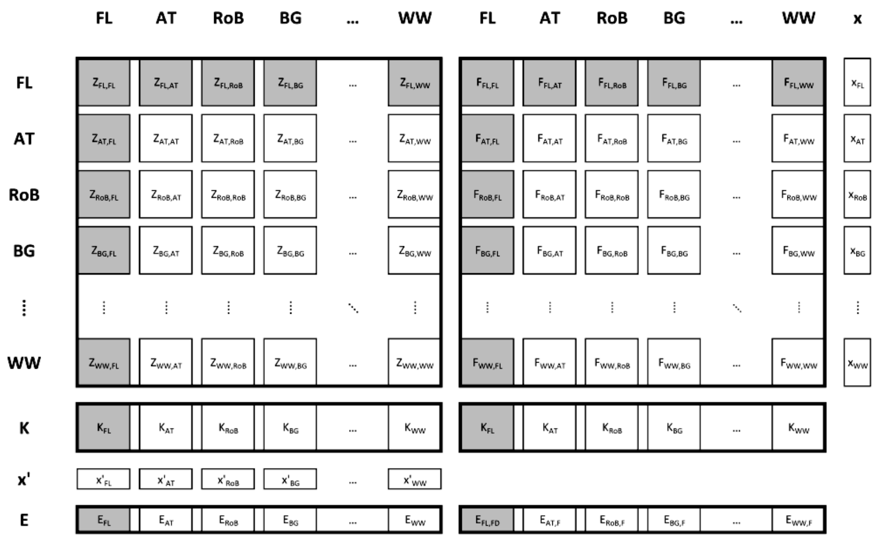

FIGURE 46: THE STRUCTURE OF THE FLEMISH ENVIRONMENTALLY EXTENDED LOCAL INPUT-OUTPUT TABLE COMBINED WITH AN ENVIRONMENTALLY EXTENDED MULTIREGIONAL INPUT-OUTPUT TABLE. THE BASIC STRUCTURE ORIGINATES FROM THE FLEMISH EE-RIO, EXTENDED WITH MRIO COEFFICIENTS ON INTERNATIONAL TRADE FOR INTERMEDIATE USE ($Z_{X,Y}$ WITH X≠Y), COUNTRY-SPECIFIC ECONOMIC STRUCTURES ($Z_{X,Y}$ WITH X=Y, K_X AND F_X) AND RELATED SOCIAL AND ENVIRONMENTAL IMPACTS (E_X). BELGIUM IS INCLUDED IN THE MODEL, BUT IN THE CALCULATION FOR FLANDERS (FL) IT IS INTERPRETED AS REST OF BELGIUM (ROB). Z: INTERINDUSTRY DELIVERIES; K: VALUE ADDED, TRADE MARGINS AND TAXES LESS SUBSIDIES; X: OUTPUT; E: EXTENSIONS; F: FINAL DEMAND; AT: AUSTRIA; BG: BULGARIA; …: OTHER COUNTRIES IN MRIO; WW: MODEL FOR REST OF THE WORLD (ADAPTED FROM: DILS ET AL., 2012).

Indicators calculated from the Flemish EE-RIO table, containing 122 sectors, coupled with the MRIO table WIOD, containing 35 sectors, 40 regions and a model to represent the rest of the world, are assumed to constitute the best available estimation possible via the WIOD database; indicators calculated from the Flemish EE-RIO table containing 122 sectors, coupled with the MRIO table EXIOBASE 2, containing 163 sectors, 43 regions and 5 rest-of- world regions, are assumed to be the best available estimation via the EXIOBASE 2 database. Performing the same calculations with a less detailed IO model (e.g. via sector or country aggregation) results in values that deviate from these best estimations. The difference between the two values provides an indication of the error made using the less detailed IO model. By carefully selecting these less detailed IO models, we are able to provide indications regarding the magnitude of errors resulting from the imperfect layout of an IO model from the perspective of local analysis. The models used in this paper and the errors they contain are listed in **Table 29**. The models are chosen to separately present aggregation errors distinguishing sector aggregation and country aggregation, time errors and specification errors. They are defined to estimate the effect on indicator values, by using models containing separated errors. For example, aggregating the Flemish model into only 35 sectors (AE(S)_35) will give insights into the advantages of investing in EE-RIOT with higher sector detail, while the importance of including specific data on neighbouring countries will be illustrated by the difference between models AE(C)_BE and AE(C)_NB. The models listed are constructed via aggregation of sectors or regions and via connection with different EE-MRIO databases. In the naming of the models, we use AE to refer to an aggregation error, TE for time errors and SE for specification errors. To specify the difference between sector aggregation and country aggregation we use (S) and (C), respectively.

TABLE 29: IMPERFECT IO MODELS USING THE FLEMISH EE-RIO AND EE-MRIO WIOD OR EXIOBASE 2 TO ESTIMATE SPECIFICATION, AGGREGATION AND TIME ERRORS. MODEL A IS THE MOST DETAILED MODEL AVAILABLE AND IS ASSUMED TO PROVIDE THE BEST ESTIMATION VALUES POSSIBLE FOR ALL INDICATORS. ALL OTHER MODELS ARE LESS DETAILED IO MODELS IMPLYING THAT THEIR CALCULATION VALUES INHERENTLY CONTAIN ERRORS. THE OPTIONS MENTIONED IN THE FIRST COLUMN REFER TO TABLE 27.

model	description	Flemish EE-RIO	EE-MRIO WIOD	EE-MRIO EXIOBASE 2
A option 3	best model available	122 sectors	35 sectors 40+1 regions	163 sectors 43+5 regions
AE(S)_35 option 3	aggregation error in Flemish EE-RIO table: aggregate sectors in accordance with WIOD-classification	35 sectors	35 sectors 40+1 regions	163 sectors 43+5 regions
AE(S)_PRI option 3	aggregation error of the primary industry in both Flemish EE-RIO table and EE-MRIO: all primary sectors aggregated into one sector	113 sectors	34 sectors 40+1 regions	130 sectors 43+5 regions
AE(S)_SEC option 3	aggregation error of the secondary industry in both Flemish EE-RIO table and EE-MRIO: all secondary sectors aggregated into one sector	64 sectors	20 sectors 40+1 regions	84 sectors 43+5 regions
AE(S)_TER option 3	aggregation error of the tertiary industry in both Flemish EE-RIO table and EE-MRIO: all tertiary sectors aggregated into one sector	70 sectors	19 sectors 40+1 regions	115 sectors 43+5 regions
AE(S)_3 option 3	aggregation error of all industries in both Flemish EE-RIO table and EE-MRIO: all primary sectors aggregated into one sector, all secondary sectors aggregated into one sector and all tertiary sectors aggregated into one sector	3 sectors	3 sectors 40+1 regions	3 sectors 43+5 regions
AE(C)_EU option 3	aggregation error of non-EU countries in EE-MRIO: all non-EU countries are aggregated into one single rest-of-world model	122 sectors	35 sectors 27+1 regions	163 sectors 27+1 regions
AE(C)_NB option 3	aggregation error of all non-neighbouring countries of Belgium in EE-MRIO: all non-neighbouring	122 sectors	35 sectors	163 sectors 5+1 regions

	countries of Belgium are aggregated into one single rest-of-world model		5+1 regions	
AE(C)_BE option 3	aggregation error of all countries in EE-MRIO: all countries are aggregated into one single rest-of-world model except for Belgium	122 sectors	35 sectors 1+1 region	163 sectors 1+1 regions
AE(C)_FL option 3	aggregation error of all countries in EE-MRIO: all countries are aggregated into one single rest-of-world model	122 sectors	35 sectors 1 region	163 sectors 1 region
TE_05 option 3	time error in WIOD: using the EE-MRIO WIOD model of 2005 instead of 2007	122 sectors	35 sectors 40+1 regions	/
TE_03 option 3	time error in WIOD: using the EE-MRIO WIOD model of 2003 instead of 2007	122 sectors	35 sectors 40+1 regions	/
TE_01 option 3	time error in WIOD: using the EE-MRIO WIOD model of 2001 instead of 2007	122 sectors	35 sectors 40+1 regions	/
SE_DTA option 1	specification errors by using only the Flemish EE-RIO and using local coefficients for interregional trade (domestic technology assumption for import)	122 sectors	/	/
SE_MRIO option 2	specification errors by using only the EE-MRIO and using Belgian data to represent Flanders	/	35 sectors 40+1 regions	163 sectors 43+5 regions

3.3.5 Results and discussion

Model A is used to calculate four economic and five non-economic footprints for Flanders, based on the Flemish EE-RIO-model with both WIOD and EXIOBASE 2. The footprint results based on these two models are considered to be the best estimation possible. The estimation results are presented in **Table 30**. Comparing the footprint estimations between both models reveals large differences for some indicators, especially for the employment, material and energy footprint and the service content in export.

TABLE 30: FOOTPRINT ESTIMATION RESULTS BASED ON MODEL A. THESE RESULTS ARE THE BEST ESTIMATION POSSIBLE USING THE FLEMISH EE-RIO MODEL COUPLED WITH EITHER THE EE-MRIO WIOD OR EE-MRIO EXIOBASE 2.

indicator	unit	EE-MRIO WIOD	EE-MRIO EXIOBASE 2	%Δ
domestic value added footprint	10^6 euro	101,794	101,705	0.1%
service content in exports	10^6 euro	25,696	27,728	7.6%
material value footprint	10^6 euro	7,779	7,535	3.2%
compensation footprint	10^6 euro	90,409	91,918	1.6%
employment footprint	persons	4,207,632	5,477,736	26.2%
carbon footprint	ton	83,993,650	87,525,258	4.1%
material footprint	kiloton	141,259	168,584	17.6%
energy footprint	terajoule	2,346,141	2,801,601	17.7%
water footprint	1,000 m³	12,693,837	12,997,982	2.4%

The differences in **Table 30** are caused by differences in the EE-MRIOs, as the same EE-RIO is used in both models. For example, the small difference in the domestic value added footprint (0.09%) is devoted to quantitative differences in EE-MRIOs on Flemish reimport (i.e. importing back previously exported products). This reimport contains domestic value added potentially ending in local consumption. Quantitative model differences result in a different estimation value for this indicator. Another example is the volume of primary materials used in the production of products in local consumption. The WIOD EE-MRIO links domestic extraction to one mining industry, whereas the EXIOBASE 2 EE-MRIO links domestic extraction to 15 mining industries. Differences in prices per weight of resources are not as reflected in as much detail in WIOD as in EXIOBASE 2. This is one potential explanation of the large difference between both MRIO options for model A.

Assuming that calculations based on model A result in the best estimation possible, then all the other models described in **Table 29** result in estimations of lower quality as these models do not use all the available information. Estimations for nine indicators were calculated using 24 imperfect models. Firstly, the multipliers underlying the footprints are discussed. Multiplier deviations already provide an indication of the expected deviation in footprints. Secondly, the footprint deviations are discussed. The reason that the estimation and description of both footprints and underlying multipliers is elaborated in this paper is the possible coincidence in the estimation of footprints. Although the estimation of a footprint could approximate the best estimation possible, the errors in the underlying multipliers provide information on the quality and reliability of this estimation.

3.3.5.1 Errors in domestic and foreign multipliers

The footprint estimations are a weighted (based on final demand) result of their underlying multipliers. The multipliers of both local and foreign sectors are calculated based on eq. (1) and (2) and compared to the multipliers resulting from model A. The multiplier deviations from model A are presented in **Figure 47** (domestic sector multipliers) and **Figure 48** (foreign sector multipliers). The underlying multiplier deviations provide an indication of the calculated overall indicator deviations (**Figure 49**). The EE-RIO of Flanders contains 122 sectors, so 122 multipliers can be calculated. In analogy, we calculate 35 multipliers for WIOD and 163 multipliers for EXIOBASE per country. Foreign multipliers are aggregated into 'one country' weighted by sectoral output, resulting in only 35 multipliers for WIOD and 163 multipliers for EXIOBASE in **Figure 48**. Aggregation into one country creates comparability between models, however it underestimates potential multiplier errors for all models, except for AE(C)_FL. The multiplier deviations are summarized in boxplots. The upper and lower whiskers reflect data within 1.5 times the interquartile range. Values outside the boxplot are outliers. Extreme values are removed only from both figures to improve readability, but not from the results.

Changes in sector aggregation (models AE(S)_35, AE(S)_PRI, AE(S)_SEC, AE(S)_TER and AE(S)_3) have a varying impact on domestic and foreign multipliers:

- For economic indicators the average multiplier deviation after sector aggregation is close to zero, but outliers occur with all indicators. Only the foreign multipliers underlying the domestic value added footprint do not deviate from model A.

- For non-economic indicators the average multiplier deviation is close to zero, but the number of outliers is considerable, especially in foreign multipliers (except with model AE(S)_35). Special cases are found in domestic multipliers underlying the employment and water footprint. Both have on average a (mathematically) positive domestic multiplier deviation, meaning that most multipliers are overestimations compared to model A. However, most outliers have negative values, meaning large underestimations compared to model A. This is a direct consequence of aggregating heterogeneous sectors. Both via WIOD and EXIOBASE 2, the largest spreads, interpreted in terms of the interquartile range, in domestic and foreign multiplier deviations are found in model AE(S)_SEC and AE(S)_3. The impact of using model AE(S)_35 depends on the indicator. Large spreads in domestic multiplier deviation are found for the service content in export and the domestic value added, compensation and carbon footprints, whereas low spreads in deviations are found for the material value and the material and water footprint. As model AE(S)_35 only affects the domestic EE-RIO, limited deviations are found for foreign multipliers. The impact of model AE(S)_PRI, measured by the spread in multiplier deviation, is low for all indicators, except for the water, employment and material footprint as these indicators are to a large extent determined by primary sector coefficients. Aggregation of secondary sectors (AE(S)_SEC) affects all indicators. A possible explanation is the large heterogeneity regarding coefficients of secondary sectors compared to primary and tertiary sectors. The impact of model AE(S)_TER is smallest for all indicators. A possible explanation is a smaller heterogeneity of tertiary sectors compared to primary and secondary sectors for the indicators under consideration.

Country aggregation (AE(C)_EU, AE(C)_NB, AE(C)_BE and AE(C)_FL) and time errors (TE_05, TE_03 and TE_01) have less influence on domestic multipliers underlying economic indicators compared to secondary sector aggregation (AE(S)_SEC) or drastic sector aggregation (AE(S)_3):

- Domestic multipliers underlying non-economic indicators used in this paper are more strongly influenced by changes in the underlying model compared to the economic indicators.
- Domestic multipliers underlying the carbon and energy footprints experience limited influence from changes in the underlying model, although there is a tendency to a small positive domestic multiplier deviation on average.
- Based on the number and magnitude of outliers, the domestic multiplier deviation is more pronounced in the employment and water footprint. The average impact is small and close to zero for the material footprint, but the number and magnitude of outliers is large.
- Once neighbouring countries are also aggregated (in models AE(C)_BE and AE(C)_FL), the spread in multiplier deviation is between 1.1 and 2.4 times larger than their disaggregated equivalents (AE(C)_EU and AE(C)_NB). The effect on domestic multipliers by using AE(C)_EU and AE(C)_NB is close to zero for all non-economic indicators, while on average it has a tendency to positive deviations for AE(C)_BE and AE(C)_FL. Aggregating important trading partners will increase estimation errors.
- Apart from some outliers, the effect of TE_05, TE_03 and TE_01 is small for all domestic multipliers underlying non-economic indicators, except on the employment multiplier.

Estimating foreign multipliers with models including country aggregation and time errors show a small and equal spread in deviations for all indicators. It is only for the economic indicators and the employment footprint that the spread in deviations tends to increase from TE_05 to TE_01. For the other indicators, there is no visible pattern in the spread. Caution is required with errors pointing in the same direction. Even small multiplier errors that all have the same sign (so, mainly positive or mainly negative errors) will certainly lead to errors in footprint estimations, as no compensation effect of cancelling out positive and negative errors exists.

Only using the Flemish EE-RIO model with the domestic technology assumption for imports (model SE_DTA) has a varying impact on domestic multipliers per indicator. For example, it overestimates multipliers for the compensation footprint, but underestimates multipliers for the employment footprint. This is an indication that a model for the Flemish sectors is not a reflection of global sectors. The spread in domestic multiplier deviations is highest for indicators largely determined by foreign specific economic characteristics: the material value, employment, material and water footprint. The errors of not taking into account these specific foreign economic characteristics are reflected via imports into domestic multipliers, resulting in on average over- or underestimations with large outliers. Large outliers also occur for domestic multipliers calculated from solely using an EE-MRIO model (model SE_MRIO) in all indicators. Accordingly, a model of the national (Belgian) economy is not a reflection of local sectors (Flanders). For all economic indicators, the spread in domestic multiplier deviations is larger using model SE_MRIO compared to SE_DTA. The same is true for the energy and carbon footprint, while the opposite is true for water, material and employment footprint. This confirms that footprints determined by mostly local data are calculated at least from an EE-RIO model, while measures determined by mostly foreign data are calculated at least from an EE-MRIO model. Model SE_DTA does not include foreign specific data which results in substantial multiplier deviations for all indicators, except for the domestic value added footprint. Foreign multipliers from model SE_MRIO do not deviate substantially from model A, as these foreign multipliers are based on complete EE-MRIOs.

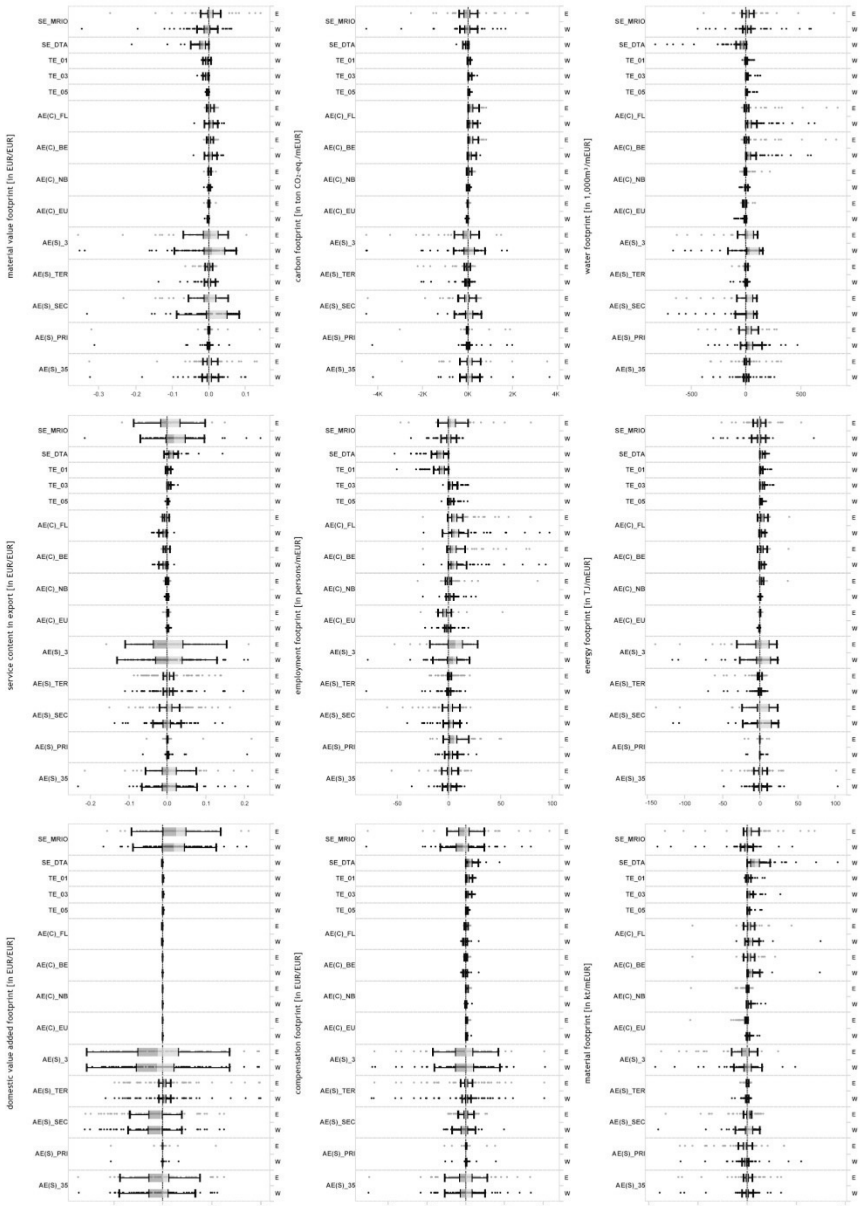

FIGURE 47: MULTIPLIER DEVIATION OF <u>LOCAL SECTORS</u> FROM MODEL A FOR NINE INDICATORS. CALCULATIONS USING MODELS DESCRIBED IN **TABLE 29** (W: FLEMISH EE-RIO WITH EE-MRIO WIOD; E: FLEMISH EE-RIO WITH EE-MRIO EXIOBASE 2).

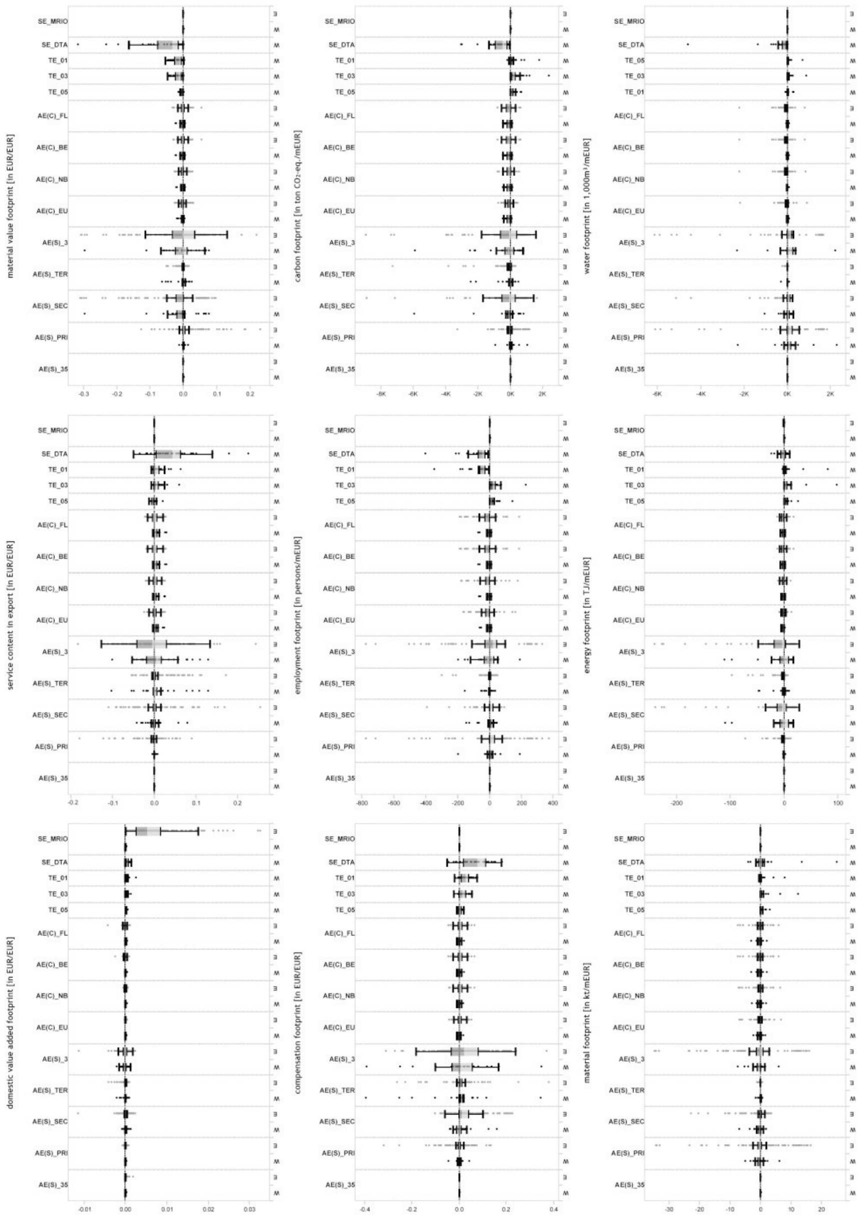

FIGURE 48: MULTIPLIER DEVIATION OF FOREIGN SECTORS FROM MODEL A FOR NINE INDICATORS. CALCULATIONS USING MODELS DESCRIBED IN **TABLE 29** (W: FLEMISH EE-RIO WITH EE-MRIO WIOD; E: FLEMISH EE-RIO WITH EE-MRIO EXIOBASE 2).

3.3.5.2 Errors in footprints

Figure 49 displays the footprint absolute deviation from model A. For example, the estimation result for DVA based on model AE(S)_35 is 100,573 million euros, compared to 101,793 million euros based on model A. The absolute deviation ($= \mathrm{abs}((\mathrm{AE(S)\_35} - \mathrm{A})/\mathrm{A})$) between model AE(S)_35 and model A is therefore 1.2%. The scale of the vertical axis in **Figure 49** differs for some indicators, but the 10% deviation is marked to increase comparability.

Figure 49 reveals no fixed pattern in all nine indicators. Different patterns are visible not only for each model, but also for each indicator. The absolute deviation differs per model and per indicator:

- Aggregating Flemish sectors in the EE-RIO from 122 to 35 sectors (AE(S)_35) reveals no absolute deviations above the 10% level, although the spread, number and magnitude of outliers in domestic multiplier deviation was considerable for all indicators.
- Deviations in estimations from model AE(S)_PRI (primary sector aggregation in EE-RIO and EE-MRIO) fluctuate between 0% and 35% and are largest for employment, material and water footprint. The latter were already indicated by the major multiplier deviations, as these indicators are mainly determined by primary sector characteristics. The deviation is less than 5% for all economic indicators and the carbon and energy footprint; above 10% for the employment (only with EXIOBASE 2) and water footprint; and close to 10% for the material footprint.
- Based on the spread and number of outliers in multiplier deviations, we expect to see large footprint deviations based on model AE(S)_SEC (secondary sector aggregation in EE-RIO and EE-MRIO). Estimations deviate more than 10% for material value (only with WIOD), material (only with EXIOBASE 2), energy (only with EXIOBASE 2) and water footprint (only with WIOD). However, only limited deviations occur for service content in exports and the domestic value added, compensation, employment and carbon footprint. Clearly, coincidence in cancelling out over- and underestimations via the weighting of multipliers occurred. However, the large spread in their underlying multipliers indicates these estimations are of lesser quality and reliability.
- Estimations based on model AE(S)_TER (tertiary sector aggregation in EE-RIO and EE-MRIO) reveal no absolute deviation above the 10% level, although the number and magnitude of outliers in multiplier deviation is large.
- Deviations in estimations from model AE(S)_3 (primary, secondary and tertiary sector aggregation in EE-RIO and EE-MRIO) show major fluctuation between 0% and 51%. Looking at the number and magnitude of outliers and the spread in multiplier deviation, large footprint deviations were expected for all indicators. However, model AE(S)_3 results in deviations above the 10% level for only the employment and water footprint. Apparently as the footprint errors are smaller than expected, using three average coefficients for primary, secondary and tertiary increased the coincidence of cancelling out over- and underestimations. However, the footprint estimations are of low quality and cannot be considered reliable.

Models AE(C)_EU to AE(C)_FL differ in country aggregation. AE(C)_EU (all country aggregation except EU-27 countries) and AE(C)_NB (all country aggregation except neighbouring countries) have limited impact (<5%) on the economic indicators and variable impact on the non-economic indicators. Both

AE(C)_BE (all country aggregation except Belgium) and AE(C)_FL (all country aggregation) have a small impact on the economic indicators, except for the material value footprint. AE(C)_BE and AE(C)_FL have large deviations (>10%) for all non-economic indicators. In general, these results confirm the expectations based on the multiplier deviations. Also, the deviation is in general larger once neighbouring countries (i.e. equal to major trading partners) are aggregated.

The Flemish EE-RIO model based on 2007 data is coupled with the WIOD EE-MRIO model for 2005 (TE_05), 2003 (TE_03) and 2001 (TE_01). Based on the nine indicators used in this paper, estimation results using model TE_05 deviate less compared to model TE_03. The absolute deviation using model TE_05 is less than 10% for all indicators, while model TE_03 leads to a deviation above 10% for material value footprint and all non-economic indicators. The absolute deviation using model TE_01 ranges from 0% to 31%. Although the multiplier deviation underlying all indicators was rather small, the footprint results reveal large deviations, especially for the non-economic indicators and the material value footprint. A closer look reveals systematic under- or overestimations for all underlying multipliers, for all models including time errors. Trends generate an error in multipliers, but more importantly an error pointing in mainly the same direction. This certainly results in footprint errors as no coincidence is left for cancelling out over- and underestimations. For example, domestic and foreign multipliers underlying the GHG footprint based on models TE_05 to TE_01 are mainly positive. Using WIOD 2005, 2003 and 2001 instead of WIOD 2007 therefore overestimates the multipliers, resulting in an overestimation of the GHG footprint between 4% and 13% depending on the model used.

Model SE_DTA, based only on an EE-RIO model, results in estimations with a variable range of errors compared to model A: some approximate model A and some deviate largely. All estimations for economic indicators deviate less than 5%, except for MVC which deviates 36%. Looking at the underlying multipliers, the deviation shows a different picture, as large deviations were found across all indicators except domestic value added footprint. Estimations for the non-economic indicators deviate close to or more than 10%. Only using the EE-MRIO WIOD or EXIOBASE 2 (SE_MRIO) for local analysis results in estimations deviating less than 10% using WIOD and fluctuating between 1% and 26% using EXIOBASE 2. This result is not consistent with the findings from the underlying multipliers expecting large deviations for all indicators.

Looking at the economic indicators, the material value footprint shows the largest deviation with both WIOD and EXIOBASE 2. The average deviation over 24 models is 7%, compared to 2% for the domestic value added footprint and 1% for the service content in exports and the compensation footprint. A possible explanation is that the material value footprint is based on the value added generated by only the primary sectors, which are limited in size compared to the secondary and tertiary sectors. A small coefficient deviation results in large footprint estimation errors. In contrast, the other economic indicators are based on all sectors, or particularly on the tertiary sectors, which are much larger in terms of economic output. When we compare the non-economic indicators, the water footprint has the largest deviation both with WIOD and EXIOBASE 2. The average over 24 models is 24% compared to 18% for the material footprint, 15% for the employment footprint and 10% for the energy and carbon. Comparing the models over all indicators, models AE(S)_3 (only with WIOD), AE(C)_BE, AE(C)_FL, TE_03 and SE_DTA result in footprint estimations with a deviation of on average 10% or more.

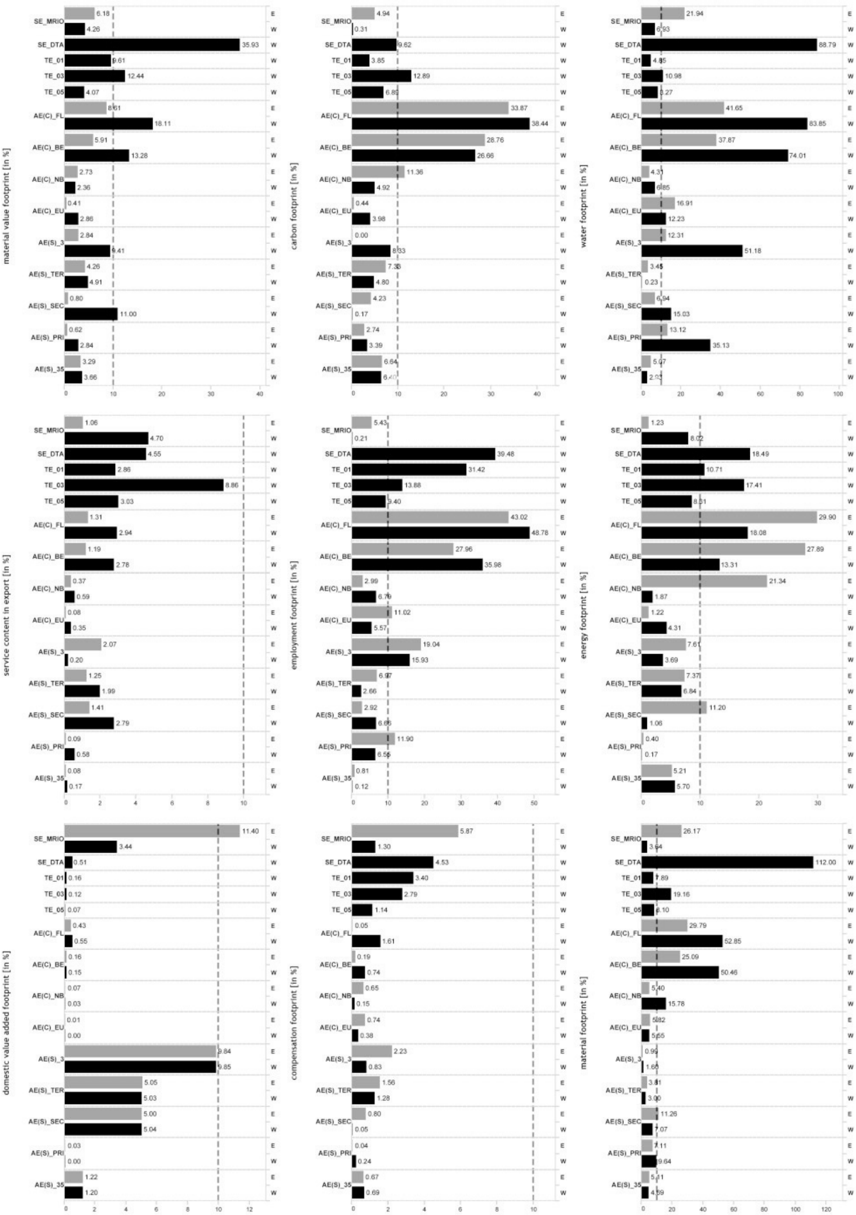

FIGURE 49: ABSOLUTE DEVIATION FROM MODEL A OF CALCULATION RESULTS FOR NINE INDICATORS (IN %). CALCULATIONS USING MODELS DESCRIBED IN **TABLE 29** (W: FLEMISH EE-RIO WITH EE-MRIO WIOD; E: FLEMISH EE-RIO WITH EE-MRIO EXIOBASE 2).

3.3.6 Conclusion and discussion

A combined environmentally extended local input-output (EE-RIO) and environmentally extended multiregion input-output (EE-MRIO) model (option 3; see **Table 27**) results in the best local footprint estimation possible, as this estimation is based on all data available, in comparison to option 1 or 2. For all indicators tested in this paper, except the domestic value added footprint, the domestic technology assumption (option 1) and national data to represent a local area (option 2) results in substantial specification errors leading to unreliable indicator estimations. For footprint estimations of small open economies it is recommended to not rely on these approximations anymore. The domestic value added footprint is a special case as it is almost completely based on local economic characteristics, whereby the domestic technology assumption (option 1) results in acceptable indicator estimations. For all other indicators, which depend on a combination of local and foreign economic characteristics linked with trade data, estimations are best based on combined EE-RIO and EE-MRIO data (option 3).

Estimating footprints and underlying multipliers for local analysis based only on an EE-RIO model (making use of the domestic technology assumption) results in significant errors, especially for non-economic indicators. Estimations for economic footprints solely based on an EE-RIO model may contain large errors if footprints are mainly built up from foreign values, as with the material value footprint in the case of Flanders. This is due to the fact that, in the Flemish open economy, the percentage of the material value footprint originating outside Flanders is 88% using either WIOD or EXIOBASE 2 as MRIO-models WIOD and EXIOBASE 2.

The more the weight of an indicator depends on foreign values, the lower the expected errors that result from using only an EE-MRIO model and not using local data from an EE-RIO model. Conversely, the more the weight of the indicator depends on domestic values, the lower the errors from using only an EE-RIO and not using an EE-MRIO model. For example, the domestic value added footprint is mainly based on local values. Estimations for this indicator using only the EE-RIO model result in a 1% deviation from a combined EE-RIO and EE-MRIO model, while using only the EE-MRIO model results in 3% and 11% deviations, based on WIOD and EXIOBASE 2 respectively. The material footprint is mainly based on foreign values. Estimations using only the EE-RIO model results in 112% deviation, while using only the EE-MRIO results in 4% and 26% footprint deviations using WIOD and EXIOBASE 2, respectively.

Sector aggregation implies that multipliers deviate from their disaggregated alternative. The more heterogeneous sectors are aggregated, the wider the spread in deviations. Note that the interpretation of heterogeneous sectors can be different for each indicator. Two sectors can have a similar energy use per unit of output, while their water use can differ considerably. For all indicators, we find that the more aggregated the sectors, the greater the deviation in the underlying multipliers becomes. Primary, secondary and tertiary sector aggregation is tested in this paper as an extreme case in which all sectors are aggregated into one sector. Secondary sector aggregation results in the largest deviations compared to the disaggregated model. Tertiary sector aggregation has only a limited impact for the selected footprints. Even for the service content in export, the tertiary sector aggregation has only limited influence on the multipliers and footprint. The effect of primary sector aggregation depends on the indicator. The water, material and employment footprint require primary sector disaggregation, while the primary sector aggregation error is much smaller for the other indicators tested. The need for primary sector disaggregation is therefore dependent on the type of indicator.

Country aggregation implies a loss of country-specific data in the model. In this paper, four types of country aggregation are tested, ranging from all countries aggregated into one single world model, to only Belgium in the model, all the neighbouring countries of Belgium in the model and EU-27-countries in the model. All other countries not included separately are represented by a proxy model for the rest of the world. In our case, multiplier deviations and footprint estimations become unacceptably large once neighbouring countries are aggregated, as these countries are among the major trading partners of Flanders.

Time errors in estimations arise if the model consists of different time reference data. In this paper, we linked the Flemish EE-RIO model of 2007 to the WIOD model of 2007 (best case) and 2005, 2003 and 2001 (including time errors). The effect of time errors differs for each indicator. The time error is larger in multipliers underlying non-economic indicators. A possible reason lies in the faster changes in developing economies and one of the explanations put forward by Steen-Olson et al. (2014) for a higher impact of sector aggregation in environmental IO analysis compared to economic IO analysis. Furthermore, not surprisingly, time errors are larger if the time gap of data in the model increases. The differences between indicators can be explained by the variability of coefficients both in time and per region/country. Trends amplify this effect.

Deviations from the best model available in domestic and foreign multipliers underlying the indicators help to understand deviations of indicator estimations. Flemish final consumption (in 2007) consists of 24% foreign consumption and 76% local consumption. This means that footprints are determined by approximately three quarters domestic multipliers and approximately one quarter foreign multipliers. Large multiplier deviations may result in the largest indicator deviations. However, this is not always the case. For example, when we consider the carbon footprint, both the underlying domestic and foreign multipliers have a wide spread in their deviations compared to model A, but the indicator estimation approaches model A. Clearly, coincidence in weighting multipliers based on consumption levels in estimating the indicator can give results approximating the best estimation possible via the cancelling out of over- and underestimations. Therefore, consistent conclusions for errors based on only the indicator deviation cannot be drawn without looking further into underlying multipliers. The interpretation of multiplier deviations helps to determine the reliability of footprint estimations.

Regions may or may not have their own (EE)-IO model. This paper leads to recommendations for both cases. Researchers should reflect on the indicator being studied before choosing the optimum model: Is the indicator determined by mainly domestic or foreign economic/environmental characteristics? Does import play an important role in the estimation of the indicator? Is the footprint influenced by large country and/or sector differences? Are the underlying coefficients stable over time or subject to trends?

This paper has highlighted lessons and advice regarding the above questions, illustrated by the case of Flanders. From a local perspective when facing the task of aligning local data with data in an (EE-) MRIO model, the preferable option is to use a combined or linked EE-RIO and EE-MRIO model with the highest available resolution, otherwise specification errors would become unacceptably large in a globalized world, due to the assumption of domestic technology and price levels abroad. By combining a EE-RIO and a EE-MRIO model, the analysis is based on all the local data available, adapted to the local economic characteristics, and includes global sectoral use/creation/impacts. For open economies, such as

Flanders, most indicators are determined both by local and global specific characteristics, resulting in large specification errors if not all country-specific data is included in the model. Indicators mainly determined by domestic characteristics require at least the use of an EE-RIO model; indicators mainly determined by foreign characteristics require at least the use of an EE-MRIO model.

From the footprints tested in this paper, we can conclude that aggregation of non-neighbouring countries (i.e. aggregating no major trading partners) leads to small errors. All the indicators tested benefit from secondary sector disaggregation. Only some indicators benefit from primary sector disaggregation, for example the water and material footprint, as these indicators are largely determined by primary sector coefficients. Using data based on a different year is only a valuable option in estimations for indicators if coefficients tend to be stable over time. Trends could have only a small impact on coefficients and multipliers, however, the consistent over- or underestimation of coefficients and multipliers certainly results in deviated footprint estimations. A detailed reflection on the indicator under consideration to determine the optimum model helps to understand the possible estimation errors in final footprint estimations. The key is to find the optimal balance between investments in model adoption and/or extension and the reliability of estimation results.

Based on the analysis, the following conclusions and proposals can be formulated:

- ✓ **A timely update of Flemish (or Belgian interregional) input-output tables is recommended.**
- ✓ **Flemish (or Belgian interregional) input-output tables should put extra efforts in secondary sector disaggregation, especially in sector relevant to the circular economy (e.g. collection, recovery, repair, leasing and renting).**
- ✓ **Extension tables of the Flemish input-output database should be extended with waste flows and secondary material use.**
- ✓ **Flanders should actively follow international developments in environmentally extended multiregional input-output databases, especially those including major trading partners of Flanders.**
- ✓ **Flanders should continuously invest in combining their local input-output tables with existing multi-regional input-output tables.**

CHAPTER 4

4. Comparing a territorial-based and a consumption-based approach to assess local and global environmental performance of cities

This chapter is an illustration of applying the methodology described in Chapter 2 on the urban area of Brussels Capital Region and contains redrafted parts from 'Comparing a territorial-based and a consumption-based approach to assess local and global environmental performance of cities' by Athanassiadis A., Christis M., Bouillard P., Vercalsteren A., Crawford R. & Khan A. My contributions are related to the consumption based approach based on input-output analysis. The parts where I did not have a contribution are removed.

KEY MESSAGE

In the framework of pressing local and global environmental challenges it is essential to understand that cities are complex systems dependent on and linked to the rest of the world through global supply chains that embody an array of environmental flows. Cities are thus a complex articulation that intertwine local and global challenges which rely at their extended hinterland for their resource use and pollution emission. To assess the environmental sustainability of an urban area in a comprehensive manner, it is not only necessary to measure its local and direct environmental performance but also to understand and take into account its global and indirect environmental counterparts.

The paper presents a comparative analysis of a territorial-based and a consumption-based approach to estimate both direct and embodied resource use and pollution flows for the case of Brussels Capital Region (Belgium). The territorial-based approach is based on local energy, water and material consumption measured data as well as measured data on waste generation and pollution emissions. The estimation of indirect resource use and pollution emissions (or consumption-based approach) is based on the regional IO-tables of the city-region of Brussels extended with multi-region input-output tables, taking into account the global flows of consumption. The comparison of these two approaches is particularly relevant in the case of cities that have limited productive activities and limited or no extraction of materials as the impact on the hinterland is often underestimated or neglected by local (environmental) policies which are only based on territorial-based figures.

The results show that the indirect primary energy use, GHG emissions and material use estimated by the consumption-based approach is more than three times higher than local measures indicate. The embodied water use, estimated via IOA, was over 40 times higher than the local water consumption. It shows that territorial-based approach underestimate the resource needs and pollution emissions of a city and can therefore be insufficient or even be misguiding. By mapping the origin of embodied flows it is in fact possible to illustrate the open character of an urban economy and its dependence on the global hinterland. Finally, this paper discusses the possibility and relevance to combine these two approaches to create a hybrid framework that measures the full environmental performance of cities both accurately and comprehensively.

Keywords

- Urban metabolism (UM)
- Multi-region input-output analysis (MRIO)
- Environmental footprint of cities
- Direct and indirect flows
- Local and global consumption
- EW-MFA

Citation: Athanassiadis A., Christis M., Bouillard P., Vercalsteren A., Crawford R. & Khan A. (2016). Comparing a territorial-based and a consumption-based approach to assess the local and global environmental performance of cities. Journal of Cleaner Production. doi:10.1016/j.jclepro.2016.10.068

4.1 Introduction to the application

The incumbent creation and expansion of urban areas due to the increase of urban population will increase direct resource use and its associated environmental effect. In addition, the construction of new urban infrastructure will add a considerable embodied environmental effect both locally and globally (Müller et al., 2013). Indeed, urban areas are open systems depending on the outside world or hinterland to provide materials and products and to absorb and process waste (Bai, 2007). In other words, cities are nodes of a complex global network that receive and distribute information, capital, and population but also matter, energy and water flows in various forms. Therefore, cities can be seen as neuralgic nodes of resource consumption that mobilize resource flows and stocks from around the world to fulfil both its inhabitants' and economic needs. To consider an urban area as sustainable it is necessary that its inflows of material and energy and its disposal of waste and generation of pollution do not exceed the capacity of its hinterland (Kennedy et al., 2007; Rees & Wackernagel, 1996).

To manage and mitigate existing and future environmental pressure coming from cities, it is first necessary to have a clearer idea of how urban areas function. Aside from a comprehensive monitoring of resource use and pollution emissions it is important to have a better understanding of the origin of these flows as well as the responsible actors.

However, the environmental assessment of a city is complex and currently there is no commonly accepted and widely adopted methodology (Loiseau et al., 2012). A number of accounting methods and tools have been used for to measure and understand the metabolism of cities such as material flow accounts, ecological footprint, substance flow analysis, emergy analysis, exergy analysis, environmentally extended input-output analysis, physical IO-tables, ecological network analysis, process analysis, and hybrid IO life cycle assessment (Dias et al., 2014).

Baynes and Wiedmann (2012) distinguished two main approaches for assessing urban environmental sustainability: the production or territorial-based approach and the consumption-based approach. These two approaches often use different accounting methodologies showing two different sides of urban resource use and pollution emissions. The former generally uses local and often more accurate data reporting direct resource flows and pollution flows entering and exiting urban areas due to local consumption and production regardless of whether these activities are serving the local inhabitants or people outside the city boundaries (Minx et al., 2011). On the other side of the spectrum, the consumption-based approach encompasses all the flows needed to satisfy the consumption of a city, directly and indirectly, wherever in the world these may occur (Minx et al., 2011). This approach uses local (when available), national and multi-region (MR) environmentally-extended IO-tables to approximate consumption of a city as physical flows that can be imported or exported from around the globe, or in other words the environmental flows embodied in trade.

While the territorial approach can, in principle, be considered as more accurate in quantifying the direct impact of a territory, this only presents a partial view of urban consumption and pollution as cities are rarely self-sufficient (Baynes et al., 2011). Indeed, the territorial-based approach falls short in modelling and expressing the complex articulation and interconnectedness between cities and the rest of the world through the global economy (Lenzen, M. et al., 2012; Lenzen & Peters, 2010). On the other hand, the consumption-based approach can encapsulate a more complete picture of urban consumption, however results represent estimates that cannot be physically validated in their entirety. Therefore, putting side to side the results of these two approaches is particularly relevant in order to assess both the local and global environmental pressure of cities especially for cities that have limited productive activities and limited or no extraction of materials. While both approaches study the same urban area they have a major difference in the definition of their system boundaries. The territorial approach focuses only at the city level accounting all flows entering and exiting the urban area disregarding all other flows. The consumption-based approach focuses on the environmental performance of the same urban area, but takes into account all flows that are directly or indirectly mobilised for the city's consumption across the entire globe. Therefore, in the consumption-based approach the system boundaries are nested including both the local and global simultaneously. Munksgaard et al. (2005) stress that accounting for environmental pressure on a purely territorial basis may be appropriate for impacts such as localized urban pollution or urban microclimate. However, an assessment of global effects such as climate change needs to take into account indirect contributions from outside the city boundary.

Material use and environmental flow indicators or footprints are calculated from three perspectives: the consumption, the territorial and the production perspective (EEA, 2013b). The consumption perspective includes resource use and environmental flows during the use phase (direct or use) and the production phase (indirect and import) of the consumed products. The production phase can be subdivided into a domestic part (indirect) and an abroad part (export). The territorial perspective includes all resource use and environmental flows on the domestic territory. It equals the use phase and the domestic production phase, independent of its destination. Both production for domestic consumption (indirect) and foreign consumption (export) are counted in the territorial perspective. These three perspectives are summarised in **Figure 50**.

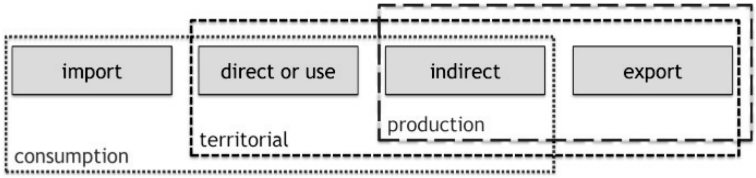

FIGURE 50: THE CONSUMPTION, PRODUCTION AND TERRITORIAL PERSPECTIVE OF ENVIRONMENTAL FLOWS OR FOOTPRINTS.

To assess the local and global resource use and atmospheric pollution emission of Brussels, two approaches are used:

- Territorial-based approach (TBA; using local data) using a number of accounting methodologies such as Material Flow Analysis, Ecological Footprint, Emergy and Exergy analysis, Input-Output Analysis and others in order to measure or estimate the direct environmental performance or direct urban metabolism (UM) of a territory (Zhang et al., 2015). Territorial-based approach comprehensively considers all resource use and pollution emissions flows entering and exiting an urban area regardless if these flows are satisfying the needs of local inhabitants or of foreign economies (Minx et al., 2011).
- Consumption-based approach (CBA; using IOA methodology) considering all direct or indirect resource use and pollution emissions flows required to satisfy local consumption regardless if these flows are occurring locally or globally (Minx et al., 2011). In contrast with the territorial-based approach, the consumption-based approach includes all flows that are associated with imports and exports and thus provide and a description of both the direct and indirect metabolic profile of cities (from the consumption perspective).

4.2 CITY-LEVEL INPUT-OUTPUT DATA

The city IO tables of Brussels Capital Region (2007 data), compiled by the Belgian Federal Planning Bureau, details 118 sectors and 119 products (Avonds, 2008). The monetary tables contain an inter-industry matrix Z, a final demand matrix F and a value added matrix K. Extensions are not included in the IO-table. Expenditure accounts for Brussels are gathered from the Household Budget Survey (HBS). This dataset (1978; 1999-2010; 2012 data) provides revenues, expenses and assets (in euro) per capita, per household and totals for the Brussels Capital Region. Expenditures are subdivided based on the COICOP-nomenclature (Classification of Individual Consumption According to Purpose). The sample size (n=657; population size N=500,249) is considered sufficient to distinguish between the main COICOP-categories (2-digit level). These main categories are for example: food and non-alcoholic beverages, clothing and footwear, and health (DGSIE 2014). The extension data in city IO tables are not always available and if available the level of detail can be insufficient. If coefficients on the city level are lacking, a possible solution is to use national coefficients from (MR)IO tables. The city IO tables of Brussels contain no extensions. We used extension data (converted into coefficients) of Flanders instead. This choice only has implication for the estimation of territorial flows and could partly explain differences between results from IOA and UM.

WIOD (world input-output database) (1995-2011 data) is a global EE-MRIO constructed as part of a project of the 7th Framework Programme funded by the European Commission. The database covers 35 sectors across 40 regions/countries and 1 Rest of World region, with approx. 50 items in the extension tables (Dietzenbacher, Erik et al., 2013). Belgium is one of the regions in the model and the country extensions are assumed to also represent Brussels Capital Region. The WIOD-extensions contain country and sector specific data on (1) gross energy use (in TJ) subdivided over 27 categories, including for instance diesel, hard coal, gasoline, and natural gas, (2) emissions to air (in tonnes) including 8 emissions to air and aggregates like greenhouse gas emissions, (3) land use (in 1000 ha) for 4 subcategories, (4) both used and unused material use (in tonnes) in 12 categories and aggregates on biomass, fossils and minerals and (5) water use (in 1000 m³) in 3 categories. For this city analysis, the following extensions were used: total water use, biomass (animals, feed, food, forestry and other), fossil (coal, gas oil and other), minerals (construction, industrial and metals), total gross and total net energy use and emissions to air (CO_2, CH_4, N_2O, NO_X, SO_X, CO, NMVOC and NH_3).

4.3 Summary of the results

The IOA methodology demonstrates the large differences between the city and country level in terms of material demand, availability and export. For instance, **Figure 51** shows that both for Brussels and Belgium, the domestic extraction is smaller than the amount of imports and there is considerable more imports compared to the export. Meaning both Brussels and Belgium are net-material importers. In addition, it can be seen that the ratio of imports to imports expressed in their raw material equivalents differs between Brussels and Belgium. This difference emphasises that Belgium imports a higher fraction (51%) of products in an early production stage (raw materials) and a lower fraction (23%) of products in a late production stage (finished products) compared to Brussels (importing fractions of 15% and 65%, respectively). Also, the amount of traded materials per capita is smaller for Brussels compared to Belgium. These findings are linked to the discrepancy between the EW-MFA of Brussels and Belgium reiterating how cities are often centres of consumption with little productive capacities, highly depending on their hinterland to satisfy their needs. Finally, it can be pointed out that while the RMC for Brussels and Belgium are comparable and vary around 25 to 28 ton/cap, the DMC differs at 10 and 22 ton/cap, respectively. With comparable RMC and lower DMC, the impact on the hinterland is much larger comparing the city of Brussels with the nation Belgium.

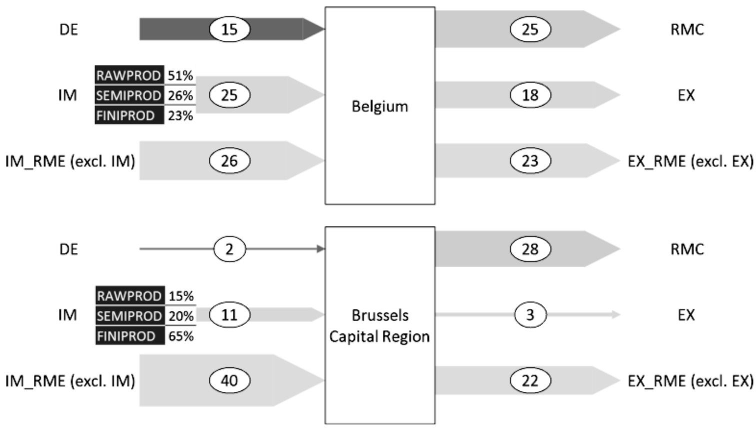

FIGURE 51: ECONOMY WIDE-MATERIAL FLOW ANALYSIS OF BELGIUM (TOP) AND BRUSSELS CAPITAL REGION (BOTTOM) IN 2007, IN TON PER CAPITA. DE= DOMESTIC EXTRACTION; IM=IMPORTS; IM_RME=IMPORTS IN RAW MATERIAL EQUIVALENTS; EX=EXPORTS; EX_RME=EXPORTS IN RAW MATERIAL EQUIVALENTS; DMC=DOMESTIC MATERIAL CONSUMPTION; RMC=RAW MATERIAL CONSUMPTION

TBA results using local data are more accurate data, generally more frequently published and enabling a more detailed temporal evolution. In addition, due to its flexible methodology it is most appropriate at the urban scale, can be easily used by local administrations and has a large pool of existing case studies. Finally, spatializing TBA using local data can help to identify local drivers of resource use and pollution flows. However, the TBA fails to take into account the embodied resource consumption and pollution flows taking place outside the city boundaries associated with trade. On the other hand, the CBA and TBA using IOA methodology is based on local, national IO and MRIO tables as well as their environmental extensions which have limited availability and need experts to use them. However, the IOA methodology uses a robust and systemically complete methodology which can measure production, territorial and consumption perspective indicators on resource use and pollution flows. While this approach is still relatively new at the urban scale (Baynes et al., 2011; Baynes & Wiedmann, 2012; Chen et al., 2016; Chen et al.; Wiedmann, Thomas O. et al., 2015) and suffers from limitations due to the uncertainties associated with IO data and estimates, it can provide valuable additions to the more accurate aspect of the metabolism balance. The advantages of the CBA expansion includes spatializing the environmental hinterland of urban systems and providing a better understanding of the macro-scale drivers leading to resource use and pollution flows.

Table 31 presents a direct comparison of the TBA using local data and TBA and CBA results based on IOA. In other words, IOA methodology results illustrate both the consumption-based approach (CBA-IOA) and the territorial-based approach (TBA-IOA). The CBA-IOA/TBA ratios illustrate how usual TBA underestimates the environmental pressures it generates through the resource use and pollution flows that are embodied in trade to satisfy Brussels' final demand. A TBA-IOA/TBA ratio closer to 1 provides a stronger validation of the IOA results (TBA-IOA) compared with the TBA results using local data.

The results for the CBA-IOA/TBA ratio show that Brussels is using approximately 3 times more final energy, 42 times more water, 3 times more materials (the TBA value considered for this ratio is the one of imports) and emits 4 times more GHG-emissions, 23 times more CO-emissions and 31 times more SO_X-emissions than the values measured by the TBA using local data. These high ratios offer compelling evidence for the need to implement more comprehensive environmental policies. The ratio indicates the significance of the global hinterland in regard to the resource needs and emissions of Brussels. It also highlights a different and more complete, compared to TBA, environmental profile of Brussels that takes into account its global environmental pressure and responsibility.

On a separate note, the TBA-IOA/TBA ratios from Table 31 show some encouraging findings as the difference between TBA and TBA-IOA results is not very high for some flows and the highest difference between TBA and TBA-IOA results is a factor of 2.8. In the case of gross energy and water use the TBA-IOA/TBA ratio is very close to 1 meaning that TBA and TBA-IOA results portray comparable direct environmental profiles of Brussels.

TABLE 31: COMPARING TERRITORIAL-BASED APPROACH USING LOCAL DATA AND CONSUMPTION-BASED AND TERRITORIAL-BASED APPROACH RESULTS OF BRUSSELS USING INPUT-OUTPUT ANALYSIS TO ASSESS THE DIRECT AND INDIRECT RESOURCE USE AND POLLUTION EMISSIONS OF BRUSSELS CAPITAL REGION IN 2007.

			(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	FLOW	**Unit**	**TBA**	**Import IOA**	**Direct IOA**	**Indirect IOA**	**Export IOA**	**CBA-IOA (2+3+4)**	**TBA-IOA (3+4+5)**	**CBA-IOA/TBA (6)/(1)**	**TBA-IOA/TBA (7)/(1)**
ENERGY	**Final energy use per source**	**TJ**	**81,158**	**177,814**	**54,644**	**16,192**	**39,953**	**248,651**	**110,790**	**3.06**	**1.37**
	Electricity	TJ	20,754	21,127	6,651	6,301	15,079	34,079	28,030	1.64	1.35
	Natural gas	TJ	31,068	41,423	14,175	6,235	14,979	61,833	35,389	1.99	1.14
	Petroleum products	TJ	28,044	42,138	32,381	3,617	9,825	78,136	45,822	2.79	1.63
	Others	TJ	583	73,125	1,438	40	71	74,603	1,548	127.96	2.66
	Gross energy use	TJ	**118,612**	**304,573**	**54,644**	**16,599**	**40,670**	**375,816**	**111,913**	**3.17**	**0.94**
WATER	**Total water use**	10^3 m^3	59,169	2,415,413	44,810	5,651	12,267	2,465,874	62,728	41.68	**1.06**
MATERIALS	**Imports**	kt	8,459	29,014	-	-	-		-		-
	Local Consumption	kt	-	-	0	540	-	27,937	540	3.43	-
	Exports	kt	4,833	-	-	-	1,617		-		-
	Solid Waste	kt	2,160	-	-	-	-	-	-	-	-
AIR POLLUTION	**GHG (CO_2, CH_4, N_20 + F Gases)**	**kt-CO_2eq**	**3,937**	**13,282**	**3,293**	**738**	**1,656**	**17,313**	**5,687**	**4.40**	**1.44**
	CO_2	kt	3,652	9,958	3,261	692	1,582	13,911	5,535	3.81	1.52
	CO	t	8,424	176,718	13,348	709	2,234	190,775	16,292	22.65	1.93
	SO_x	t	980	27,901	1,877	224	685	30,003	2,786	30.61	2.84
	NO_x	t	5,850	32,651	2,424	1,722	3,657	36,798	7,804	6.29	1.33

4.4 Conclusion and discussion

The comparison of the two approaches as well of their results provides new findings that contribute to the scientific communities of both approaches and provide a more comprehensive framework to the environmental assessment of urban areas. Firstly, the CBA results demonstrate how much Brussels relies on its global hinterland. Indeed, the results of this study not only show a more complete environmental footprint of Brussels compared to a traditional TBA study, but also allow the origin and destination of input and output flows as well as the spatial representation of Brussels hinterland to be traced. The CBA-IOA/TBA ratio in **Table 31** underlines that current urban environmental policies of Brussels only target a small percentage of its actual total environmental footprint. These findings should in fact change the focus of current policies from energy and water savings strategies towards circular and sharing economy strategies. While in direct metabolic (or TBA) terms consumer products are often only accounted as materials flows, in indirect metabolic terms (or CBA) the same products are also accounted for all the energy, water, pollution emissions and other flows that were necessary along their entire supply chains. The CBA-IOA/TBA ratio as well as the results from **Table 31** also gives a better understanding of the environmental responsibility of Brussels. For instance, while in the TBA results, Brussels receives all of its water use (mostly drinkable water) from a relatively small radius (within Belgium), in CBA results it is possible to see that Brussels only receives 7.5% of its water needs from Belgium. Nevertheless, The results from **Table 31** showed that for most of the considered flows, TBA and TBA-IOA results are, in the case of Brussels, roughly similar. This implies that IOA methodology could also be used as a first approximation of a TBA when some local data are missing (provided that local IO tables and expenditure data are available). In addition, the latter finding is essential for the IOA methodology as it enables to provide a rough validation to IOA-based figures that are usually criticized to have important uncertainties.

To ensure the validity of IOA-based results found in this study it would interesting to examine the consistency of the TBA-IOA/TBA and CBA-IOA/TBA ratios for other years, for other cities as well as for other MRIO databases (Moran & Wood, 2014). In fact, it is important to reiterate that the results from this study are specific to a city with little or no productive activities. If this exercise was carried out for an urban area with extractive and productive activities (Baynes et al., 2011) results could be polar opposite (CBA-IOA/TBA equal or even lower than 1) and the associated environmental policies would also be very different.

This study therefore points out that IOA could be a starting point for a first estimation of environmental footprints at the city level. The results could help TBA research using local data to refine the search for data and narrow the focus of a more in-depth analysis. As a top-down approach, IOA provides a complete estimation of indicators, which in turn can be structurally refined with bottom-up TBA data. The analysis carried out for Brussels enables adding a more global perspective to traditional TBA studies by tracing the origin of direct and indirect environmental flows. In addition, this analysis enables to validate IO results at a city-scale which might foster the use of IO-results to suggest urban environmental policies that cover the entire hinterland of urban areas.

To conclude, the comparison of TBA and CBA results opens a new path for research in terms of urban environmental assessment by underlining the need for a hybrid methodology combining accuracy and comprehensiveness. This methodology, should produce results for different flows, but also for their respective sectoral use. As such, it would be possible to trace how local economic sectors influence the global network of production/consumption and which economic policies affect most local and global environmental pressures. Future research could also investigate the similarities and differences between TBA and IOA-TBA drivers to produce more coherent and holistic environmental policies that take into account the local and global parameters that influence resource use and pollution emissions. These policies should not only focus on the use of resources locally but also globally for the local needs of cities. Finally, the paper underlines the need for a methodological framework linking the TBA using local data and the IOA methodology to connect local socio-economic and territorial challenges with their associated global environmental consequences. In fact, in a context of hyperconnected and globalized urban economies, this methodology could become an essential tool for cities enabling them reduce their local environmental pressure and addressing their local challenges on the one hand, while making sure that they simultaneously do not burden other parts of the world from a social, economic or environmental perspective, on the other.

A critical note is added to the extension data used in this chapter. The model uses Flemish extension coefficients instead of coefficients specifically developed for the Brussels Capital Region. The coefficients contain data on, for example, the amount of emissions per unit of output. By using the Flemish coefficients, it is assumed that the Brussels sectors have a comparable emission level per unit of output. This is a strong assumption leading to errors in territorial estimations. However, the focus of the IOA-approach was to estimate the impact on the hinterland, which did not rely on these local extension data. Also, the estimation of the territorial impact was accompanied by an urban metabolism method and estimation results were compared.

CHAPTER 5

5. Value in sustainable materials management strategies for open economies - Case of Flanders

This chapter is redrafted from Christis M., Geerken T., Vercalsteren A. & Vrancken K. (2015). Value in sustainable materials management strategies for open economies - Case of Flanders. Resources, Conservation and Recycling, 103, 110-124. doi:10.1016/j.resconrec.2015.07.014

KEY MESSAGE

An improved top-down methodology is described in Christis et al. (2015) for estimating the substitution potential of intensifying specific SMM-strategies and material efficiency strategies. The estimated strategies are: reuse, recycling, food waste prevention and energy recovery. Reaching higher levels of SMM-strategies may provide economic and environmental opportunities (i.e., in terms of GDP, jobs, reduced impacts), but not all options will have a net win–win–win property in practice, as they reduce the need for producing new commodities. The open economic characteristics of Flanders are fully integrated in this methodology. The method shows the potential industries affected by an intensified SMM-strategy represented by a budget, GHG-emissions saved and jobs lost. This budget can be used to create (local) GDP and (local) employment through new SMM-strategies. From a strict regional self-interest perspective, it is preferable to increase local economic participation in globalised value chains.

For every million euro in expenditures saved on newly produced reusable goods by an intensified SMM-reuse strategy in Flanders, GHG-emissions are reduced globally by 0.70 kt, and global employment is reduced by 31 jobs, 5 of which are in Flanders. On average, Flanders generates 34.1% value added in value chains of newly produced reusable goods. So, substituting one million euro of expenditures on newly produced reusable products with a reuse system, should at least generate 341,000 EUR value added and 5 jobs in Flanders to maintain the current economic level. Striving to a net positive environmental impacts, the new reuse system should not have more than 0.70 kt GHG-emissions per million euro substitution.

The substitution potential for the SMM-strategies from the case study are summarised in **Table 32**.

TABLE 32: CASE STUDY RESULTS. THE PERCENTAGES BETWEEN BRACKETS REPRESENT THE FLEMISH SHARE IN THE ENVIRONMENTAL AND EMPLOYMENT BUDGET.

SMM-STRATEGIES	**ECONOMIC BUDGET**	**ENVIRONMENTAL BUDGET**	**EMPLOYMENT BUDGET**
(unit)	*percentage local value added creation*	*in kt CO_2-eq. per million euro economic budget*	*in number of employees per million euro economic budget*
energy recovery	13.2	2.43 (26.3%)	22.99 (4.8%)
food waste prevention	29.8	1.47 (25.8%)	53.18 (9.4%)
recycling	9.8	2.56 (7.3%)	46.54 (2.2%)
reuse	34.1	0.70 (25.7%)	31.07 (15.8%)

Highlights

- A methodology to assess the regional potential of SMM-strategies.
- Example SMM-strategies included in the paper: energy recovery, food waste prevention, recycling and re-use.
- Substitution potentials vary between SMM-strategies and from a local/global view.
- Reuse creates the largest maximum economic substitution potential.
- Household consumption and investments contain large potentials for SMM-strategies.

Keywords

- sustainable materials management strategies
- reuse
- recycling
- food waste prevention
- energy recovery
- input–output analysis

Citation: Christis M., Geerken T., Vercalsteren A. & Vrancken K. (2015). Value in sustainable material management strategies for open economies case of Flanders (Belgium). Resources, Conservation and Recycling, 103, 110-124. http://dx.doi.org/10.1016/j.resconrec.2015.07.014

5.1 ABSTRACT

Sustainable Materials Management (SMM) strategies, such as reuse, recycling and energy recovery aim, to capture more of the embedded resource or material value in products and waste streams. Reuse, recycling and energy recovery are existing activities in every society but they are poorly reflected in official statistics. Reaching higher levels of reuse, recycling and energy recovery may provide economic and environmental opportunities (i.e., in terms of GDP, jobs, reduced impacts), but not all options will have a net win-win-win property in practice, as they reduce the need for producing new commodities. In open economies, many primary resources, components and products are imported from abroad, and many goods produced are exported abroad.

This paper describes a top-down methodology for estimating the substitution potential of intensifying specific SMM-strategies and material efficiency strategies. We combined both regional and multi-regional EE-IO (environmentally extended input-output) models to link industrial sectors to SMM-strategies. Our method enables us to compare the different SMM and material efficiency strategies in terms of the maximum available budgets for reaching them on a break even basis, maximum savings in global warming emissions and substituted employment effects, both through a regional and global perspective.

We add a case on Flanders (Northern region in Belgium) to illustrate the methodology. Flanders is currently developing a policy for SMM. Selecting new regional actions for a Sustainable Materials Management policy can benefit from a good understanding of the international entangled value chains. It is important to understand how much of the chain is within reach of domestic policies and also to assess the consequences in terms of potential winners and losers, regarding GDP, jobs and environmental impacts, both domestically and abroad.

We illustrated the potential outcomes for Flanders from four generic SMM-strategies: energy recovery, food waste prevention, recycling and reuse. From a strict regional self-interest perspective, it is preferable to substitute foreign value chains with local economic activities. Reuse creates by far the largest budget for new activities to realize the strategy (31.2 % of Flemish GDP compared to 8.3 % for food waste prevention, 6.2 % for energy recovery and 4.2 % for recycling). All four strategies have similar and significant potentials to reduce greenhouse gas emissions. However, food waste prevention and reuse have higher potentials to reduce Flemish territorial GHG-emissions. From a pure Flemish employment perspective, the energy recovery and recycling strategies could replace the fewest Flemish jobs, and from a global perspective, all strategies most likely imply losses of jobs abroad.

5.2 INTRODUCTION

In the EU policy context, natural resources have a wide scope; raw materials (minerals, biomass, metals and fossil energy carriers) environmental media (air, water, soil), flow resources (wind, geothermal, tidal and solar energy) and space (land area) are all included in the term ‘natural resources’. The ‘media’ resources are both a source for use and a sink for absorbing emissions. For several years, the political and research interest in the area of the so-called “material” resources has been growing for several reasons: (1) a strong EU dependency on supply from abroad, especially when certain resources are supplied by only a few countries, which may pose security risks for their supply (European Commission, 2011); (2) a scarcity of finite resources not only raises their price or creates high price volatility but can also force producers to extract and produce materials from lower ore grades, leading to higher environmental impacts; and (3) changes in energy systems, such as photovoltaic or windmills, will require many more scarce materials (Kleijn & van der Voet, 2010).

At the international level, UNEP's resource panel has dedicated a specific focus on scarcity, and the OECD has developed a strategy for Sustainable Materials Management (SMM) (OECD, 2012) with an integrated view on raw materials. At the national level, the German resource programme 'ProgRess' (BMU, 2012) has placed a focus on abiotic raw materials that are not used primarily for energy production (ores, industrial minerals, construction minerals). In addition, biotic raw materials are also included when they are used as physical materials in goods. All of these initiatives, although restricted to the perspective of physical materials, also consider the linkages with other (fossil) resources.

Strategies, that have existed for 100 years through continuous improvement efforts that aim for the production of materials with lower emissions are complemented by a related field of research called "material efficiency", defined as "delivering material services with less overall material production". Material efficiency can be considered to be a set of strategies for using less material, complementary to strategies focussing on more efficient production of materials (Allwood et al., 2013).

Political interest for converting waste into a resource is reflected in the EU Directive 2008/98/EC on waste, which EU Member States are obliged to transpose into national policy. In the Belgian policy context, with the three regions of Flanders, Walloon and Brussels, waste policy is a regional responsibility. The Flemish region created the so-called "materials decree" in 2012, delivering both the transposition of the EU Directive 2008/98/EC, as well as providing foundations for a framework for an enhanced policy on Sustainable Materials Management in Flanders. The SMM-policy in Flanders is designed as a general framework and provides a basis for implementing measures after the analysis of existing material flows and impacts and the consultation of stakeholders. This policy demand has led to the selection of Flanders as a case study for this paper.

Sustainable Materials Management strategies, such as reuse, recycling and energy recovery, aim to capture more of the embedded resource or material value in products and waste streams (Benton & Hazell, 2013). These SMM-strategies are closely related to the EU Directive 2008/98/EC, which states the waste management hierarchy: 'Waste legislation and policy of the EU Member States shall apply as a priority order the following waste management hierarchy: (1) prevention, (2) preparing for reuse, (3) recycling, (4) other recovery, e.g., energy recovery, and (5) disposal'. The economic losses and environmental gains of diminishing the current production are partially or fully countered by increased reuse, recycling and energy recovery activities carrying economic gains and environmental costs (Corsten et al., 2013). Reaching higher levels of reuse, recycling and energy recovery may provide economic and environmental opportunities (in terms of GDP, jobs, reduced impacts), but not all options will have a net win-win-win property in practice, as they reduce the need for producing new commodities. In open economies, many primary resources, components and products are imported from abroad and many goods produced locally are exported abroad. Selecting new national or regional actions for SMM-policy can benefit from a good understanding of these internationally entangled value chains. It is important to understand how much of these chains are within reach of regional policies and to know the consequences in terms of winners and losers, regarding GDP, jobs and environmental impacts, both domestic and abroad.

Detailed statistical information on recycling activities and on the level of reuse (such as second-hand markets) is currently relatively poor in all parts of the world, making it difficult to assess the actual level of circularity. Understanding the levels of recycling would benefit from so-called physical input-output tables at a detailed sectorial level. It is not highly likely that these data will be collected soon based on real bottom-up statistics collected in the same way in all relevant countries and regions of the associated value chains. Haas et al. (2015) applied a sociometabolic approach to assess the circularity of global material flows presented for main material groups for the year 2005 (Haas et al., 2015). Their estimate shows while globally 4 Gt/year of waste materials are recycled, this flow is of moderate size compared to 62 Gt/year of processed materials and output of 41 Gt/year. They recognize that the level of uncertainty of specific materials may indeed be considerable, but assume that, for the overall aim of their article, the reliability of the data and estimates is sufficient. Today, models and statistics containing information on added value are considerably better developed as reflected in monetary input-output models. These models have been extended with satellite tables for environmental extensions, resource use and jobs. The recent development of EE-MRIO (environmentally extended multiregional input-output) tables covering the majority of the economically contributing countries in the world and their trade relations offers new basic data for analysis of internationally entangled value chains.

This paper sets out a methodology for answering the following questions relevant for further policy development of Sustainable Materials Management in open economies from a value chain perspective:

1. How much value from primary sectors is an economy importing from abroad either directly or embedded in products, compared to the value from primary sectors[27] produced domestically?
2. How much primary, secondary and tertiary sector value produced within or imported by an economy is exported abroad as materials or embedded in products?
3. How is the primary, secondary and tertiary sector value in an economy distributed across final consumption from households, NPISH (non-profit institutions serving households), governments, investments and changes in inventories?
4. What is/are the maximum substitution potential/effects of intensifying generic SMM-strategies for food waste prevention, energy recovery, reuse and recycling (in terms of jobs, value added and GHG-emissions) for a regional economy and the rest of the world? In other words, what are the potential losses in current GDP (and GHG-emissions and employment) due to intensifying SMM-strategies and determining the budget for new SMM-strategies?

Answers to the first two questions will illustrate the openness and dependence of a regional economy on foreign primary resources and related trade importance, as well as the material value flowing abroad through exports and thus no longer available for domestic reuse, recycling and energy recovery. The answer to question 3 provides insights into the primary material dependence of specific

[27]Throughout this paper we classify sectors listed in NACE Rev. 1.1: 01–05 in the primary sector. Likewise we define the secondary sector based on NACE Rev. 1.1: 10–45 and tertiary sector based on NACE Rev. 1.1: 50–99.

regional consumption categories, which helps prioritize future policy actions. The answers to question 4 are relevant for policy makers as they provide the potentials of different intensification strategies and compare their potentials. The methodology is applied to the case of Flanders for illustration purposes.

In *5.3 Approach and method*, we state our approach and detail the methodology applied. The calculation method, formulas and procedures are listed in *5.4 Calculation framework and procedures*. In *5.5 Combining the Flemish input-output database with global multi-regional input-output databases* we describe the data used for the case of Flanders, we briefly explain MRIO-tables, the coupling of Flemish regional IO-tables to a world MRIO-model and we refer to the different data sources used in this paper to estimate the substitution potentials for Flanders. *5.6. Results and discussion* contains results on the case of Flanders and a short discussion thereof. Finally, *5.7 Conclusions* repeats the most important findings and presents the conclusions. *5.8 Appendix A* contains an illustration of the methodology on a hypothetical economy with only five sectors. The illustration shows, amongst others, the necessity of sector disaggregation and the possible budget overlap between non-cumulative SMM-strategies.

5.3 APPROACH AND METHOD

Answering questions 1 to 3 requires existing methodologies based on recently published datasets. The methodology applied is based on straightforward IO-formulas (based on the Leontief inverse) on value added and related environmental and social impact calculations. See for example: (Chen et al., 2012; Foster-McGregor & Stehrer, 2013; Johnson & Noguera, 2012; Koopman et al., 2010; OECD, 2013; OECD et al., 2013; Timmer et al., 2014; Wiedmann et al., 2007). Our novel methodological aspect is needed for answering question 4 and is presented below in more detail.

To answer the fourth question, this paper describes a top-down methodology estimating the maximum substitution potential associated with generic SMM-strategies related to total regional final demand. Added value is the core element in our analysis. Primary resources (like ores in nature) obtain economic value when extracted due to input value of the mining or harvesting industry. This input value comprises input costs, compensations of employees, operating surpluses and taxes less subsidies. Upward pressure on prices of raw materials is reflected in increasing input value, for example increasing royalties and concessions, increasing input costs due to limited resource availability, increasing operating surpluses due to, for example, monopolisation of resources. During the next steps in the value chain the material value increases again when producing engineering materials, which, after being first processed as raw materials, become more pure or ready to use. A further transformation into components and assembly again increases the product value. At the moment when most products enter the market they reach their maximum economic value, which is equal to the total value added that was generated in its production network (or supply chain network). After consumption a product's value usually declines due to being, for instance, used, out-dated or damaged, but exceptions exist, such as antiques and buildings. At the end of a useful life a product may still contain value (for reuse, for recycling or for incineration).

The built-up value across international chains of regional final consumption can be linked to SMM-strategies: (1) reuse value when a component or product is reused (related to such strategies as life time extension, repair, remanufacturing, refurbishment and component reuse); (2) recycling value at the level of the material as a substitution for primary or other current secondary production routes; and (3) caloric value when incinerated with energy recovery.

Waste prevention, as another generic SMM-strategy, is not linked to the remaining value of materials or components in end-of-life products. Waste prevention strategies in general try to reduce waste generation and, in doing so, reduce the need for new production. This reduced need for new production has a negative impact on GDP and employment but has a positive impact on the environment due to decreasing such parameters as material use and emissions. For food related final consumption the potential for reuse and recycling is relatively limited due to practical and health reasons. Therefore, we did not include the SMM-strategies of reuse and recycling in the food domain. Nonetheless we considered it more relevant to include the SMM-strategy of waste prevention for the food domain. Current high levels of food waste drew attention to the potential of its reduction. The recent EU Commission Communication (EC, 2014) proposes that Member States develop national food-waste prevention strategies to ensure food waste across the life cycle chain is reduced by at least 30 % by 2025. A similar non-food generic SMM or material efficiency strategy is the one that aims to manufacture goods with less input from primary sectors. This strategy will reduce the production of involved primary sectors and can be modelled identically to the SMM-strategy of recycling as the substitution potential consists of less primary production.

To estimate the maximum substitution potential (question 4), we examined the potential amount of economic activities replaced under intensified generic SMM-strategies. The word intensified expresses the fact that today the four SMM-strategies are already implemented in society to a certain but not exactly known extent. The maximum substitution potential we assess is only based on one side of the “medal” of intensified strategies: it concerns the saved costs and reduced environmental impacts by decreased demand for current production chains. The maximum substitution potential is estimated by the replaced economic activities in terms of GDP, jobs and climate change. This estimation can be interpreted as a maximum budget for new economic activities needed to raise the SMM-strategies to higher levels of implementation. So, the budget for new economic activities in SMM-strategies is estimated by the value of current production chains. We do not estimate the additional efforts, the economic costs, or the environmental impacts of production factors, such as labour, capital, energy, and transport needed for new activities under intensified SMM-strategies. The interpretation, development and implementation of SMM-strategies is a very complicated exercise from a top-down perspective with lots of uncertainty depending on a variety of different specific contexts. Required efforts differ widely across such parameters as regions, specific markets, goods, materials, and needed innovations. Several sources have fully recognized the complexity of assessing and realizing the net benefits for generic material efficiency strategies:

- “Improving material efficiency requires insights from a wide range of disciplines still leading to many open questions.” (Allwood et al., 2011);
- “No analyses have been found for the global potential of reuse across all products.” (Cooper & Allwood, 2012);
- “A material efficiency policy may be targeted directly at extending the lifetime of products, but this could have impacts on the economy which are very difficult to anticipate ex ante in a given context.” (Söderholm & Tilton, 2012); and

- “The economic impacts are context specific with regard to innovation, technology and country.” (Walz, 2011).

Nonetheless the assessment of the maximum substitution potential for generic SMM-strategies is still useful for prioritizing activities in the context of SMM, as it shows their potential economic and environmental impacts. It provides a maximum budget in which the efforts for realising the intensified generic SMM-strategies should fit to make them breakeven: when the cost for implementing the intensified SMM-strategy is lower than the substituted GDP, the strategy becomes economically attractive. The climate change emissions for implementing an SMM-strategy should be lower than the emissions from replaced economic activities to be environmentally attractive. The number of jobs needed to implement any SMM-strategy should be compared to the jobs lost from the replaced economic activities to determine whether the strategy creates jobs in net terms both from a regional and global point of view. Although we do not quantify the efforts and impacts for implementing these SMM-strategies due to the reasons of complexity referred to above, we still can make interesting comparisons between the potentials of the different SMM-strategies. The four generic SMM-strategies will differ regarding the economic, environmental and job creation potentials.

Attempts to quantify the net potential of certain strategies have been reported in the grey literature, for example: (Bastijn et al., 2013; EMF, 2013a, 2013b; WEF, 2014). These studies start from a detailed micro-level analysis of a limited number of products (e.g., mobile phones, washing machines, and electrical components). Based on product-level results, EMF and WEF calculate a net material cost savings[28], which express the savings by consumers extrapolated to the total demand of the European Union of different SMM related transition scenarios. Bastein estimates the changes in value and quantity of products due to expected changes in society behaviour and policy. These impacts are extrapolated to the total economy of the Netherlands and effects of demand substitution (for example increased reuse will decrease demand for new products) are estimated. Both studies use input-output tables to extrapolate product-level results to economy-wide results. Our approach on the contrary is a top-down methodology, covering full sectors. We do not attempt to estimate nor elaborate on the necessary efforts and (rebound) effects for implementing and executing the SMM-strategies. Next, for the economic potential, we also estimate the environmental impacts and employment effects.

5.4 Calculation framework and procedures

Final products are consumed; intermediate products move on in the production process. Final consumption includes public and private consumption, investments and changes in inventories. Value added includes both labour and capital used in production processes. To estimate the maximum substitution value, we calculated the value contained in final products strictly related to different SMM-strategies. Our method of added value analysis is based on the decomposition of global value chains (for example: (Hoekstra, 2005; Timmer et al., 2014)) combined with our own assessment of connecting sectors to the different SMM-strategies and disaggregating sectors that generate value linked to multiple SMM-strategies. Our methodology builds upon classic Leontief calculations benefitting from increased global data availability. What we added to this methodology is the allocation of

[28]Net result by EMF includes the costs of reuse, remanufacture, recycle and refurbishments.

different production sectors to SMM-strategies while avoiding double counting between strategies. An illustration of the necessity of disaggregation is shown in *5.8 Appendix A*.

Determining the economic, environmental and employment impact and potential of intensifying SMM-strategies (food waste prevention, energy recovery, recycling and reuse) is a three-step procedure:

1. Link SMM-strategies to economic sectors generating value directly related to these strategies (*5.4.1 Link SMM-strategies to economic sectors*);
2. Determine the total economic, environmental and employment impact (maximum substitution value) of the different SMM-strategies (impact based on one year's regional final demand) (*5.4.2 Estimate the maximum substitution value of SMM-strategies*); and
3. Determine the potential of the intensified strategy as a fraction of this total value (per million euro) to compare the different strategies (*5.4.3 Determine comparable potentials of intensified strategies*).

For environmental impacts we have selected global warming[29] as a leading indicator because of political interest, but other environmental impacts, for which data are available, can be analysed following an identical procedure. *5.8 Appendix A* contains a step-by-step elaborated numerical example of our methodology.

5.4.1 Link SMM-strategies to economic sectors

In the first step, only 'end-point' sectors are linked to SMM-strategies, meaning that only the sectors delivering the materials, goods or services linked to the SMM-strategy are considered.

The maximum substitution potential for the SMM-strategy of food waste prevention only considers the value of food producing activities. The sectors producing food products are the agricultural sector (excluding forestry) (NACE Rev. 1.1 divisions 01 and 05) and the food processing industry (NACE Rev. 1.1 divisions 15 and 16). Supply chains of these sectors will be included via the calculation method we use in step 2. There is an overlap between these supply chains, e.g., the supply chain of the food processing industry is largely determined by the agricultural sector, but the methodology based on value added will avoid this double counting (see step 2). The SMM-strategy of energy recovery includes fossil energy inputs for energy use. The maximum substitution potential of energy recovery is estimated by the total value of fossil energy inputs used in our current system (products of NACE Rev. 1.1 divisions 10, 11, 12, 23 and 40). The products of these sectors have the potential to be replaced by sustainable energy inputs. Their combined value determines the maximum substitution value for the SMM-strategy of energy recovery. The maximum substitution potential of the SMM-strategy of recycling is estimated by the value of all recyclable material inputs in our current production system. In our method, recyclable material inputs are restricted to all primary material resources, basic metals, basic plastics and glass, but excluding fossil energy carriers and biomass other than wood (products of NACE Rev. 1.1 divisions 02, 13, 14, 24.16, 26.1 and 27). Intensifying the SMM-strategy of recycling will increase recycling rates and decrease demand for newly produced recyclable (primary) materials. Their combined value determines the maximum substitution value for the SMM-strategy of recycling. The maximum substitution potential of the

[29] GWP is calculated as GHG-emissions including carbon dioxide (impact factor 1), methane (impact factor 21) and nitrous oxide (impact factor 310).

SMM-strategy of reuse is estimated by the value of all reusable components and products in our current production system. In our method, the reusable components and products are restricted to clothing, wood products, rubber and plastics, non-metallic mineral products (excl. glass), fabricated metal products, machinery, equipment and constructions (NACE Rev. 1 divisions 17- 20, 25, 26, 28-36 and 45). **Table 33** summarizes step 1 providing a detailed list of sectors linked to the SMM-strategies.

TABLE 33: SMM-STRATEGIES LINKED TO SECTORS BASED ON THE NACE REV. 1.1 CLASSIFICATION. THE LISTED SECTORS SHOULD BE CONSIDERED AS 'END-POINT', MEANING THEY DELIVER MATERIALS, GOODS OR SERVICES TO FINAL CONSUMPTION DIRECTLY RELATED TO THE SMM-STRATEGY. CALCULATIONS WILL INCLUDE THEIR SUPPLY CHAINS AS WELL (SEE STEP 2).

SMM-STRATEGY	NACE REV. 1.1
food waste prevention	01 Agriculture, hunting and related service activities 05 Fishing, fish farming and related services activities 15 Manufacture of food products and beverages 16 Manufacture of tobacco products
energy recovery	10 Mining of coal and lignite; extraction of peat 11 Extraction of crude petroleum and natural gas, service activities 12 Mining of uranium and thorium ores 23 Manufacture of coke, refined petroleum products and nuclear fuel 40 Electricity, gas, steam and hot water supply
recycling	02 Forestry, logging and related service activities 13 Mining of metal ores 14 Other mining and quarrying 24.16 Manufacture of plastics in primary forms 26.1 Manufacture of glass and glass products 27 Manufacture of basic metals
reuse	17 Manufacture of textiles and textile products 18 Manufacture of wearing apparel; dressing and dyeing of fur 19 Manufacture of leather and leather products 20 Manufacture of wood and wood products 25 Manufacture of rubber and plastic products 26 Manufacture of other non-metallic mineral products excluding 26.1 Manufacture of glass and glass products 28 Manufacture of fabricated metal products, except machinery and equipment 29 Manufacture of machinery and equipment n.e.c. 30 Manufacture of office machinery and computers 31 Manufacture of electrical machinery and apparatus n.e.c. 32 Manufacture of radio, television and communication equipment and apparatus 33 Manufacture of medical, precision and optical instruments, watches and clocks 34 Manufacture of motor vehicles, trailers and semi-trailers 35 Manufacture of other transport equipment 36 Manufacture of furniture; manufacture n.e.c. 45 Construction

Note that the linkages between sectors and SMM-strategies cannot be perfect by definition due to the limited sector details in the available data sources. Some sectors will be included, but their value contributions cannot be completely attributed to the SMM-strategies. Other sectors will be excluded, while their value contributions should partially be attributed to the SMM-strategies. Working with rather rough macro-/meso-economic models as IO-models inherently implies under- and overestimations. These estimation errors can be attributed to aggregation errors (Bouwmeester & Oosterhaven, 2013). We only include sectors that can (almost) completely be linked to an SMM-strategy and still have potential left for the SMM-strategies, resulting in a minimum potential. Direct final consumption from such sectors as recycling, repair, rental and leasing are excluded from our calculation of the substitution potential, as their value cannot be substituted by other economic activities via any of the intensified SMM-strategies. Evidently these activities are important when implementing the intensification of the SMM-strategies, and they have to appear on the other side of the "medal" (see *5.3 Approach and method*). The indirect consumption from these sectors is included via the supply chain approach because they contribute to the current production value of materials, components and products. As calculations include the supply chains of the listed sectors, a large variety of primary, secondary and tertiary sectors will eventually determine the total value related to the SMM-strategies, although they are not directly linked to the strategy. For example, the transport sector is not linked to any of the SMM-strategies defined in our method (see Table 33), meaning the value of transport once the material or product is finished, but not sold to a final customer, is not included in the value linked to an SMM-strategy. The value generated by transport activities in the supply chain of sectors linked to the SMM-strategies is nonetheless included as it contributes to the value of the unfinished material or product at that stage.

Our calculations consider the total supply chains of materials and products, which unmistakably imply overlapping supply chains between the SMM-strategies of recycling and reuse because reusable components and goods could include recyclable materials. To estimate only the extra value linked to the reuse strategy in our method, reuse only considers the extra production steps as illustrated in Figure 52. This makes the resulting reuse and recycle strategy potentials cumulative, and we can assess each strategy's substitution potential. Of course in reality an intensified reuse strategy will reduce the available waste streams available for recycling in the short term, so with an intensified SMM-strategy of reuse the recycling will take place later in time. Waste prevention, focusing on food, depicts other materials or products than recycling and reuse do, making the overlap between these strategies small and resulting in cumulative strategy potentials. The overlap between energy recovery and the other SMM-strategies is large, making the resulting recovery potential not cumulative with and dependent on the other strategies. The illustration provided in *5.8 Appendix A* explains with a numerical example the possible overlap between different SMM-strategies.

The SMM-strategies of energy recovery, recycling and reuse capture value of materials in goods. This value is, in competitive markets, equal to the value of similar goods depending on the current production methods and costs, including primary and secondary production routes. There are factors that increase or decrease this value, but in our method we assume the current production price as the maximum value for recovered goods. Factors such as a recycling-label could upgrade this value, but increased material supplies (with constant demand) put a downward pressure on prices. The viability of the new activity depends on many factors such as the quality and volume of recovered materials and the costs and efficiency of the plant. However, the total economic impact of an SMM-activity is limited to the current total value of the materials in a region. Stated differently, the total economic value of regionally available materials determines the maximum substitution potential of the SMM-activity. We calculate the total economic value of materials in goods as the total economic value of materials used in the production chains for the regional final demand (excluding exports). Some materials are outside the control of regional policies as production steps take place outside the region making their ‘waste materials’ unavailable for a Flemish SMM-activity. Next to the economic potential, both the environmental effect on greenhouse gas emissions and the social effect on employment are calculated for Flanders and the world economy. In our method, we do not consider positive economic growth effects from a first mover advantage, as this consideration would require an estimation of the available rest streams from domestic and foreign final demand.

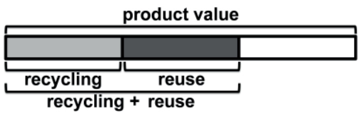

FIGURE 52: PRODUCT VALUE CONTAINING NON-OVERLAPPING RECYCLING OF MATERIALS AND REUSE VALUE OF GOODS OR COMPONENTS FROM GOODS. TO BE CUMULATIVE STRATEGIES, RECYCLING AND REUSE SHOULD NOT CONTAIN OVERLAPPING VALUE GENERATION. THE RECYCLING OF RECYCLABLE MATERIALS IS LINKED TO THE SMM-STRATEGY OF RECYCLING; THE REUSE OF GOODS OR COMPONENTS FROM GOODS IS LINKED TO THE SMM-STRATEGY OF REUSE, EXCLUDING THE VALUE OF RECYCLABLE MATERIALS IN RE-USABLE COMPONENTS. THE WHITE BLOCK INDICATES OTHER VALUE ADDING ACTIVITIES IN THE PRODUCTION PROCESS OF A PRODUCT, WHICH ARE NOT DIRECTLY OR INDIRECTLY LINKED TO THE RECYCLING AND REUSE STRATEGIES (E.G., WHOLESALE AND RETAIL ADDED VALUE AT THE END OF THE PRODUCTION NETWORK). THESE VALUE CREATING ACTIVITIES DO ADD VALUE TO THE TOTAL PRODUCT VALUE, BUT NOT TO THE RECYCLING OR REUSE POTENTIAL.

5.4.2 Estimate the maximum substitution value of SMM-strategies

In **step 2**, calculations are based on the detailed monetary regional EE-IO-tables combined with recently published global EE-MRIO tables. Linking regional IO-tables to MRIO-tables keeps specific regional economic characteristics and includes the international characteristic of value chains including country specific sectoral data. MRIO-tables include an interindustry matrix Z detailing the monetary intra- and interregional flows between sectors, a final demand matrix F specifying in monetary units the final demand of households, governments, NPISH, gross fixed capital formations and changes in inventories, an added value matrix K including per sector data on compensation of employees, operating surpluses and taxes less subsidies in monetary units and many extensions in matrix E such as primary material use, emissions, and employment figures in which the units depend on the extension. The output vector x can be calculated as the row sums of matrix Z and F (output) or the column sums of matrix Z an K (input). In a global MRIO-matrix Z and F contain sectors and final demand categories of all regions (country specific data), meaning they include all intermediary flows including imports and exports and all final demand imports. The main advantage of MRIO-calculations is that they are capable of capturing the complete production network of goods and services.

Dividing an extension vector[30] (e) by the output vector (x) results in an extension coefficient vector ($\mathrm{e}^{\mathrm{coef}}$). Multiplying $\mathrm{e}^{\mathrm{coef}}$ with both the Leontief inverse ($\mathrm{L} =$

[30]Row vector of matrix E.

$(I - A)^{-1}$; $A = Z \times \hat{x}^{-1}$) (Leontief, 1966) and F results in the total amount of the extension triggered by the final demand (Eder et al., 2006; Eurostat, 2008; Kitzes, 2013; Rose, A. Z. & Miernyk, W., 1989). If e represents CO_2-emissions then $e^{coef}_{CO_2} \times L \times F$ results in the total, considering the global production network, CO_2-emissions emitted by sectors to produce goods and services for the final demand (Suh, 2009; ten Raa, 2005). If both e^{coef} and F are diagonalized (represented by a ^), then $\widehat{e^{coef}} \times L \times \hat{F}$ results in a matrix with dimensions equal to the number of sectors in the model. As we used a multi-region model the dimensions are equal to the number of sectors times the number of regions. The sum of the elements in $\widehat{e^{coef}} \times L \times \hat{F}$ is equal to $e^{coef} \times L \times F$. However, the elements in $\widehat{e^{coef}} \times L \times \hat{F}$ provide extra information by detailing both the source of the extension (which sectors deliver or emit the extension) as well as the sink of the extension (to which final good or service is the extension linked).

To estimate the total economic, environmental and employment impacts for each of the different SMM-strategies, we use a two-step methodology (step 2a and 2b) visualised in Figure 53. Note that the impacts are based on a certain reference year, meaning the results are potentials of one year linked to the economic situation and market forces of that reference year.

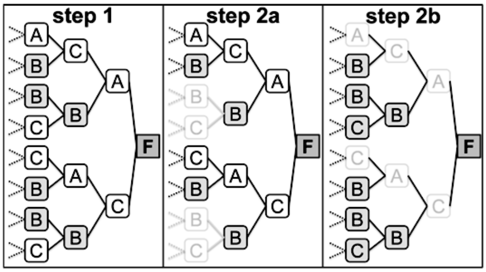

FIGURE 53: SIMPLIFIED EXAMPLE OF THE TWO-STEP PROCEDURE TO ESTIMATE THE POTENTIAL OF AN SMM-STRATEGY. F REFLECTS FINAL DEMAND; A, B AND C REPRESENT SECTORS (EACH LETTER COULD CORRESPOND WITH EITHER PRIMARY, SECONDARY OR TERTIARY SECTOR) IN A 'COMPLEX' NETWORK OF SUPPLY CHAINS. IN STEP 1, THE SECTORS (SHADED GREY) ARE LINKED TO AN SMM-STRATEGY (IN THIS SIMPLIFIED EXAMPLE, SECTOR B REPRESENTS ANY OF THE SECTORS LISTED IN **TABLE 1**, LINKED TO AN SMM-STRATEGY UNDER CONSIDERATION). IN STEP 2A, STARTING FROM F, ALL SECTORS B FIRST ENCOUNTERED (SO LATEST STEP IN SUPPLY CHAIN) ARE IDENTIFIED (SHADED GREY). ONLY THE CLOSEST PRODUCTION STEPS TO THE FINAL DEMAND ARE IDENTIFIED TO AVOID DOUBLE COUNTING OF (PARTS OF) SUPPLY CHAINS. THE TOTAL VALUE OF THE SHADED SECTORS IS THE SUM OF OWN VALUE ADDED AND THE VALUE OF THEIR SUPPLY CHAINS (SUPPLY CHAINS SHOWN IN LIGHT GREY LINKS AND BOXES). IN STEP 2B, THIS TOTAL VALUE IS REDISTRIBUTED OVER THE OWN VALUE ADDED OF SECTOR B AND THE VALUE ADDED OF A, B AND C IN THE SUPPLY CHAIN OF SECTOR B (SHADED GREY). NO VALUE IS ATTRIBUTED TO THE LIGHT GREY BOXES IN STEP 2B AS THESE WERE NOT LINKED TO THE SMM-STRATEGY. PER SMM-STRATEGY THE CALCULATION STARTS AGAIN FROM STEP 1.

Step 2a determines the total value of sectors linked to an SMM-strategy. This value includes the own value generation and the value of its supply chain. To avoid double counting identified sectors, the columns in matrix A of the corresponding sectors listed in step 1 are set to zero and a new L is calculated. Replacing these columns with zeros erases in the new L the supply chains of those sectors and avoids double counting the same or other sectors in the supply chain of an identified sector. For each identified sector, we calculated the total value spent or used by these sectors. As we erased their supply chain, we needed to attach their own value added and the supply chain value to the identified sector itself. Methodologically this is performed by replacing the corresponding elements in vector $\mathrm{k}^{\mathrm{coef}}$ [31] for the identified sectors by one. Replacing by one will count not only the own value added of these sectors but also the total value added generated in their supply chain. All other elements in $\mathrm{k}^{\mathrm{coef}}$ are set to zero, as they were not identified in step 1. Replacing by zero will not count the value added of these sectors. Calculating $\widehat{\mathrm{k}^{\mathrm{coef}}} \times \mathrm{L} \times \hat{\mathrm{F}}$, with both adopted L and $\mathrm{k}^{\mathrm{coef}}$, results in the total economic value of the sectors linked to an SMM-strategy, but as we adapted L and $\mathrm{k}^{\mathrm{coef}}$ the attribution of value added is not correct: the total value is attached to the identified sectors and not distributed over the supply chain participants. This distortion forced us to introduce an additional step 2b in our methodology.

The redistribution is covered in step 2b. Step 2a estimates the total economic value linked to the different SMM-strategies, but step 2b corrects the value added allocation and estimates the environmental and employment impacts. Summing the row elements of the resulting matrix of step 2a results in a column vector (F^*) with non-zero elements for the sectors linked to the SMM-strategy in step 1 and zero elements elsewhere. These non-zero elements represent the summed value added generated in those sectors and their supply chains. Now, $\widehat{\mathrm{k}^{\mathrm{coef}}} \times \mathrm{L} \times \widehat{\mathrm{F}^*}$ is calculated with original $\mathrm{k}^{\mathrm{coef}}$ and L, but with the new final demand vector. This redistributes the non-zero elements of the column vector in F^* to the linked sectors' own value added and to their supply chain participants. The GHG-emissions and employment are calculated by repeating step 2b and substituting the coefficient vector $\mathrm{k}^{\mathrm{coef}}$ with extension coefficient vectors of GHG-emissions and employment. Note that the basic assumption when working with IO tables is that the monetary flows are linearly related to the extensions (industry technology assumption: each industry has its own specific way of production, irrespective of its product mix (Eurostat, 2008), resulting in linearly related economic, environmental and employment impacts).

5.4.3 Determine comparable potentials of intensified strategies

Step 3 of our method does not include how the intensification of the strategy is developed and implemented, as described in *5.2 Introduction*. We also do not estimate the fraction of the total economic substitution potentials that can be considered realistic. Information on existing recycling, reuse and energy recovery activities in quantitative terms is limited. One of the few known sources, suggests that approx. 30 % of all steel and aluminium components by mass (and mainly used in construction, large vehicles and industrial equipment) could be reused (Cooper & Allwood, 2012). Because basic information is missing, we simply express results in absolute values and in substitution losses or gains per (million) euro replaced production value to compare the different SMM-strategies. We are interested to know the differences in the substitution potentials of the SMM-strategies. Also, we would like to know the differences in how much employment or global warming is potentially replaced by the intensified SMM-strategies. Both social and environmental consequences are linearly related to the economic substitution

[31] Vector $\mathrm{k}^{\mathrm{coef}}$ is the coefficient row vector of matrix K in which all columns are summed and divided by q.

potential. For example, if waste prevention intensification strategy A has two times the economic impact of waste prevention intensification strategy B, strategy A will also have two times the social and environmental impact of strategy B. This linearity assumption is a basic condition used in IO models in general. By presenting the potential in changes per million euro intensification, future work on net potentials can easily be scaled to estimate the net impacts of detailed (if known in terms of needed efforts) intensification strategies. The analysis does not include depreciation estimates for goods in general (this varies strongly across goods), as we calculate only the amount of displaced economic activities (induced by either life time extension, remanufacturing, or component reuse).

The substitution potential that we have assessed is a maximum substitution potential related to final consumption. In reality it is most probably smaller, for example, because certain manufacturing companies use their own in-house transport activities for delivering their final products from their gates to retail, shops or other final destinations. In our analysis we have not attributed (reuse) value to these in-house final transport steps, but we have included all transport steps needed to produce the materials and goods. By including these transport steps we cannot see the difference between the transport of intermediate goods and the transport of final goods from gate to retail. This could result in the maximum substitution potential from these manufacturing sectors being overestimated, which at the same time overestimates the potential for the same amounts in the reuse potential. If these transport activities happen at the manufacturers of final products, this may lead to a certain overestimation. Another point of attention when using the results is the fact that our assessment is not trying to assess the desirability of SMM-strategies in general from an overall environmental point of view as this will vary in many different contexts. “Longer lifetimes imply a slower rate of capital turnover but also a lost opportunity to produce more energy and material efficient products” (Söderholm & Tilton, 2012). For example, giving cars a longer life by 1 % leads to lower production emissions for producing cars, which is included in our substitution potential. The emissions that could be saved by recycling old cars and producing new cars (with much lower emissions per distance) are not included in our top-down analysis focussing on the materials related potential. These considerations should be included when assessing the net societal benefits of the different options.

Furthermore it is not likely that substitution potential can ever be fully achieved because the required efforts will exceed the savings. An example of recycling: “It has to be acknowledged that at some stage there will be a cut-off point where recycling will become too difficult and burdensome to provide a net benefit. A circular economy cannot promote recycling in perpetuity.” (Andersen, 2007).

5.5 Combining the Flemish input-output database with global multi-regional input-output databases

The Flemish EE-RIO-table (2007 data) contains 122 sectors (of which 116 have a non-zero output), 9 final use categories, three import regions: RoB (rest of Belgium), REU (rest of Europe) and RoW (rest of world) and 6 value added categories (Federaal Planbureau, 2007). Environmental data in the extension tables comprises approx. 400 items. Social data are added via extensions and supplemented with sector-aggregated annual accounts of companies provided by the National Bank of Belgium. WIOD (world input-output database) (1995-2011 data) is a global EE-MRIO constructed by a project of the 7th Framework

Programme funded by the European Commission. The database covers 35 sectors for 40 regions/countries and 1 rest of world region and approx. 50 items in the extension tables (Timmers, 2012). EXIOBASE 1.0 (2000 data) is a global EE-MRIO constructed by the Exiopol project funded by the European Commission. It includes 129 sectors for 43 countries and 1 rest of world region and approx. 400 items in the extension tables (Tukker, Arnold et al., 2009). Flanders is indirectly included in these MRIO-tables dataset via Belgium.

All calculations are based on an EE-IO-table of Flanders linked to the EE-MRIO table WIOD. This coupling enables us to focus on Flanders without losing the multiregional sector specific information. Subtracting the Flemish final demand from the Belgian final demand and recalculating the total model (recalculating matrices Z, E, K and q) results in an EE-MRIO including Flanders as a separate region. Due to the limited sector detail provided by WIOD we make use of the EXIOBASE 1.0 database for disaggregating sectors that contain relatively large shares of different SMM-strategies:

- ‘agriculture, hunting, forestry and fishing’ to separate forestry;
- ‘mining and quarrying’ to distinguish between fossil energy carriers and other mining and quarrying;
- ‘other non-metallic minerals’ to separate glass and glass products;
- ‘basic metals and fabricated metals’ to separate basic metals from fabricated metals; and
- ‘manufacturing, n.e.c.; recycling’ to separate manufacturing n.e.c.

For the disaggregation of the ‘chemicals and chemical products’-sector into a ‘manufacture of plastics in primary forms’ and a ‘rest’ category, we used the US 2000 IO-tables from EORA (Lenzen et al., 2013; Tukker et al., 2013). The sector disaggregation is performed via the extra information provided in EXIOBASE 1.0 and EORA in coefficient matrices A, $\mathrm{K}^{\mathrm{coef}}$ and $\mathrm{E}^{\mathrm{coef}}$ and final demand matrix F.

5.6. RESULTS AND DISCUSSION

5.6.1 How much value from primary sectors is Flanders importing from abroad either directly or embedded in products, compared to the value from primary sectors produced domestically?

The share of added value from primary sectors (in Flanders or abroad), including the value of their supply chain produced for Flemish final demand by households, NPISH, governments and investments, compared to the overall Flemish GDP is limited to approx. 8%. The primary sector value in economic terms is made up of 57% own value added and 43% supply chain value. This supply chain value states the value of the interindustry inputs into the primary sectors. The Flemish primary sectors deliver only one tenth (mainly from agriculture and some clay and sand mining and quarrying) of this 8%, whereas primary sectors abroad deliver by far the largest share (nine tenths of the 8%) through mining, quarrying and agriculture.

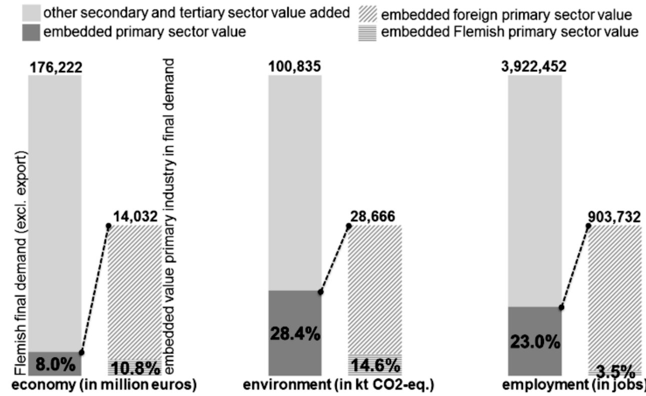

FIGURE 54: THE TOTAL EMBEDDED ECONOMIC VALUE, ENVIRONMENTAL IMPACT AND EMPLOYMENT SPLIT-UP ACROSS DOMESTIC AND FOREIGN PRIMARY SECTORS (INCLUDING OWN VALUE ADDED AND THE VALUE OF THEIR SUPPLY CHAINS) IN TOTAL FLEMISH FINAL DEMAND. THE BAR CHART ILLUSTRATES THE ECONOMIC VALUE REPRESENTED BY VALUE ADDED IN MILLION EUROS, ENVIRONMENTAL VALUE EXPRESSED BY GHG-EMISSIONS IN KT CO2-EQUIVALENTS AND EMPLOYMENT VALUE IN NUMBER OF PERSONS. THE LEFT BAR IS THE TOTAL FLEMISH FINAL DEMAND INDICATING THE SHARE OF GLOBAL EMBEDDED PRIMARY SECTOR OUTPUT VALUE. THE RIGHT BAR IS THE TOTAL EMBEDDED (DIRECT AND INDIRECT) VALUE IN THE FLEMISH FINAL CONSUMPTION OF THE DOMESTIC AND FOREIGN PRIMARY INDUSTRY, INCLUDING THEIR SUPPLY CHAINS. THE PERCENTAGE ON THE RIGHT BAR INDICATES THE SHARE OF FLEMISH PRIMARY SECTOR VALUE IN GLOBAL EMBEDDED PRIMARY SECTOR VALUE. THIS BAR ILLUSTRATES THE OUTPUT VALUE OF PRIMARY SECTOR PRODUCTS DIRECTLY OR INDIRECTLY BOUGHT BY FLEMISH FINAL CONSUMPTION. TOTALS ARE MENTIONED ABOVE EACH BAR.

Examining at the associated GHG-emissions (28 %) and jobs (23 %), we observe that the shares for the primary sectors in general are much higher showing that in terms of pollution per euro output but also jobs per euro output, the score (in Flanders and abroad) is much higher on average. The GHG per euro for Flemish primary sectors is higher than the average primary sector, but we should realise that primary sector activity in Flanders, consisting of mainly agriculture and some sand and clay, cannot be directly compared to primary sectors abroad containing more mining and quarrying activities. Many people abroad (872,000) have a job associated with Flemish final consumption whereas the Flemish jobs in primary sectors or in the supply chains linked to the primary industry are disproportionally limited to 31,800. The total number of people employed in only the primary sectors in Flanders is higher (57,000), showing that the agricultural sector also creates employment for consumption abroad through exports.

5.6.2 How much primary, secondary and tertiary sector value produced in or imported by Flanders is exported abroad as materials or embedded in products?

A basic understanding of the Flemish production and consumption (and associated environmental impacts and jobs) and its connections abroad via imports and exports is needed to address the potential of SMM and generic material efficiency strategies, such as recycling, life time extension or reuse as products/components, waste prevention, energy recovery and food waste prevention. For example, primary sectors are mainly linked to the recycling of materials, whereas secondary sectors are more linked to their reuse. In Figure 54 the primary sector value is shown as the sum of the sector's own value and the value of the supply chains directly delivering inputs to the primary sectors. The values presented in Figure 55 solely refer to the primary, secondary and tertiary sectors' own value added. Per category the left bar represents the production perspective in which the Flemish primary, secondary and tertiary sectors' value creation are linked to domestic and foreign final consumption. The right bar represents the consumption perspective in which the Flemish consumption is linked to domestic and foreign primary, secondary and tertiary value creation. The production perspective includes all domestic or territorial impacts linked to global final demand, while the consumption perspective includes global impacts linked to domestic or territorial final demand.

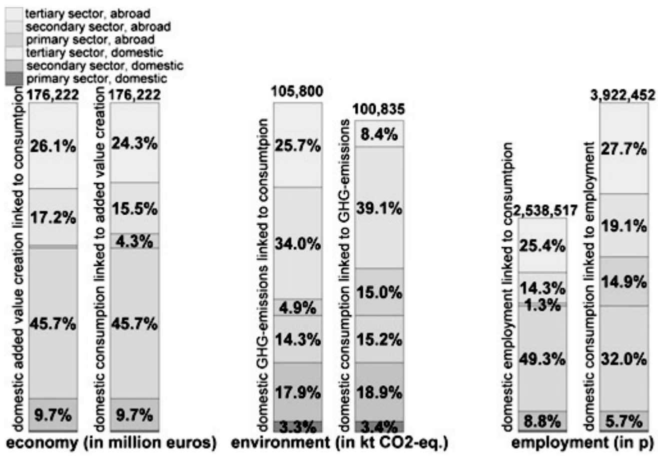

FIGURE 55: THE GLOBAL PRIMARY, SECONDARY AND TERTIARY SECTOR VALUE CONTRIBUTIONS FROM BOTH A FLEMISH PRODUCTION AND CONSUMPTION PERSPECTIVE. THE BAR CHART ILLUSTRATES THE ECONOMIC VALUE REPRESENTED BY VALUE ADDED IN MILLION EUROS, ENVIRONMENTAL VALUE EXPRESSED BY GHG-EMISSIONS IN KT CO2-EQUIVALENTS AND EMPLOYMENT VALUE IN NUMBER OF PERSONS. THE LEFT BAR REPRESENTS THE PRODUCTION PERSPECTIVE SHOWING THE SOURCES (PRIMARY, SECONDARY AND TERTIARY SECTOR VALUE CONTRIBUTION) AND THE SINKS (DOMESTIC OR ABROAD CONSUMPTION FOR FINAL USE) OF FLEMISH VALUE CREATION. THESE SINKS INDICATE THE CONSUMPTION FOR FINAL USE, MEANING THE CONSUMER AT THE END OF THE PRODUCTION CHAIN IN WHICH THE FLEMISH SECTOR HAS CONTRIBUTED AND GENERATED ITS VALUE. THE RIGHT BAR SHOWS THE DOMESTIC OR ABROAD PRIMARY, SECONDARY OR TERTIARY SECTOR VALUE CONTRIBUTION TO TOTAL FLEMISH FINAL DEMAND. CONTRIBUTIONS BELOW 1 % ARE NOT EXPLICITLY REFERRED TO. TOTALS ARE MENTIONED ABOVE EACH BAR.

Figure 55 (economy) presents the total Flemish GDP of approx. 176 billion euros from a production and an expenditure perspective. Still, 56% of the total added value that Flemish sectors create is linked to products bought by Flemish final demand (direct or embedded) with a dominant contribution of 45,7% by the domestic tertiary sector (economy – left bar). The remaining Flemish added value creation (44%) is linked to final consumption abroad with both high secondary and tertiary sector contributions. Relatively more Flemish secondary and less tertiary added value is exported via products compared to Flemish value added in Flemish final consumption. The relatively high share of the Flemish tertiary sector added value in products consumed abroad, 26%, can be explained by the high amount of direct exports of services and the high amount of embedded value from the tertiary economy in exports (mainly wholesale and commission trade, transport and supporting activities and other business activities). The right bar of economy shows how the Flemish GDP is being spent by final demand categories (category split-up is shown in Figure 56) separated by primary, secondary and tertiary sectors' value added creation by Flemish and foreign sectors. The domestic spending in the right bar evidently equals the accumulated domestic added value in the left bar, as they indicate the same values, but from a production and consumption perspective, respectively. Comparing the abroad part of the left bar with the abroad part of the right bar shows how strongly final consumption in Flanders depends on imports from primary sectors, but at the same time, we observe the relatively low share in added value of primary sectors compared to secondary and tertiary sectors. The economy part stresses the openness of the Flemish economy both from a production (export) and consumption (import) perspective.

The results on global warming show that domestically emitted GHG-emissions are mainly linked (approx. 65%) to final consumption abroad (environment – left bar) and have a higher share compared to their economic equivalent (approx. 44%). This finding can be explained by the higher energy demands from primary and secondary sectors compared to tertiary sectors. GHG-emissions emitted in the production of all products intended for Flemish final consumption (environment – right bar) are mainly emitted abroad (approx. 63%). Comparing the production and consumption perspectives, we conclude that Flanders is a net exporter of GHG-emissions of approx. 5,000 kt CO2-equivalents. This conclusion does not take into account emissions during the consumption phase (e.g., emissions to air caused by private transport), but only emissions during the production phase (e.g., emissions to air caused by the manufacturing of gasoline and diesel).

The results on domestic employment (employment – left bar) show that the number of jobs across the sectors is more or less proportional to the economic added value. Only in the (small) primary sectors is the number of jobs relatively higher due to lower wages or higher shares of part-time or seasonal employment. The proportionality can be explained by the very high share of labour cost in most economic activities. The result on employment triggered by Flemish final demand shows a high share of foreign employment compared to the economic value it represents, meaning that Flemish demand creates more jobs abroad, which can be explained by lower wage levels abroad especially in the primary sectors (14,9% of total employment for an economic share of only 4,3%). Comparing the production and consumption perspectives, we conclude that Flanders is a net importer of approx. 1.4 million jobs.

5.6.3 How is the primary, secondary and tertiary sector value in Flanders disturbed across final consumption from households, NPISH, governments, investments and changes in inventories?

For the Flemish Policy on Sustainable Materials Management it is important to understand where the added value of primary and secondary sectors flows in the final demand categories that remain in Flanders as they are directly reachable in a circular economy context.

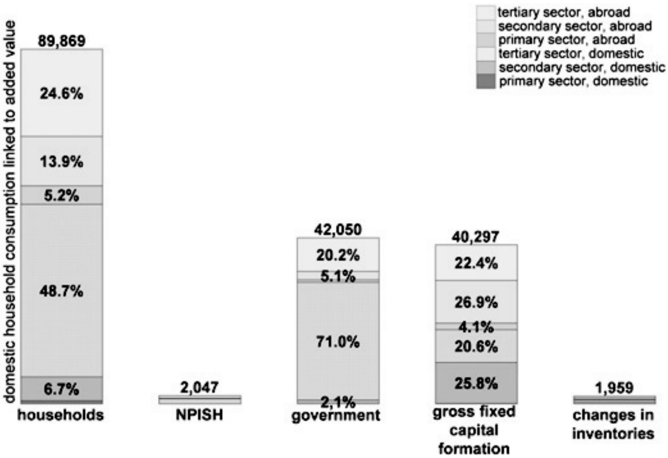

FIGURE 56: PRIMARY, SECONDARY AND TERTIARY SECTOR VALUE ADDED CONTRIBUTION TO THE DIFFERENT FLEMISH CONSUMPTION CATEGORIES. FLEMISH FINAL CONSUMPTION IS DIVIDED INTO HOUSEHOLD CONSUMPTION, NPISH (NON-PROFIT INSTITUTIONS SERVING HOUSEHOLDS), GOVERNMENT PUBLIC AND PRIVATE CONSUMPTION, GROSS FIXED CAPITAL FORMATIONS AND CHANGES IN INVENTORIES. THE ECONOMIC VALUE REPRESENTED IS THE VALUE ADDED GENERATED BY FLEMISH OR FOREIGN PRIMARY, SECONDARY AND TERTIARY SECTORS FROM A VALUE CHAIN PERSPECTIVE. CONTRIBUTIONS BELOW 1% ARE NOT EXPLICITLY REFERRED TO. TOTALS ARE MENTIONED ABOVE EACH BAR. THE SUM OF THIS BAR CHART EQUALS THE RIGHT BAR OF ECONOMY IN FIGURE 55.

A split of final demand shows that household consumption, government spending and gross fixed capital formation (investments in durable goods by economic sectors) are the dominant categories in economic terms. A comparison among the three dominant categories shows that the product value from primary sectors flows mainly to households (6.1% of 88 billion euros or 5.4 billion euros) and gross fixed capital formation (4.3% of 40 billion euros or 1.7 billion euros), indicating that households and gross fixed capital formation are the most important candidates for possible additional policies regarding recycling, food waste reduction and material efficiency. Value from products from secondary sectors mainly flows to gross fixed capital formation (52.7% of 40 billion euros or 20.8 billion euros) and households (20.6% of 88 billion euros or 18.2 billion euros). This clearly indicates that policies for life time extension, reuse of products/components and sharing of products will find the largest budget for realizing the strategies in the final demand categories of gross fixed capital formation and households and, to a lesser extent, in government consumption (7.2% of 41 billion euros or 3.0 billion euros).

5.6.4 What is/are the maximum substitution potential/effects of intensifying generic SMM-strategies on food waste prevention, energy recovery, reuse and recycling (in terms of GDP, jobs and GHG) for Flanders and abroad?

All observations above are based on the classic classification of sectors into primary, secondary and tertiary sectors, and demand is classified as the last sector delivering the product (good or service) to the final user. As it is based on value added, there is no double counting involved (see *5.4 Calculation framework and procedures*). To answer the fourth question we take a closer look at the sectors and their embedded value in the intermediate inputs of other sectors. For example, assuming that tertiary sectors do not contribute to the potential value for reuse is a rough first order approach, as primary and secondary sectors need tertiary sectors as inputs to realize their goods. In our methodology described in section 3, we included all value (of any type of sector) in the supply chain as well, without double counting.

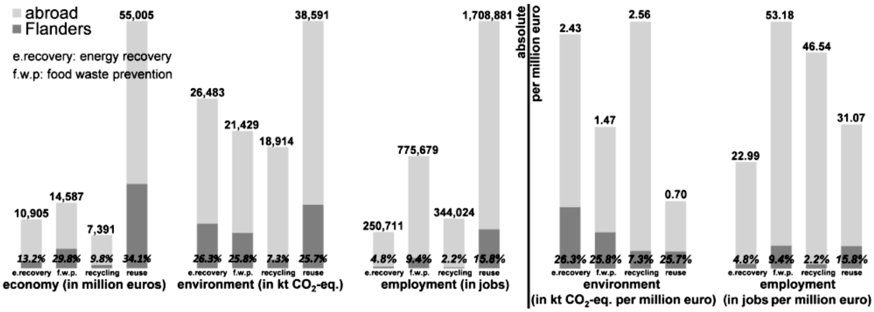

FIGURE 57: THE ABSOLUTE SUBSTITUTION POTENTIAL (LEFT HAND SIDE) AND PER MILLION EURO SUBSTITUTION POTENTIAL (RIGHT HAND SIDE) OF FOUR GENERIC SMM-STRATEGIES: ENERGY RECOVERY, FOOD WASTE PREVENTION, RECYCLING AND REUSE FOR FLANDERS. THE BARS REPRESENT THE SUBSTITUTION POTENTIAL PER STRATEGY FOR ECONOMY EXPRESSED IN MILLION EUROS VALUE ADDED, FOR ENVIRONMENT EXPRESSED IN KT CO2-EQUIVALENTS AND FOR EMPLOYMENT IN NUMBER OF JOBS. THE SHARES INDICATE THE FLEMISH PART IN THIS POTENTIAL. TOTALS ARE MENTIONED ABOVE EACH BAR. THE RIGHT HAND SIDE, EXPRESSED PER MILLION EURO SUBSTITUTION POTENTIAL, ALLOWS DIRECT COMPARISON ACROSS STRATEGIES OF IMPACTS ON ENVIRONMENT AND EMPLOYMENT.

The maximum economic substitution potential in absolute terms for the reuse strategy is approximately a factor 7.5 higher than the recycling strategy. Note that in the reuse strategy the recycling potential is excluded, so a policy solely focussing on reuse has a maximum budget of 62 billion euros (=reuse + recycling, see Figure 52). It shows that the budget for new economic activities (like more reverse logistics) needed for intensifying the reuse strategy is much larger than the budget for intensifying the recycling strategy. At the same we observe that intensified reuse and food waste prevention strategies substitute high shares of added value in Flanders, meaning that intensified reuse and food waste prevention strategies affect the Flemish economy relatively more than the recycling and energy recovery strategies. We conclude that from an economic perspective the substitution potential is by far the largest for the reuse strategy, although reuse can have the highest potential impact on lost economic activities in Flanders.

The budget of the different SMM-strategies shown in Figure 57 is estimated from the value of the current domestic and foreign economic activities that have the potential to be replaced by new activities under an intensified SMM-strategy in Flanders. Figure 58 illustrates this economic (in added value) build-up of both global sectors and only Flemish sectors that are potentially affected under an intensified SMM-strategy in Flanders. The bar chart shows clear differences between strategies and between global and local impacts in the different sectors. For example, the Flemish mining and quarrying sector (sector 2 in Figure 58) is less affected by an intensified energy recovery and recycling SMM-strategy compared to the global impact on this sector. For each strategy, the results show a mix of straightforward and non-straightforward results. For example, the SMM-strategy of food waste prevention affects agriculture and food processing but also largely affects the service related sectors. The SMM-strategy of reuse affects the manufacturing industries but also has a substantial impact on construction activities, especially in Flanders. The figure shows the potential large economic impact on service sectors from all SMM-strategies, even though these sectors were not directly linked to any of the SMM-strategies. This shows their importance in value chains of primary and secondary sectors.

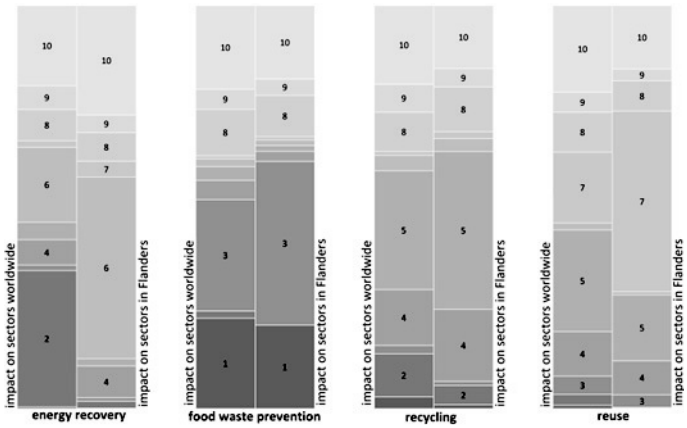

FIGURE 58: THE ECONOMIC IMPACTS ON GLOBAL SECTORS (LEFT BAR) AND ONLY FLEMISH SECTORS (RIGHT BAR) PER EURO SUBSTITUTION POTENTIAL BY INTENSIFIED SMM-STRATEGIES IN FLANDERS (HEIGHT OF BARS REPRESENTS ONE EURO SUBSTITUTION POTENTIAL; SECTOR IMPACTS ARE EXPRESSED IN SHARES). SECTOR IMPACTS DIFFER ACROSS STRATEGIES AND SECTOR IMPACTS DIFFER IN FLANDERS COMPARED TO ABROAD BY INTENSIFIED SMM-STRATEGIES. 1: AGRICULTURE, HUNTING, FORESTRY AND FISHING (01-05); 2: MINING AND QUARRYING (10-14); 3: MANUFACTURING – FOOD, TEXTILES, LEATHER, WOOD AND PAPER (15-22); 4: MANUFACTURING – COKE, CHEMISTRY, RUBBER AND PLASTICS AND OTHER NON-METALLIC (23-26); 5: MANUFACTURING – METALS, MACHINERY, EQUIPMENT, TRANSPORT AND OTHER MANUFACTURING (27-37); 6: ELECTRICITY, GAS AND WATER SUPPLY (40-41); 7: CONSTRUCTION (45); 8: SALE, WHOLESALE AND RETAIL (50-55); 9: TRANSPORT (60-63); 10: OTHER SERVICES (64-99).

If we look at the substitution potential regarding global warming (Figure 57) the considered strategies show a more equal potential: the reason for this is that food production, energy production and raw materials emit much more carbon emissions per million euro compared to secondary manufacturing activities. Another observation is that energy recovery, food waste prevention and reuse show a similar share of approx. 26 % regarding emissions in Flanders compared to approx. 74 % of emissions abroad. From a territorial accounting perspective these three strategies show more potential than recycling.

From an employment perspective, Figure 57 shows that intensified strategies for reuse and food waste prevention will substitute the most jobs for the current production activities. Energy recovery and recycling will substitute fewer jobs for the current production activities and even fewer jobs in Flanders. The relative values show high values for food waste prevention and recycling and lower values for energy recovery and reuse.

Comparing the four strategies' potentials from the different perspectives:

- *Economically*: reuse creates by far the largest budget for new activities to realize the strategy but also has the largest rebound effect on Flemish GDP (and employment);
- *Global warming*: all four strategies have similar and significant potentials to reduce emissions or oil dependence. Energy recovery, food waste prevention and reuse have higher potentials to reduce Flemish territorial GHG-emissions;
- *Employment*: from a "world" employment perspective it is important to realize that so many people all over the world are employed in jobs that are associated with Flemish final demand. If the objective were to create new Flemish jobs in additional local activities to realize the strategies while delivering the same final demand, this most likely would mean the loss of many jobs abroad. This raises the issue of solidarity and collaboration across the nations. From a pure self-interest Flemish employment perspective, the strategies of energy recovery and recycling replace the fewest Flemish jobs.

5.7 CONCLUSIONS

We developed a methodology to assess the potential of SMM-strategies by allocating (disaggregated) production sectors to each of the strategies. Although the concept of added value as such does not involve double counting, SMM-strategies' budgets do overlap. Policies employing a single SMM-strategy are not influenced by overlapping strategies. However, the maximum substitution potential of policies employing multiple SMM-strategies are influenced by this overlap. To avoid double counting for the reuse and recycling strategies, we were able to estimate the maximum substitution budget of a combined reuse and recycling intensification strategy. Food waste prevention focuses on different sectors/products, making the overlap with other SMM-strategies small. Energy supply is entangled in all supply chains; therefore, it is important to consider this overlap when estimating maximum substitution potentials of policies including energy recovery.

The case study on Flanders stressed its open economy:

- more than 90 % of the value of primary material resources needed for Flemish final demand originates from abroad;
- approx. 44 % of the value that is created in Flanders is paid by final demand abroad (exports), leaving significant material quantities out of reach for local circular economy activities; and
- approx. 44 % of the total Flemish final consumption expenditures are directly or indirectly 'leaking' abroad from a value chain perspective via imports.

The value of primary sectors (even when their supply chain value is included) is low compared to the value that secondary and tertiary economic activities generate.

The output of the primary sector only contributes 8.0 % of the total value of Flemish final consumption. Without the supply chain value this contribution is only 5.2 %. However, the impact on GHG-emissions and employment is more substantial with contributions of 28.4 % and 23.0 %, respectively (including the supply chain of the primary industry).

The first order approach in terms of primary, secondary and tertiary sectors shows that policies for life time extension, reuse of products/components and sharing of products will find the largest budgetary envelope (31.2 % of Flemish GDP compared to 8.3 % for food waste prevention, 6.2 % for energy recovery and 4.2 % for recycling) for realizing the strategies. The final demand categories containing large potential value for SMM-strategies are gross fixed capital formation and households and, to a lesser extent, government consumption. The diversity of potentially impacted sectors of an intensified SMM-strategy is large and differs between a global and Flemish perspective.

Our method of linking SMM and material efficiency strategies shows only one side of the 'medal'. The maximum substitution potential or budget is estimated by the value of the current production system. The method shows the potential industries affected by an intensified SMM-strategy represented by a budget, GHG-emissions saved and jobs lost. This budget can be used to create (local) GDP and (local) employment through new SMM-strategies. It shows that the substitution potential varies across the strategies and whether is it looked at from a local or global perspective. In economic terms reuse creates by far the largest maximum substitution potential for new activities to realize the strategy. To impact global warming all four strategies have similar and significant potential to reduce emissions. Energy recovery, food waste prevention and reuse have a higher potential to reduce Flemish territorial GHG-emissions. The strategies of energy recovery and recycling replace the fewest Flemish jobs in relative terms, but from a global perspective, all strategies most likely imply the loss of jobs abroad, of course assuming fulfilment of the same Flemish final demand.

For every million euro in expenditures saved on primary energy sources by an intensified SMM energy recovery strategy, GHG-emissions are reduced globally by 2.43 kt on average, and global employment is reduced by 23 jobs on average, one of which is in Flanders. This means that the effect of reducing demand for primary energy sources by one million euro due to an SMM energy recovery strategy is to reduce emissions by 2.43 kt GHG-emissions and employment by 23 jobs. It also creates a budget of one million euro for new (local) activities under the SMM energy recovery strategy. To reduce global GHG-emissions, these new activities should create less than 2.43 kt GHG-emissions. To create a net increase in local jobs, these new activities should create more than 1 job in Flanders. For every million euro in expenditures saved on food by an intensified SMM food waste prevention strategy, GHG-emissions are reduced by 1.47 kt globally, and global employment is reduced by 53 jobs, approx. 5 of which are in Flanders. For every million euro in expenditures saved on recyclable materials by an intensified SMM recycling strategy, GHG-emissions are reduced 2.56 kt on average globally, and global employment is decreased by 47 jobs on average, 1 of which is in Flanders. For every million euro in expenditures saved on reusable goods by an intensified SMM reuse strategy, GHG-emissions are reduced globally by 0.70 kt, and global employment is reduced by 31 jobs, 5 of which are in Flanders.

We did not assess the other side of the 'medal' due to complexity. How much of these new activities (and their impacts) are needed to realize (part of) the strategies? To what extent can these new activities affect current expenditures? When the direct effects in Flanders can be quantified for specific actions, one could quantify the indirect effects in Flanders and abroad by classic IO-calculations to determine the resulting net effects on GDP, GHG-emissions and employment.

5.8 Appendix A

The hypothetical economy, simplified in terms of a limited number of sectors, is presented in Figure 5A.1 to illustrate our methodology. The illustration also shows the necessity of sector disaggregation (e.g., in WIOD-data, world multiregional input output database, there exists only one metal sector covering both primary and secondary activities) and the possible budget overlap between non-cumulative SMM-strategies.

The hypothetical economy contains four sectors: (A) extraction of non-energy raw materials, (B) extraction and production of energy from fossil sources, (C+D) metal sector and (E) the production of applications (e.g., domestic household appliances). Additionally, it contains one final demand category consuming energy from sector B and appliances from sector E. The metal sector contains shares of both added value in terms of material production (recycling potential) as well as added value on steel component production (reuse potential). By disaggregating the metal sector, we are able to correctly link the value added generation of the material production part and the value of their supply chains to recycling and link the value added generation of the steel component production part and the value of their supply chain to reuse. The three steps of our methodology (see section 3) are applied to this hypothetical economy.

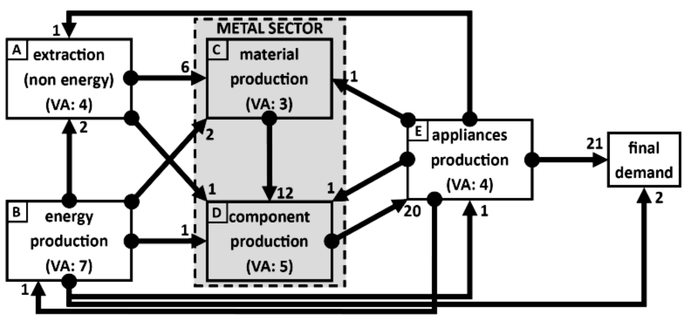

Figure 5A.1: Hypothetical economy containing four sectors and one final demand category. The metal sector is disaggregated into material and component production to allow a better linking of sectors to different SMM-strategies. All numbers are in million euros; VA: value added.

From Figure 5A.1 we can deduct matrices Z (interindustry matrix), F (final demand), x (output), k (value added), A (interindustry coefficient matrix) and L (Leontief inverse). e (employment vector) is added to include one non-economic parameter. $\mathrm{e}^{\mathrm{coef}}$ (employment coefficient vector) is deducted from e. I is an identity matrix: '1' on the main diagonal and '0' elsewhere. Numbers in Z, F, x are in million euros, e is in number of employees, matrices A and $\mathrm{k}^{\mathrm{coef}}$ are coefficient matrixes (dimensionless) and matrix $\mathrm{e}^{\mathrm{coef}}$ is in number of employees per one million euro output.

$$Z = \begin{bmatrix} 0 & 0 & 6 & 1 & 0 \\ 2 & 0 & 2 & 1 & 1 \\ 0 & 0 & 0 & 12 & 0 \\ 0 & 0 & 0 & 0 & 20 \\ 1 & 1 & 1 & 1 & 0 \end{bmatrix}; \ F = \begin{bmatrix} 0 \\ 2 \\ 0 \\ 0 \\ 21 \end{bmatrix}; \ x = \begin{bmatrix} 7 \\ 8 \\ 12 \\ 20 \\ 25 \end{bmatrix}$$

$$k = [4 \quad 7 \quad 3 \quad 5 \quad 4]$$

$$e = [90 \quad 150 \quad 60 \quad 80 \quad 40]$$

$$A = Z \times \hat{x}^{-1} = \begin{bmatrix} 0 & 0 & 0.5 & 0.05 & 0 \\ 0.29 & 0 & 0.17 & 0.05 & 0.04 \\ 0 & 0 & 0 & 0.6 & 0 \\ 0 & 0 & 0 & 0 & 0.8 \\ 0.14 & 0.13 & 0.08 & 0.05 & 0 \end{bmatrix}$$

$$L = (I - A)^{-1} = \begin{bmatrix} 1.06 & 0.04 & 0.56 & 0.41 & 0.33 \\ 0.34 & 1.04 & 0.36 & 0.3 & 0.28 \\ 0.1 & 0.07 & 1.11 & 0.7 & 0.56 \\ 0.17 & 0.12 & 0.18 & 1.17 & 0.94 \\ 0.21 & 0.15 & 0.23 & 0.21 & 1.18 \end{bmatrix}$$

$$e^{coef} = e \times \hat{x}^{-1} = [12.9 \quad 18.8 \quad 5 \quad 4 \quad 1.6]$$

STEP 1: LINK SMM-STRATEGIES TO ECONOMIC SECTORS

The SMM-strategies are linked to the sectors of our hypothetical economy:

- energy recovery: sector B;
- recycling: sector A and sector C; and
- reuse: sector D and sector E.

The SMM-strategy of food waste prevention is not included in this illustration. An intensified energy recovery strategy increased energy supply from non-fossil sources (new activity). Assuming a constant total energy demand, the demand for fossil energy declines (sector B). The expenditures saved on sector B determine the budget, calculated as the maximum substitution potential, for the new activity. Both sectors A and C produce recyclable materials. The output of sectors D and E contains recyclable materials, but their added value does not contribute to the recycling value of the materials in their output. Sectors D and E produce components and products and by doing so generate value added, containing value linked to the reuse strategy.

STEP 2: ESTIMATE THE MAXIMUM SUBSTITUTION VALUE OF SMM-STRATEGIES

Energy recovery

<u>Step 2A: Estimating the maximum economic substitution value without double counting</u>

Develop a new k (k^{coef*}) and A (A^{*}) by replacing all elements in the column corresponding to sector B in matrix A with '0' and replacing all elements in the column corresponding to sector B in vector k with '1'.

$$A^* = \begin{bmatrix} 0 & 0 & 0.5 & 0.05 & 0 \\ 0.29 & 0 & 0.17 & 0.05 & 0.04 \\ 0 & 0 & 0 & 0.6 & 0 \\ 0 & 0 & 0 & 0 & 0.8 \\ 0.14 & 0 & 0.08 & 0.05 & 0 \end{bmatrix}; k^{coef*} = [0 \quad 1 \quad 0 \quad 0 \quad 0]$$

$F^* = \hat{k}^{coef^*} \times L^* \times \hat{F} \times i$ with i column vector containing only '1'.

$$F^* = \begin{bmatrix} 0 \\ 7.73 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

<u>Step 2B: Distributing added value across supply chain participants and estimating the maximum non-economic substitution values</u>

$$\text{economic budget} = i' \times \hat{k}^{coef} \times L \times \hat{F}^* \times i = i' \times \begin{bmatrix} 0.18 \\ 7 \\ 0.14 \\ 0.23 \\ 0.18 \end{bmatrix} = 7.73 \text{ million euros}$$

Step 2B correctly redistributes the economic budget estimated in step 2A over the five sectors. The total budget or maximum substitution value of energy recovery is 7.73 million euros. The substitution will largely affect sector B (7 million euros) and has minor effects on the other sectors (A, C, D and E) with a cumulative impact of 0.73 million euros. In this example, only sector B is linked to energy recovery, nevertheless all four other sectors contribute to the economic budget due to their participation in the supply chain of sector B. Independent from the sectors linked to the SMM-strategies, all sectors (primary, secondary and tertiary) can contribute to the economic budget via their supply chain participations.

$$\text{employment budget} = i' \times \hat{e}^{coef} \times L \times \hat{F}^* \times i = i' \times \begin{bmatrix} 4.09 \\ 150 \\ 2.73 \\ 3.64 \\ 1.82 \end{bmatrix} = 162.27 \text{ employees}$$

The SMM-strategy energy recovery has a maximum employment impact of 162.27 employees, mainly in sector B. The newly created activities under the SMM-strategy should at least create the same number of jobs to avoid job depletion.

Recycling

<u>Step 2A: Estimating the maximum economic substitution value without double counting</u>

$$A^* = \begin{bmatrix} 0 & 0 & 0 & 0.05 & 0 \\ 0 & 0 & 0 & 0.05 & 0.04 \\ 0 & 0 & 0 & 0.6 & 0 \\ 0 & 0 & 0 & 0 & 0.8 \\ 0 & 0.13 & 0 & 0.05 & 0 \end{bmatrix}; k^{coef*} = [1 \quad 0 \quad 1 \quad 0 \quad 0]$$

$$F^* = \hat{k}^{coef^*} \times L^* \times \hat{F} \times i = \begin{bmatrix} 0.89 \\ 0 \\ 10.7 \\ 0 \\ 0 \end{bmatrix}$$

Step 2B: Distributing added value across supply chain participants and estimating the maximum non-economic substitution values

$$\text{economic budget} = \text{i}' \times \hat{\text{k}}^{\text{coef}} \times \text{L} \times \hat{\text{F}}^{*} \times \text{i} = \text{i}' \times \begin{bmatrix} 4 \\ 3.68 \\ 3 \\ 0.53 \\ 0.42 \end{bmatrix} = 11.63 \text{ million euros}$$

$$\text{employment budget} = \text{i}' \times \hat{\text{e}}^{\text{coef}} \times \text{L} \times \hat{\text{F}}^{*} \times \text{i} = \text{i}' \times \begin{bmatrix} 90 \\ 78.9 \\ 60 \\ 8.42 \\ 4.21 \end{bmatrix} = 241.58 \text{ employees}$$

Reuse

Step 2A: Estimating the maximum economic substitution value without double counting

$$\text{A}^{*} = \begin{bmatrix} 0 & 0 & 0.5 & 0 & 0 \\ 0.29 & 0 & 0.17 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0.14 & 0.13 & 0.08 & 0 & 0 \end{bmatrix}; \text{k}^{\text{coef}*} = [0 \quad 0 \quad 0 \quad 1 \quad 1]$$

$$\text{F}^{*} = \hat{\text{k}}^{\text{coef}^{*}} \times \text{L}^{*} \times \hat{\text{F}} \times \text{i} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 21.3 \end{bmatrix}$$

Step 2B: Distributing added value across supply chain participants and estimating the maximum non-economic substitution values

$$\text{economic budget} = \text{i}' \times \hat{\text{k}}^{\text{coef}} \times \text{L} \times \hat{\text{F}}^{*} \times \text{i} = \text{i}' \times \begin{bmatrix} 4 \\ 5.25 \\ 3 \\ 5 \\ 4 \end{bmatrix} = 21.25 \text{ million euros}$$

$$\text{employment budget} = \text{i}' \times \hat{\text{e}}^{\text{coef}} \times \text{L} \times \hat{\text{F}}^{*} \times \text{i} = \text{i}' \times \begin{bmatrix} 90 \\ 112.5 \\ 60 \\ 80 \\ 40 \end{bmatrix} = 383.5 \text{ employees}$$

STEP3: DETERMINE COMPARABLE POTENTIALS OF INTENSIFIED SMM-STRATEGIES

TABLE 5A.1: COMPARABLE POTENTIALS OF INTENSIFIED SMM-STRATEGIES OF THE HYPOTHETICAL ECONOMY (NON-CUMULATIVE STRATEGIES).

SMM-STRATEGIES	ECONOMIC BUDGET	EMPLOYMENT BUDGET
(unit)	*in million euros*	*in number of employees per million euro economic budget*
energy recovery	7.73	21.00

recycling	11.63	20.77
reuse	21.25	18.00

Reuse creates by far the largest economic budget or maximum substitution potential (21.25 million euros) compared to recycling (11.63 million euros) and energy recovery (7.73 million euros). The relative impact on employment shows a different picture. Per million euro, the intensified SMM-strategies substitute approx. 21 employees for energy recovery and recycling and 18 employees for reuse.

The overlap between strategies influences the maximum substitution potential. Products and components being reused are not available for recycling in the short term and their reuse also diminishes demand for energy in the current production system. Depending on the new activities in an intensified reuse SMM-strategy, the possibility of increased demand for energy exists. Likewise, products and components being recycled are no longer available for reuse, which decreases demand for energy inputs in raw material extraction and production. As the total added value generation in the hypothetical economy is 23 million euros (sum of value added generation of the five sectors), the total budget or maximum substitution potential cannot exceed 23 million euros. This shows that energy recovery, recycling and reuse represented in Table 5A.1 cannot be considered as simultaneous cumulative strategies. Energy recovery is entangled in both recycling and reuse. Recycling and reuse can be cumulative when applied in the correct order (first reuse, then recycling). Their combined maximum budget equals 21.25 million euros, 11.63 million of which are attributed to the recycling budget, and the remainder (9.62 million euros) to the reuse budget.

From the illustration on the hypothetical economy we conclude that a policy solely focussing on intensifying the SMM-strategy of reuse has an economic budget of 21.25 million euros. Per million euros, the SMM-strategy reduces employment by 18 employees (with a relatively equal impact on all sectors). A policy solely focussing on intensifying the SMM-strategy of recycling has an economic budget of 11.63 million euros. Per million euros, the SMM-strategy reduces employment by almost 21 employees (mainly in sectors A, B and C). A policy solely focussing on intensifying the SMM-strategy of energy recovery has an economic budget of 7.7. million euros. Per million euros, the SMM-strategy reduces employment by 21 employees (mainly in sector B).

The methodological example illustrated above is limited to several sectors in one national economy. For our manuscript we used all 35 WIOD sectors, adding six sectors by disaggregation to avoid double counting, for 40 countries and one rest-of-world region. Next to employment, we considered GHG-emissions as another non-economic indicator.

CHAPTER 6

6. Estimating and interpreting two material indicators for Flanders: Domestic Material Consumption and Raw Material Consumption

In recent years, Europe has put more emphasis on a sustainable approach to material use. This resulted in a number of initiatives and programs, and a focus on appropriate indicator sets to identify material use, for example the raw materials scoreboard (EC, 2016b) and the resource efficiency scoreboard (EC, 2016a). The resource efficiency scoreboard is a framework for presenting key indicators relating to natural resources. The lead indicator of this framework provides a focus on resource productivity, and is defined as the ratio between gross domestic product (GDP) and domestic material consumption (DMC) (EC, 2016a). Also, the DMC is part of the raw material scoreboard, listed in the topic ‘material flows in the circular economy’ (EC, 2016b). RMC has recently been identified as a candidate for a follow-up indicator to monitor the productivity of raw materials. The 'European Resource Efficiency Platform’ also called to formulate objectives based on the RMC (EREP, 2012). The RME factors developed by Eurostat (see **Table 3**) support the estimation of the RMC.

The Flemish Government is aware of the strategic importance of materials for the economy. ‘Vlaanderen in Actie’ appointed in 2011 "sustainable materials management" as one of the major social challenges for Flanders. It wants to ensure the sustainable use of raw materials in Flanders. This is possible by developing better products, by the reuse of materials and by recycling materials. The new materials decree, replacing the waste decree, supports a systemic approach encompassing entire materials cycles. Also the current government agreement indicates a long-term policy to, for example, improve the way our society treats materials. In this context Flanders also launched the ‘Vlaams Materialen Programma’, a joint public-private action plan.

This chapters gives insights into the difference between DMC and RMC, using the case of Flanders. If assumed that resource efficiency, defined by the ratio between GDP and material use, is a good leading indicator. What is the overlap and what is the difference in measuring material use via the DMC or the RMC? Is the DMC superior to RMC or is RMC a better indicator?

In 2016, VITO NV estimated the indicators DMC and RMC for Flanders over the period 2002-2015 in a project funded by the Flemish department LNE (2016)[32]. It is recommended to estimate these indicators in long time series (+10 periods) as seasonal effects and economy-related factors may have an impact, for example, annual average temperatures and natural fluctuations, temporary disproportionately large infrastructure projects, short-term trends and trend breaks like an economic crisis. The goal of the study is to determine the material

[32] Project resulted in a report: ‘Indicatoren voor een groene economie. Update van datafiche en Exceltabellen DMC en RMC’ (Christis, et al., 2016). The results and conslusions are used in a publication by the Flemish Government ‘Hoe groen is de Vlaamse economie?’ (departement LNE, 2016).

productivity of the Flemish economy expressed by the ratio GDP (in PPP, purchasing power parity) to the primary material use (in DMC and RMC). The indicator measures the material productivity of a region: it's ability to meet the same consumption requirements with less primary material use. An increase in the material productivity indicates an improvement of the environmental (primary material) performance of production chains.

Via a bottom-up estimation of DEU, import, exports, the DMC indicator is derived (see **Table 6**). The estimation follows the definitions and concepts of "Economy-wide Material Flow Accounts (EW-MFA)" by Eurostat, enabling the comparability of the indicator with other countries. The results are available at the level of 60 individual material flows. Note that the reliability at this level of detail is not the same for all flows, often because of lack of time series, favouring an interpretation at an aggregated level of the four material groups: biomass, metal ores, non-metallic minerals and fossil energy carriers. The conversion of both imports and exports in their RME allows to derive the indicator RMC. A full description of data sources, methodology and results can found in Christis, et al. (2016b). The indicators and interpretation are presented below.

6.1 Estimation of the domestic material consumption

The DEU in Flanders fluctuates between 23 and 37 million tons, or 4 to 6 tons per capita. The extraction of biomass is fairly constant in the period 2002-2015, while the mining of non-metallic minerals has fallen sharply in the same period. In 2015 the nonmetallic minerals represent only a third of their mass in 2002. Excavated earthen material is in physical terms a relevant category within the DEU. The Eurostat manual provides this category, but only as an optional category as there are too many countries in the EU which provide no data for this variable. As (part of) the excavated and dredged material is used in the Flemish economy as an alternative raw material (see for example the Annual Report 2013 'monitoringsysteem duurzaam oppervlaktedelfstoffenbeleid' by LNE, OVAM and VITO) the non-inclusion entails a significant underestimation (local use) or overestimation (export thereof) of the DMC and RMC. So, in Flanders leads the non-inclusion of excavated earthen materials to an underestimation of the DEU, and consequently also in the DMC and RMC, as the majority is used in the Flemish economy. However, to maintain the ability to compare results with other EU Member States, the excavated soil is not included in calculations of DEU and therefore not included in the calculation of DMC and RMC.

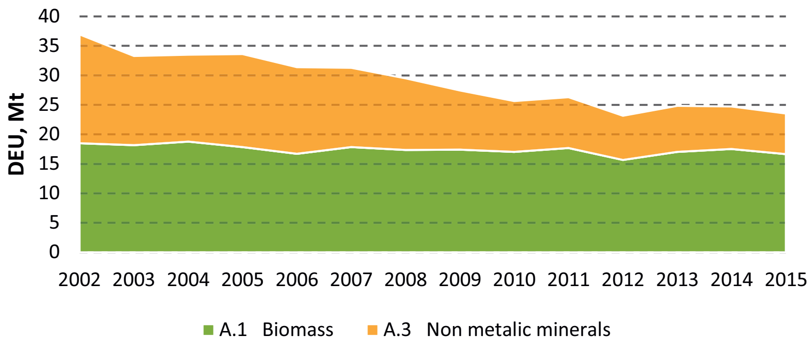

FIGURE 59: DOMESTIC EXTRACTION USED (DEU) IN FLANDERS, 2002-2015.
(SOURCE: CHRISTIS ET AL., 2016B)

The Flemish import and export vary between 201 and 281 million tons and 132 and 176 million tons, respectively. This corresponds to 34 and 44 tons per capita, and 21 and 28 tons per capita. The fossil energy carriers are the main category (by weight) in both imports and exports. Fluctuations (as in 2009) in total import are mainly determined by the fluctuations in flows associated with metal ores. In contrast, this dip in export is the result of a dip in all material groups.

The material groups used to define import and export flows are equal to those used in defining DEU. Especially for import and export flows this allocation should be considered with care, as traded products are often composed heterogeneous. Although they are composed of different materials, in this classification they are assigned to their main component. This has no impact on the overall trade flow, but it affects the internal relations of material groups in import and export.

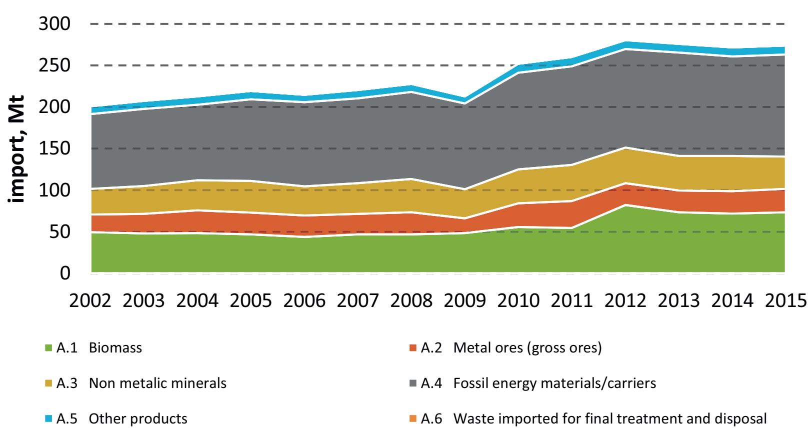

FIGURE 60: IMPORT BY FLANDERS, 2002-2015.
(SOURCE: CHRISTIS ET AL., 2016B)

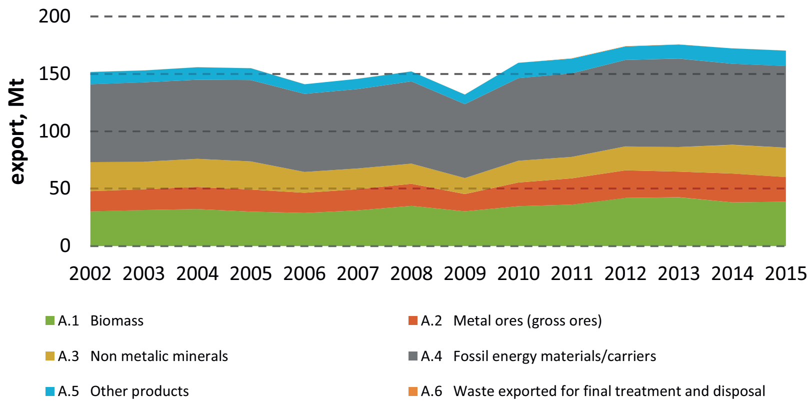

FIGURE 61: EXPORT BY FLANDERS, 2002-2015.
(SOURCE: CHRISTIS ET AL., 2016B)

The manufacturing stage of traded goods in import and export varies widely (**Table 34** and **Table 35**). The import side is dominated (average over the period 2002 to 2015 is 45%) by products with a low level of manufacturing (RAWPROD), followed by products with a high level of manufacturing (FINIPROD) (31%), and products having an average level of manufacturing (SEMIPROD) (23%). The level of manufacturing of exported products is dominated, 62%, by the products with a high level of manufacturing, followed by products with an average level of manufacturing (27%) and products with a low level of manufacturing (12%).

TABLE 34: LEVEL OF MANUFACTURING OF IMPORTED PRODUCTS BY FLANDERS, 2002-2015.
(SOURCE: CHRISTIS ET AL., 2016B)

	2002	*2004*	*2006*	*2008*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*
RAWPROD	*46%*	*44%*	*47%*	*46%*	*48%*	*47%*	*44%*	*43%*	*45%*	*42%*
SEMIPROD	*22%*	*24%*	*22%*	*22%*	*21%*	*21%*	*28%*	*26%*	*25%*	*26%*
FINIPROD	*32%*	*33%*	*30%*	*32%*	*31%*	*32%*	*28%*	*31%*	*30%*	*32%*

TABLE 35: LEVEL OF MANUFACTURING OF EXPORTED PRODUCTS, FLANDERS, 2002-2015.
(SOURCE: CHRISTIS ET AL., 2016B)

	2002	*2004*	*2006*	*2008*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*
RAWPROD	*14%*	*12%*	*14%*	*15%*	*12%*	*11%*	*10%*	*11%*	*10%*	*10%*
SEMIPROD	*29%*	*29%*	*26%*	*26%*	*27%*	*27%*	*24%*	*24%*	*25%*	*24%*
FINIPROD	*58%*	*58%*	*60%*	*59%*	*61%*	*63%*	*66%*	*65%*	*66%*	*66%*

This difference in the average stage of manufacturing between imports and exports has a significant impact on the indicators DMC and RMC. The length of the production chain of imported products is, on average, shorter than the production chain of exported products. This result will lead to a difference in the ratio between import and export and the ratio of import in RME and export in RME and affects the relationship between DMC (based on import and export) and RMC (based on import in RME and export in RME).

The DMC is calculated by adding the import to DEU and subtract the export. The Flemish DMC varies between 86 and 130 million tons in the period 2002-2015. This corresponds to 14 to 20 tons per capita. The evolution of the underlying four material categories determine the evolution of the DMC. In the period 2002-2015, biomass is constant to slightly falling (especially between 2005-2009) with a break in 2012. From 2012, the DMC of biomass is higher compared to the period 2002-2011. The metals are showing a remarkable dip in 2009 and 2012-2014. The non-metallic minerals have an increasing trend until 2005, after which it stabilizes until 2011, after which the total mass declines. Fossil energy carriers have a relatively stable increase in the period 2002-2015. Consequently, the increase in DMC is mainly determined by the increase in fossil energy carriers. The increase in the DMC per capita is less than that in the DMC in absolute value, due to an increases in Flemish population in the same period.

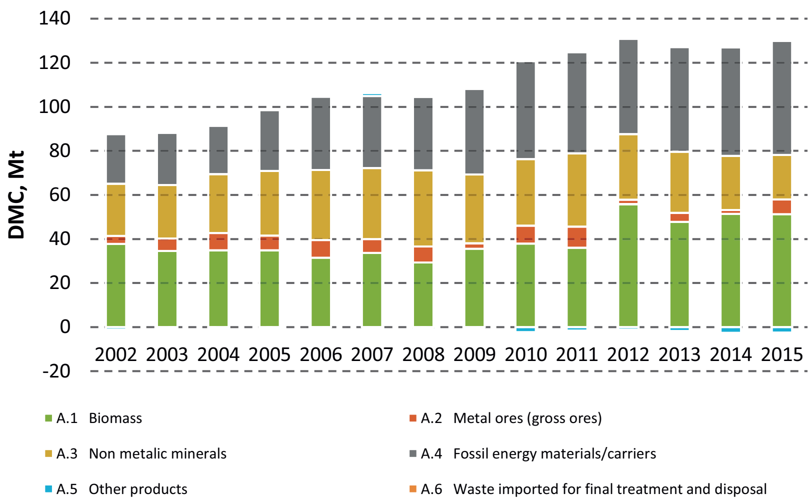

FIGURE 62: DOMESTIC MATERIAL CONSUMPTION (DMC) IN FLANDERS, 2002-2015. (SOURCE: CHRISTIS ET AL., 2016B)

In **Figure 62** is a negative value for the category 'A.5 Other products'. The category contains products that cannot be allocated to the other categories, because its complex mix of different materials. A typical example of this category is jewellery, which often are a combination of metals, minerals, wood and plastics. Therefor jewellery cannot be allocated to only one category. The negative value is the result of a characteristic of the Flemish economy: Flanders imports products with a low level of manufacturing and exports products with a high level of manufacturing. These imports can more often be allocate to the A.1-A.4 categories, while export is more often allocated to the A.5 category.

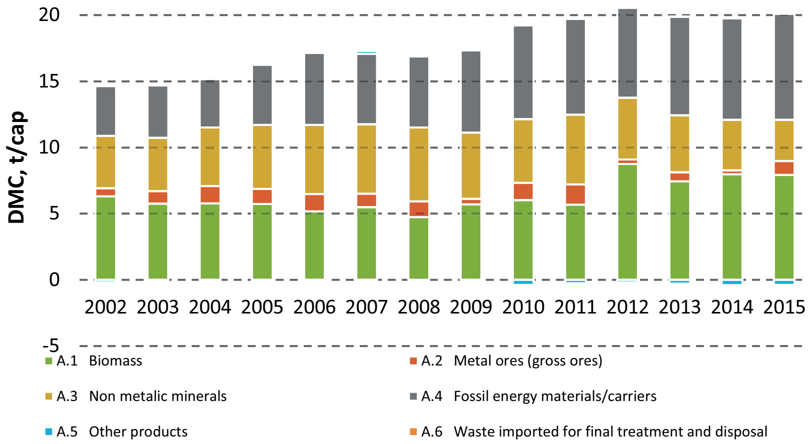

FIGURE 63: DOMESTIC MATERIAL CONSUMPTION (DMC) PER CAPITA IN FLANDERS, 2002-2015.
(SOURCE: CHRISTIS ET AL., 2016B)

The material productivity of the Flemish economy, expressed in euro GDP per kg of DMC, is on average 1.7 euro/kg in the period 2002-2015. The material intensity of the Flemish economy, expressed in kilograms per euro DMC GDP is on average 0.6 kg/euro in the period 2002-2015.

TABLE 36: THE RATIOS OF DMC AND GDP IN FLANDERS, 2002-2015.
(SOURCE: CHRISTIS ET AL., 2016B)

	2002	***2004***	***2006***	***2008***	***2010***	***2012***	***2013***	***2014***	***2015***
GDP per DMC (euro/kg)	1,80	1,78	1,65	1,74	1,60	1,58	1,65	1,70	1,73
DMC per GDP (kg/euro)	0,56	0,56	0,60	0,58	0,62	0,63	0,61	0,59	0,58

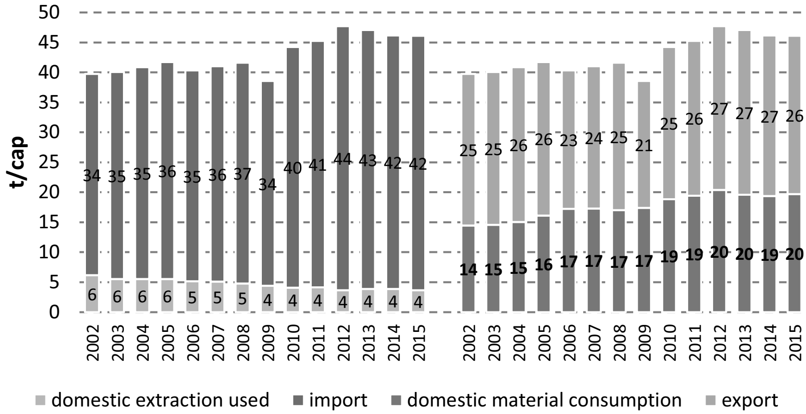

FIGURE 64: THE FORMATION OF THE DOMESTIC MATERIAL CONSUMPTION (DMC) IN FLANDERS, 2002-2015.

(SOURCE: CHRISTIS ET AL., 2016B)

6.2 ADDITIONAL STEPS TO ESTIMATE THE RAW MATERIAL CONSUMPTION

To estimate the RMC, the import and export flows are expressed in their RME. This expresses a direct trade flow in the volume of raw materials that has been (direct and indirect) needed during the production process of that product. The calculation makes use of the conversion coefficients provided by Eurostat (raw material equivalents) which are available per year over the period 2002-2013, but are not country specific. It means that the RME-coefficients represent the average EU-import for 166 product categories. The 2013 coefficients are also used for the conversion in 2014 and 2015.

Import and export statistics are available at a high level of detail, for example, in 2015 there are approximately 9,000 import flows described in the trade database. The conversion to their RME is performed on the basis of only 166 coefficients: the coefficients are not provided at the level of individual products, but only at the level of product groups. Although Eurostat also provides the conversion of CN-classification to the RME-coefficients, this results in a lower reliability of the indicator RMC compared to DMC, because of the over- and underestimates.

Expressing import in RME results in a Flemish import between 417 and 520 million tonnes or 70 to 84 tonnes per capita, in the period 2002-2015 (**Figure 65**). For export in RME, this is between 366 and 453 million tonnes or 59 and 74 tonnes per capita (**Figure 66**). In comparison to import and export, the evolution in import and export in RME is less stable. These fluctuations in import in RME are mainly caused by metals and fossil energy carriers, while for export in RME this is mainly attributed to fluctuations in metals and to a lesser extent in fossil energy carriers.

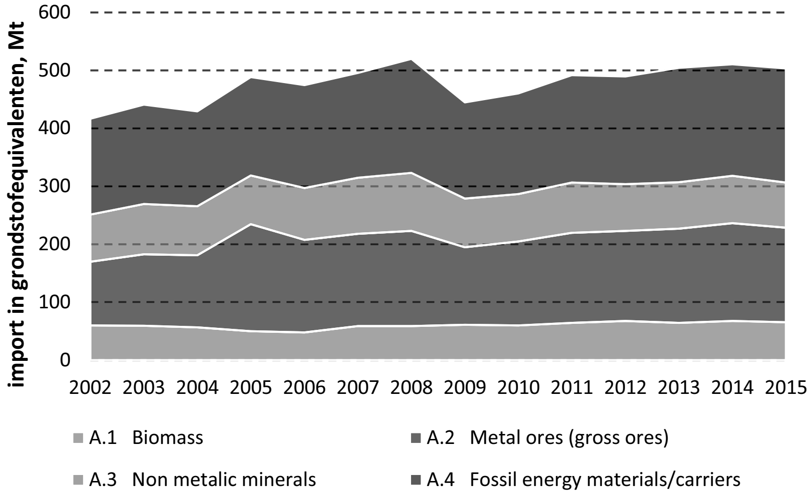

FIGURE 65: IMPORT IN RAW MATERIAL EQUIVALENTS (RME) BY FLANDERS, 2002-2015. (SOURCE: CHRISTIS ET AL., 2016B)

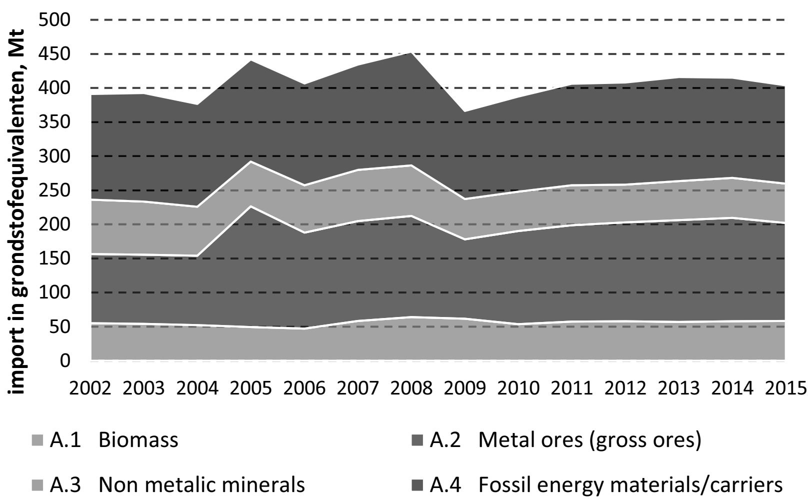

FIGURE 66: EXPORT IN RAW MATERIAL EQUIVALENTS (RME) BY FLANDERS, 2002-2015. (SOURCE: CHRISTIS ET AL., 2016B)

The ratio of import in RME to import for the period 2002-2015 is on average 1.1 for biomass, 5.9 for metal ores, 2.3 for non-metallic minerals and 1.7 for fossil energy carriers. Especially the weight of metals increases by conversion into RME. The total ratio of the four material categories is 2.0. This ratio expresses the amount of raw materials used or consumed in the production chain of traded products. A ratio equal to 1 represents a market product that is a unprocessed raw material. The higher the level of manufacturing, the greater this ratio. The ratio of export in RME to export for the period 2002-2015 is on average 1.7 for biomass, 6.8 for metal ores, 3.2 for non-metallic minerals and 2.1 for fossil energy carriers. Overall this ratio is 2.6. This shows that the average imported product by Flanders (average ratio 2.0) has a lower level of manufacturing than the average exported product by Flanders (average ratio 2.6) in the period 2002-2015. In other words, the production chain of imported products in Flanders is less material intensive than the production chain of exported products.

The RMC is calculated by summing the DEU and import in RME and subtract the export in RME. The Flemish RMC fluctuates between 62 and 123 million tons in the period 2002-2015. This corresponds to 10 and 19 tons per capita. RMC owes its fluctuations primarily to fluctuations in metals. Biomass declines until 2008, after which it increases again. As in the DMC, the RMC has a relatively constant increase in fossil energy carriers. The non-metallic minerals increased until 2005, after which they remain constant until 2011, after which they fall back.

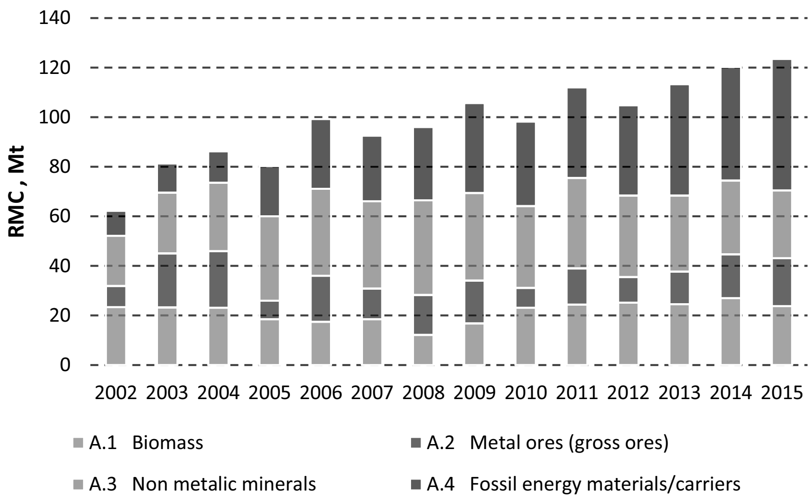

FIGURE 67: RAW MATERIAL CONSUMPTION (RMC) IN FLANDERS ESTIMATED USING RME-COEFFICIENTS, 2002-2015.
(SOURCE: CHRISTIS ET AL., 2016B)

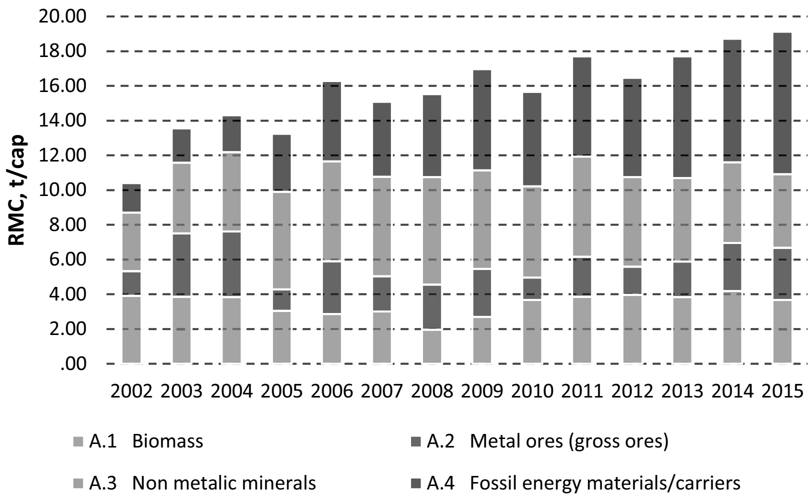

FIGURE 68: RAW MATERIAL CONSUMPTION (RMC) PER CAPITA IN FLANDERS, 2002-2015. (SOURCE: CHRISTIS ET AL., 2016B)

The material productivity of the Flemish economy, expressed in euro GDP per kg RMC is on average 1.9 euro/kg in the period 2002-2015. The material intensity of the Flemish economy, expressed in kilograms RMC per euro GDP is on average 0.5 kg/euro in the period 2002-2015.

TABLE 37: THE RATIOS OF RMC AND GDP IN FLANDERS, 2002-2015. (SOURCE: CHRISTIS ET AL., 2016B)

	2002	***2004***	***2006***	***2008***	***2010***	***2012***	***2013***	***2014***	***2015***
GDP per RMC (euro/kg)	2,50	1,87	1,75	1,91	1,93	1,95	1,83	1,76	1,79
RMC per GDP (kg/euro)	0,40	0,54	0,57	0,52	0,52	0,51	0,55	0,57	0,56

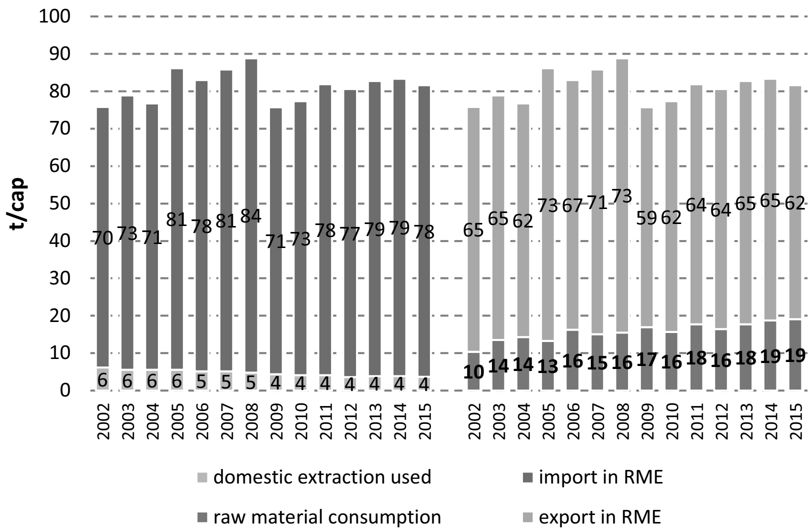

FIGURE 69: THE FORMATION OF THE RAW MATERIAL CONSUMPTION (RMC) IN FLANDERS, 2002-2015.
(SOURCE: CHRISTIS ET AL., 2016B)

6.3 COMPARING THE DOMESTIC AND RAW MATERIAL CONSUMPTION

Over the period 2002-2015 the DMC and RMC follow a similar upward trend, although the RMC is more subjected to fluctuations compared to the DMC. This can be explained by the aggregation step underlying the RMC methodology, in which thousands of trade products are converted by only 166 RME-coefficients. The decrease in DEU per capita is offset by a larger increase in import per capita. At a relatively constant level of export per capita this results in an increase in the DMC per capita. This indicates an increase in the material intensity of the Flemish economy in the period 2002-2012, caused by an increase in import. In 2012-2015 the DMC per capita stabilised. The increase in RMC per capita is volatile and continues after 2012. A possible explanation is the outsourcing of material intensive steps. Outsourcing causes a decrease (or a decrease in the growth) of the DMC, but not in the RMC.

Another observation is that the DMC is above the RMC in the period 2002-2015. This is only possible as the ratio between the import in RME and import is smaller than the ratio between export in RME and export. This implies that the imported products have a lower level of manufacturing in comparison with the exported products. The net trade (= import - export) is higher compared to the net trade expressed in RME. This means that Flanders is combining/using/consuming imported products with a lower level of manufacturing in order to export again products with a high degree of processing. By expressing the export in RME, this use/consumption is accounted for in the RMC (in contrast to DMC), resulting in a lower RMC per capita compared to the DMC per capita.

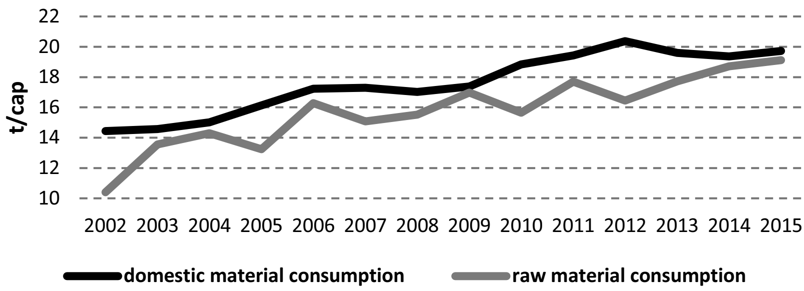

FIGURE 70: THE COMPARISON BETWEEN DOMESTIC MATERIAL CONSUMPTION (DMC) PER CAPITA AND RAW MATERIAL CONSUMPTION (RMC) PER CAPITA IN FLANDERS, 2002-2015. (SOURCE: CHRISTIS ET AL., 2016B)

An international comparison is only possible because of the standardized methodology by Eurostat for building the indicators DMC and RMC. Of course, data sources and their quality vary between regions. Note, for Flanders the estimation depended on regional and regionalized national statistics, while Eurostat makes use of standardized statistics. Still, the inclusion or exclusion of certain flows can have a big impact on the indicators. For example, the exclusion of excavated earthen materials results in a decrease in the Flemish DMC (2015) from 23 tons per capita to 20 tons per capita. Also, the use of RME-coefficients allows comparability, although these coefficients could be further improved, for example, making them country dependent.

Several factors play an important role in international comparability. Examples are: the size and productivity of an economy, population size and density, consumption patterns, climate, the composition (type of business activities) of an economy, the availability of raw materials or secondary raw materials and available technologies all have an effect on the DMC and RMC.

Flanders has a low economic productivity per amount of material in DMC in comparison to our neighbouring countries and the European average. No conclusive statement is found to explain this low position, because there are many factors playing a role. One of them is the fact that Flanders has an open economy (see *3.1 The Flemish open economy in a global context*). These import and export is much more composed of goods rather than services. In countries with a closed economy, the share of services in total economic activities are often larger. Correspondingly, Flanders has a higher share of industrial activities: the ratio of the Flemish sales by industrial activities on total sales are higher than the same ratio in Belgium and neighbouring countries (except Germany). These industrial activities are more material intensive compared to service activities. This partly explains the difference in material productivity between Flanders and Belgium. The Brussels GDP, which is included in the Belgian figure is 90% made up by added value from the service sectors, while this is only 73% in the Flemish GDP. A higher share of service activities with, on average, a high added value contribution and a low material intensity result in a positive impact on the material productivity of an economy.

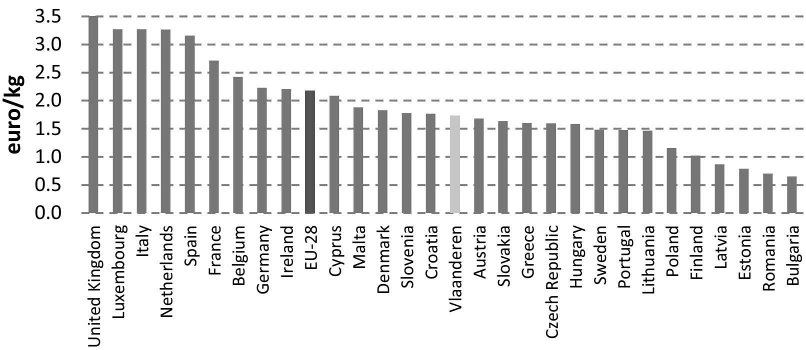

FIGURE 71: BENCHMARKING (EU-28) THE MATERIAL PRODUCTIVITY EXPRESSED IN GDP (IN PPP) PER DOMESTIC MATERIAL CONSUMPTION IN 2015.
(SOURCE: CHRISTIS ET AL., 2016B)

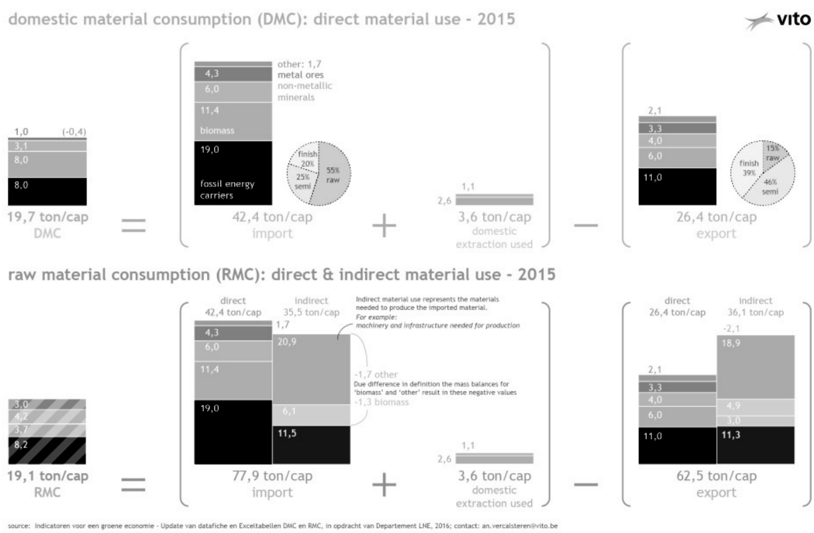

FIGURE 72: COMPARISON OF THE DMC AND RMC IN FLANDERS (2015).
(BASED ON: CHRISTIS ET AL., 2016B)

Figure 72 illustrates the overlap and the difference between the DMC and the RMC. The difference between these indicators is the exclusion or inclusion of the material rucksack of trade flows. The DMC is restricted to the actual import and export flow, while the RMC includes the material rucksack of import and export using the RME-coefficients. In Flanders, the material rucksack of import is almost equal to the import flow, with a ratio between the import flow and its material rucksack of 0.8. In contrast, the material rucksack of export is larger than the actual export flow, with a ratio between the export flow and its material rucksack of 1.4.

The methodologies supporting the calculation of both indicators DMC and RMC are available. However, there is a difference in the availability of the data sources used to estimate them. Although Eurostat provided RME-coefficients, they are not country (or region) specific and are not available at the same level of detail provided in the trade statistics. Unavoidable, this leads to over- and underestimations in RMC-calculations. A major shortcoming of the DMC is its narrow focus. It is not robust against outsourcing, meaning a country could decrease its DMC via the outsourcing of material intensive activities. Import and export conversion to RME's overcomes this shortcoming, resulting in a RMC-indicator encompassing global production chains, while maintaining the focus on local consumption. So, the RMC is superior to DMC in estimating material used linked to consumption, however, its estimation needs further improvements via improvements in the RME data sources. Increased availability of EE-MRIO models provide a promising alternative.

Conclusions, applications and policy relevance

This dissertation demonstrates the application of the Flemish EE-IO model with multi-regional monetary IOTs and other databases as a tool for sustainable materials management. A key and unique contribution of the PhD is the development of a methodology that links a regional monetary IO-model to an existing EE-MRIO model. The added value of this methodology is that it allows to maintain the sector or product classification of the regional model. Extending the Flemish EE-IO model with both monetary and physical multi-regional data allows the application of the EE-IO model as an evaluation tool for the assessment of policy measures and of the effectiveness and efficiency of closing material loops.

In combination with the development of this methodology, aggregation, specification and time errors in EE-MRIO models are estimated and discussed. The results of this exercise lead to clear guidelines for future models. For example, the model needs to give special attention to the quality of the trade linkages of the concerned region with its major trading partners. Also, the quality of footprint estimations depends on the sector or product classification. Different footprints (e.g. water vs. material footprint) require different sector disaggregation. A detailed reflection on the indicator under consideration to determine the optimum model lay-out helps to understand the possible estimation errors in final footprint estimations.

The availability of an IO-table at city level is rare. The interregional input-output model for Belgium contains such a city level model for the Brussels Capital region. Embedding this model in an EE-MRIO allows to estimate a city's impact on the hinterland, which is illustrated in Chapter 4.

An improved top-down methodology is developed and described in Chapter 5 for estimating the maximum substitution potential of intensifying specific SMM-strategies and material efficiency strategies. The estimated strategies are: reuse, recycling, food waste prevention and energy recovery. Reaching higher levels of SMM-strategies may provide economic and environmental opportunities (i.e., in terms of GDP, jobs[33], reduced impacts), but not all options will have a net win–win–win property in practice, as they reduce the need for producing new commodities. The open economic characteristics of Flanders are fully integrated in this methodology. The method shows the potential industries affected by an intensified SMM-strategy represented by a budget, GHG-emissions saved and jobs lost. This budget can be used to create (local) GDP and (local) employment through new SMM-strategies.

The PhD answers the research question "What applications make the Flemish environmentally extended input-output model (extended with regional, national and international economical and material data) an important macro-economic tool for sustainable materials management policy making in Flanders?". The generated insights supported several studies. For example, the developed methodology to link Flemish data with multi-regional data is an important asset in the calculation of **the carbon footprint of Flemish consumption (2017)** [in Dutch], a study

[33] In economic terms, extra labour is a cost. The 'win'-perspective is from a policy viewpoint: via the creation of a new economic activity a region can generate value added accompanied by extra jobs.

commissioned by VMM-MIRA and the **material footprint of Flemish consumption (2017)** [in Ducth], a study commissioned by OVAM. Combining the Flemish environmentally extended input-output and an environmentally extended multiregion input-output model results in the best Flemish footprint macro-economic estimation possible, as this estimation is based on all data available. The goal of combining these models is to analyse local specific problems embedded in the networks of globalised value chains. Based on the model resulting from this methodology, a supply chain analysis provided the framing of two studies: **Circular economy and public procurement in Brussels** [in Dutch], commissioned by Bruxelles Environnement (IBGE) and **Identifying product groups with recycled plastics (recycled content) and product groups with the potential to use recycled plastics** [in Dutch], commissioned by OVAM. Also, the developed methodology allowed a detailed study on the carbon footprint of the Flemish consumption. The study results in a quantitative insight in consumption footprints and makes the comparison with territorial emissions, supporting the discussion on how to measure emissions:

> *"The climate efforts of a country or region are assessed on the basis of the greenhouse gas emissions generated in the local territory. From this territorial perspective, economies specialising in greenhouse gas intensive sectors sometimes perform worse than other countries. When these sectors work more eco-efficiently than elsewhere, however, such specialisation may actually result in reducing global greenhouse gas emissions. Assessing greenhouse gas emissions only from a territorial perspective therefore carries the risk of counteracting such national specialisation. Moreover, the territorial perspective does not take into account the greenhouse gas emissions that are generated outside the territory in the production chains of goods and services intended for local consumers. These emissions are, however, significant: over two thirds of the greenhouse gas emissions linked to Flemish consumption originate outside Flanders. These non-Flemish emissions (88 Mtonnes CO2-eq in 2010) are on the same order of magnitude as the total greenhouse gas emissions from businesses and households in Flanders (85 Mtonnes CO2-eq in 2010), and twice as high as the amount of greenhouse gas emissions generated by Flemish companies as a result of production for exports (40 Mtonnes in 2010). About half of non-Flemish emissions originate outside Europe, including in regions where environmental standards are less strict. These non-European emissions doubled between 2003 and 2010, and were partly responsible for the increased carbon footprint. Greenhouse gas emissions in Flanders, by contrast, have shown a clearly downward trend since 2005.*
>
> *To achieve the greatest possible global environmental benefit, it is therefore not enough to focus on the level of emissions from sectors and households in Flanders alone. There is also need for a policy that is aimed at making production chains and consumer behaviour more sustainable, including internationally harmonised calculation methods and targets of footprints to evaluate the results."*

The results of this PhD support policies maximising their impact by exposing hotspots:

> *"About one third of the carbon footprint of the total Flemish consumption is caused by the households' energy use at home and on the road.*

Measures aimed at reducing energy use in the home and the number of car kilometres, can therefore already substantially reduce the carbon footprint. Some products have low greenhouse gas intensities, but nonetheless greatly contribute to the carbon footprint because significant amounts are spent on them. Thus, production chains of trade, private services and services provided by the government account for one third of the Flemish carbon footprint. Reducing greenhouse gas emissions in the service production chains can therefore have a significant effect on the carbon footprint. Also the building and renovation of homes, industrial and government buildings and infrastructure have a fairly large share in the carbon footprint (9 %) because large amounts are involved."

Also, this work enabled the link between economic activities, employment and greenhouse gas emissions:

"Making production chains and consumer behaviour more sustainable is also important from a social justice perspective. Whereas one third of greenhouse gas emissions and half of the jobs linked to Flemish consumption are outsourced to regions outside Europe, including regions with a lower welfare level and less social protection, the bulk of the added value is created within Europe, with over half in Flanders. Flemish consumption therefore contributes mainly to the Flemish and European GDP. Making international trade and production chains more sustainable may contribute not only to reducing the carbon footprint and other forms of environmental pressure, but also to reducing poverty and inequality between regions."

The literature review on material flow analysis and indicators provided the basis for the calculation of the Flemish material productivity and underlying material indicators. The study results were part of the report **Hoe groen is de Vlaamse economie? (2016)** commissioned by the Environment, Nature and Energy Department (LNE). The bottom-up estimation of the DMC and RMC indicators gave insights into the Flemish dependency on primary materials and it supported the discussion on how to measure material use:

"The Flemish material use, measured by the DMC indicator, is experiencing a steady growth between 2002 and 2012. This evolution is not accompanied with an equal growth in economic activity, as the ratio GDP/DMC dropped. Thus, during this period less economic added value is created per consumed amount of materials. After 2012, there is a drop in material use which remained at a constant level until 2015. Since 2012 the material productivity increases, however, the increase in GDP is higher meaning a relative decoupling and not an absolute decoupling. The Flemish material use in RMC increased in the period 2002-2015, although fluctuations were common. The productivity, measured by the GDP/RMC ratio, follows a fluctuating and slightly decreasing trend, although in the more recent years it has become more or less constant. The economic activity per RMC is higher than that per DMC. The only reason can be that the average imported product has a lower degree of processing compared to the average exported product. The degree of processing or stage in the production chain of traded products differs greatly. The import side is dominated by products with a low processing level (average over the period 2002-2015 is 45%). The stage of production of exported products is dominated by 62% by the products with a high degree of processing. In

recent years, the difference between the two ratios decreased, mainly because of an increase in the processing level of imported products."

In this dissertation the RMC-indicator is estimated using the RME-coefficients from Eurostat. The reason to choose for RME-coefficients from Eurostat is that they are available in time series, which is not the case for EXIOBASE v.2. The level of product detail is similar to EXIOBASE. Also, the data input to estimate the RME-coefficients is comparable as it is based on IO-methodology (supply and use tables). EXIOBASE v.3 is now available in time series, so an alternative to the RME-coefficients is available. The use of EE-MRIO models to estimate the RMC-indicators allows a detailed value chain analysis, whereas the use of RME-coefficients allows international comparability of the RMC-indicator.

A possibility for future research is a structural decomposition analysis on the evolution in DMC and RMC. Such an analysis relates the evolution to a number of factors. The most common factors in literature are the level of final demand, the product mix of final demand, the interindustry relations and material coefficients. The results show the most important driver(s) of the evolution in DMC and RMC.

The study **Secundaire materialen in de IO-tabel**, commissioned by OVAM, is analysing the secondary material flows in Flanders using the Belgian interregional input-output model. The aim of the study was twofold. On the one hand, the analysis of the data containing the model gives an overview of the available information. On the other hand a methodology is developed to include the capabilities of input-output analysis. The analysis shows that the Belgian interregional input-output model is suitable for analysing secondary material flows in Flanders. The supply and use tables give an overview of the supply and use of the waste and material recovery sector as well as an overview of the supply and use of the waste product and waste services. Also, the structure of the model allows to expand the import and export flows of the Flemish open economy using detailed trade statistics. Business data databases, such as Belfirst or Trends Top, can provide a detailed addition to the sector description. Bottom-up business information then becomes clearer, but is not a systematic way to supplement the database.

An important insight resulting from this study is the recommendation to breakdown of product and sector 38A *collection, processing and disposal of waste* in the Belgian interregional input-output table into 38A01 *services related to waste* and 38A02 *waste products*. Nevertheless, a disaggregation of the waste sector in the Flemish parts of the model contributes to a limited extent to the analysis possibilities. Due to the open characteristics of the Flemish economy, local consumption is largely dependent on foreign production. Consequently, the methodology, which departs from the consumer perspective, is especially benefiting from an equal improved model abroad.

Next to these studies, the knowledge on material flow analysis and indicators, input-output tables and calculation and estimations for Flanders underpin several discussions. For example, the hearing (dd. 24/03/2016, by Karl Vrancken) in Flemish Parliament on the topic sustainable circular economy in Flanders used the insights of changes in origin of primary raw materials between 1995 and 2009. The discussion on measuring raw material use by the DMC and RMC was elaborated on the study day circular economy (dd. 13/09/2016, by An Vercalsteren) organized by the Social and Economic Council of Flanders (SERV).

The above applications show a wide range of policy relevant application of IOA. Still, for the future, several question and further improvements for IO-models and IOA are open. This is discussed in the following paragraphs.

The fact that Flanders has a very open economy is stressed several times in this dissertation and is quantitatively underpinned in Section 3.1. This openness led to the development of the methodology to link the local model to global models, but requires further attention in the future. How can the trade link with major trading partners be improved? Currently the methodology distributes the Flemish import to the country of origin in line with the Belgian import distribution. Therefore, import by Flanders might be misallocated to another country or region. The import volume and the mix of imported products (in fact product groups) is not subjected to this potential error, and, international import by Flanders represents already 83% of total import by Belgium (based on 2017 international trade statistics by NBB - national concept). Still, potential misallocations differ per product group and will increase if models are further disaggregated.

Policy makers often highlight the role of transport in the different steps of the production chain and between production and final consumer. Most IO-models have a separate sector including transport activities. However, in-house transport (i.e. transport activities by non-transport sectors) is often not separately provided in the model. This results in underestimations of the impact from all transport activities. Ad hoc solutions are developed to correct for this underestimation. For example, to estimate in-house transport activities the consumption of diesel by non-transport sectors is used as an indicator. Likewise, issues arise for other in-house activities such as recycling, maintenance, repair, etc.

Several issues hamper the use of IO-models in estimating the potential of, or the progress towards, a circular economy: the linear technical coefficients of the IO-model do not allow to estimate changes in production networks, final demand is exogenous to IOA, hampering the modelling of C2C and C2B flows, the link between monetary and mass flows is not (always) linear which especially is an issue in the modelling of waste flows, etc. Still, the use of IOA can provide relevant insights to the topic of circular economy. The maximum substitution potential estimated in Chapter 5 is an example thereof. The IOA is capable of providing more general insights on several strategies linked to circular economy via a detailed description of current value chains. However, the current structure of the IO-model hampers to study in detail strategies like life time extensions (the model contains no link with extra maintenance or required repairs), C2C markets (final demand is exogeneous), waste prevention (difficult to trace waste in the monetary tables), substitution (due to the fixed production recipe), product-service systems (not a disaggregated sector nor a separated consumption category), etc. Also the impact of structural economic changes cannot be estimated by IOA as the IO-model is a static model. A computable general equilibrium model, which amongst others uses IO-data for compiling its social accounting matrix, might be a solution to overcome the problems linked to a static model.

The estimation of footprints via IOA can be improved in the future in order to include aspects of social (in)equity. In standard IOA a wide variety of footprints (e.g. emissions, materials) are estimated. However, they only link to final demand, household consumption, consumption domains or a single product group. These are average estimation values for a region in one year. Via the use of detailed household budget survey data, footprints could be linked to household characteristics (e.g. size, level of income, education level, age, number of children, number of elderly, etc.). The combination of the IO-model with such data would allow to estimate, analyse and compare footprints of different households revealing inequalities.

I will conclude this dissertation with stating that there is a future of IO-models in Flanders. The increased attention to footprints in addition to territorial impacts and the interest in analysing value chain networks are key drivers for future developments. A regular update of the interregional environmentally extended input-output tables for Belgium, based on qualitative data, is recommended and will generated important and timely insights in support of the Flemish (circular) economy.

Acknowledgments of financing institutions

Maarten Christis is financially supported by a research project Flemish Policy Research Centre of Sustainable Materials Management (steunpunt SuMMa).

Curriculum Vitea

Maarten Christis
Rondestraat 21
3950 Bocholt
+32 498 86 97 25
christis_maarten@hotmail.com
geboren in Maaseik op 29 april 1989
Belgische nationaliteit
burgerlijke staat: wettelijk samenwonend

EDUCATION
master in toegepaste economische wetenschappen: handelsingenieur 2010-2012
afstudeerrichting: technologie-, innovatie- en milieumanagement
Universiteit Hasselt

bachelor in toegepaste economische wetenschappen: handelsingenieur 2007-2010
Universiteit Hasselt

diploma hoger reddersbrevet 2007
BLOSO

SCI-PUBLICATIONS
published
Christis M., Geerken T., Vercalsteren A., Vrancken K. (2015). Value in sustainable materials management strategies for open economies case of Flanders (Belgium). Resources, Conservation and Recycling, 103, pp. 110-124

Christis M. , Geerken T., Vercalsteren A., Vrancken K. (2016). Improving footprint calculations of small open economies: combining local with multi-regional input–output tables. Economic Systems Research, 29, 25-47.

Athanassiadis A., Christis M., Bouillard P., Vercalsteren A., Crawford R., Khan A. (2018). Comparing a territorial-based and a consumption-based approach to assess the local and global environmental performance of cities. Journal of Cleaner Production, 173, 112-123.

in progress
Vercalsteren A., Van der Linden A., Geerken T. & Christis M. (2018). Policy needs to be covered by EE-IO capabilities. Economic Systems Research [under review]

Christis M., Athanassiadis A., Vercalsteren A. (2018) The impact of circular economy strategies in cities on global climate change. Journal of Cleaner Production Special Issue 'Cities and Climate Change' [under review]

Geerken T., Schmidt J., Boonen K., Christis M. & Merciai S. (2018). Assessment methods of the potential of a circular economy in open economies – case of Belgium. Journal of Cleaner Production. [under review]

Christis M., Breemersch K., Vercalsteren A. (2018). A detailed household footprint analysis using expenditure accounts – case of Flanders (Belgium). Journal of Cleaner Production. [under review]

Reports

Dubois M., Christis M., Crabbé A., De Römph T., Happaerts S., Hoogmartens R., Huysman S., Vermeersch I., Bergmans A., Craps M., Van Acker K. (2013). Duurzaam beheer van vlakglas in de bouw. Een stand van zaken. Via: https://steunpuntsumma.be/docs/rapport-summa-vlakglas-7-1.pdf

Dils E., Van der Linden A., Geerken T., Christis M., Vercalsteren A. (2013). Feasibility of integrating data from multi-regional IO models in the Flemish EE-IO model. Via: https://steunpuntsumma.be/docs/Exio

Dubois M., Christis M. (2014). Verkennende analyse van het economisch belang van afvalbeheer, recyclage en de circulaire economie voor Vlaanderen. Via: https://steunpuntsumma.be/nl/publicaties/summa-economisch-belang-8.pdf

Vercalsteren A., Van der Linden A., Geerken T., Christis M. (2015). Onderzoek naar beleidstoepassingen van milieu input-output modellen, studie uitgevoerd in opdracht van de Vlaamse Milieumaatschappij, MIRA, MIRA/2015/06, VITO, VITO/2015/SMAT/R/0029.

Christis M., Vercalsteren A., Van Hoof V. (2016). Indicatoren voor een groene economie – update van datafiche en Exceltabellen DMC en RMC, studie uitgevoerd in opdracht van departement LNE, 2016/SMAT/R/0745.

Vercalsteren A., Boonen K., Christis M., Dams Y., Dils E., Geerken T., Van der Linden A. (VITO) Vander Putten E. (VMM) (2017). Koolstofvoetafdruk van de Vlaamse consumptie, studie uitgevoerd in opdracht van de Vlaamse Milieumaatschappij, MIRA, MIRA/2017/03, VITO, VITO/2017/SMAT/R/1160.

Van Hoof V., Christis M., Geerken T. (2017). Circulaire economie en overheidsopdrachten in Brussel, studie uitgevoerd in opdracht van Brussels Instituut voor Milieubeheer.

Van Hoof V., Christis M., Geerken T. (VITO), Grymonprez W. (VKC). Identificeren van product(groepen) met kunststofrecyclaat (recycled content) en product(groep)en met potentieel voor het in zetten van kunststofrecyclaat, studie uitgevoerd in opdracht van de OVAM. VITO, 2017/SMAT/R/1366.

Christis M., Van der Linden A., Vercalsteren A. (2018). Secundaire materialen in de input-output tabellen, studie uitgevoerd in opdracht van de OVAM. VITO, 2018/SMAT/R/1423.

Presentations

Christis, M., Vercalsteren, A., Geerken, T. (2014, 17 July). Trade in Value Added – Linking the Flemish regional EE-IO tables with (EE-)MRIO tables. International Input-Output Association, Lisboa.

Christis M., Vrancken K. (2014, 11 December). Is Vlaanderen op weg naar Duurzaam Materiaalbeheer – Welke indicatoren hebben we nodig? SuMMa-seminarie. OVAM, Mechelen.

Christis M. (2015, 20 January). Onderzoek naar indicatoren voor duurzaam materiaalbeheer. VMP Stuurgroep, Berchem.

Christis, M., Geerken, T., Vercalsteren A. (2015, 10 July) Value in Sustainable Materials Management Strategies for an Open Economy like Flanders (Belgium). Conference of the International Society for Industrial Ecology. University of Surrey, Guildford.

Athanassiadis, A., Christis, M., Bouillard, P., Vercalsteren, A. (2015, 10 July) Combining a metabolism based approach and an input-output based approach for assessing the resource use and environmental impacts of Brussels. Conference of the International Society for Industrial Ecology. University of Surrey, Guildford.

Christis M., Boonen K., Geerken T. (2015, 27 November). The structure of the Belgian economy and its evolution over time, based on data of the World Input-Ouput Database (WIOD). First Follow-up Committee IECOMAT, BELSPO, Brussels.

Christis M., Athanassiadis A. (2017, 28 June). Impact of CE-strategies on global climate change. International Society for Industrial Ecology, Chicago.

CONFERENCES

22nd International Input-Output Association (2014, 15-18 July). Lisboa, Portugal.

Conference of the International Society for Industrial Ecology (2015, 7-10 July). University of Surrey, Guildford.

Conference of the International Society for Industrial Ecology (2017, 26-29 June). University of Illinois at Chicago, Chicago.

DESIRE final conference: Indicators for the Circular Economy – Indicators for a Green Economy (2016, 21 January). Development of a System of Indicators for a Resource Efficient Europe (DESIRE), Brussels.

Circulaire Economie: Het economisch potentieel voor België (2015, 12 November). PriceWaterhouseCoopers commissioned by Ministerie van Energie, Leefmilieu en Duurzame ontwikkeling, Brussels.

International expert workshop on demand-based measures of material flows (2015, 21-22 October). OECD, Paris.

Developing a system of indicators for a resource efficient Europe (DESIRE) (2014, 4 June). European Commission Green Week 2014, Brussels.

DESIRE Stakeholder forum meeting. (2014, 5 June). Green week 2014 side event, Brussels.

Compiling and Refining Environmental and Economic Accounts (CREEA) final conference (2014, 25 March). FP7 project CREEA, Brussels.

Industry & Innovative Sustainable Production Growth & Sustainability (i-SUP) (2014, September 2-3). VITO, Antwerp.

COURSES

3 day PhD course on Advanced LCA – consequential modelling, EIO LCA, ILUC and rebound effects (2012, 29-31 October). Aalborg University, Aalborg.

4 day PhD course on Material Flow Analysis of resource and recycling systems (2012, 10-13 June). Technical University of Denmark, Lyngby.

3 day course on IO and hybrid life cycle assessment (2018, 22-24 January). International Life Cycle Academy, Barcelona.

Reference list

Acquaye, A. A., & Duffy, A. P. (2010). Input-output analysis of Irish construction sector greenhouse gas emissions. *Building and Environment, 45*(3), 784-791. doi:10.1016/j.buildenv.2009.08.022

Adriaanse, A., Bringezu, S., Hammond, A., Moriguchi, Y., Rodenburg, E., Rogich, D., & Schütz, H. (1997). *Resource flows: the material basis of industrial economies* http://pdf.wri.org/resourceflows_bw.pdf

Alcantara, V., & Padilla, E. (2003). "Key" sectors in final energy consumption: an input-output application to the Spanish case. *Energy Policy, 31*(15), 1673-1678. doi:Pii S0301-4215(02)00233-1

Doi 10.1016/S0301-4215(02)00233-1

Alcantara, V., Tarancon, M. A., & del Rio, P. (2013). Assessing the technological responsibility of productive structures in electricity consumption. *Energy Economics, 40*, 457-467. doi:10.1016/j.eneco.2013.07.012

Alfieri, A., & Gravgård, O. P. (2009). *Recording losses in SEEA* (LG/14/3). Canberra: http://unstats.un.org/unsd/envaccounting/londongroup/meeting14/LG14_3a.pdf

Allen, W. F., Halloran, P. A., Leith, A. H., & Lindsay, M. C. (2009). Using Material Flow Analysis for Sustainable Materials Management: Part of the Equation for Priority Setting. *Journal of Industrial Ecology, 13*(5), 662-665.

Allwood, J. M., Ashby, M. F., Gutowski, T. G., & Worrel, E. (2011). Material efficiency: a white paper. *Resources, Conservation and Recycling, 55*, 362-381. doi:10.1016/j.resconrec.2010.11.002

Allwood, J. M., Ashby, M. F., Gutowski, T. G., & Worrel, E. (2013). Material efficiency: providing material services with less material production. *Philosophical Transactions of the Royal Society A, 371*, 1-15. doi:10.1098/rsta.2012.046:20120496

Andersen, M. S. (2007). An introductory note on the environmental economics of the circular economy. *Sustainable Science, 2*, 133-140. doi:10.1007/s11625-006-0013-6

Andrew, R. M., Davis, S. J., & Peters, G. P. (2013). Climate policy and dependence on traded carbon. *Environmental Research Letters, 8*(3). doi:Artn 034011

10.1088/1748-9326/8/3/034011

Andrew, R. M., & Peters, G. P. (2013). A Multi-Region Input-Ouput Table based on the Global Trade Analysis Project Database (GTAP-MRIO). *Economic Systems Research, 25*(1), 99-121. doi:10.1080/09535314.2012.761953

Andrew, R. M., Peters, G. P., & Lennox, J. (2009). Approximation and regional aggregation in multi-regional input-output analysis for national carbon footprint accounting. *Economic Systems Research, 21*(3), 311-335. doi:10.1080/09535310903541751

Arto, I., Genty, A., Rueda-Cantuche, J. M., Villanueva, A., & Andreoni, V. (2012a). *Global resources use and pollution, Volume 1 Production, Consumption and Trade (1995-2008)*

Arto, I., Genty, A., Rueda-Cantuche, J. M., Villanueva, A., & Andreoni, V. (2012b). *Global resources use and pollution, Volume 2 / Country factsheets*

Athanassiadis, Christis, Bouillard, Vercalsteren, Crawford, & Kahn. (2016). Comparing a territorial-based and a consumption-based approach to

assess the local and global environmental performance of cities. *Journal of Cleaner Production*. doi:http://dx.doi.org/10.1016/j.jclepro.2016.10.068
Avonds, L. (2008). *Raming van een regionaal input-output systeem voor België - Working Paper 18-08*. Brussel:
Avonds, L., & Vandille, G. (2008). *Monetaire input-outputtabellen voor Vlaanderen*. Brussel: http://www.ovam.be/sites/default/files/Monetaire%20input-outputtabellen%20voor%20Vlaanderen_0.pdf
Ayres, R. U. (1994). Industrial metabolism: theory and policy. In *Industrial metabolism. Restructuring for sustainable development* (pp. 23-37). Washington DC: Acadamy Press. (Reprinted from: Not in File).
Bachmann, C., Roorda, M. J., & Kennedy, C. (2015). Developing a Multi-Scale Multi-Region Input-Output Model. *Economic Systems Research, 27*(2), 172-193. doi:10.1080/09535314.2014.987730
Bai, X. (2007). Industrial ecology and the global impacts of cities. *Journal of Industrial Ecology, 11*(2), 1-6. doi:10.1162/jie.2007.1296
Bastijn, T., Roelofs, E., Rietveld, E., & Hoogendoorn, A. (2013). *Opportunities for a circular economy in the Netherlands*. Leiden:
Baynes, T., Lenzen, M., Steinberger, J. K., & Bai, X. (2011). Comparison of household consumption and regional production approaches to assess urban energy use and implications for policy. *Energy Policy, 39*(11), 7298-7309. doi:http://dx.doi.org/10.1016/j.enpol.2011.08.053
Baynes, T. M., & Wiedmann, T. (2012). General approaches for assessing urban environmental sustainability. *Current opinion in Environmental Sustainability, 4*(4), 458-464. doi:http://dx.doi.org/10.1016/j.cosust.2012.09.003
Behrens, A., Giljum, S., Kovanda, J., & Niza, S. (2007). The material basis of the global economy: worldwide patterns of natural resource extraction and their implications for sustaiinable resource use policies. *Ecological Economics, 64*(2), 444-453. doi:10.1016/j.ecolecon.2007.02.034
Benton, D., & Hazell, J. (2013). *Resource resilient UK. In: A report from the Circular Economy Task Force*. London:
Binder, C. R. (2007). From material flow analysis to material flow management Part II: the role of structural agent analysis. *Journal of Cleaner Production, 15*(17), 1605-1617. doi:10.1016/j.jclepro.2006.08.017
Binder, C. R., van der Voet, E., & Rosselot, K. S. (2009). Implementing the Results of Material Flow Analysis. *Journal of Industrial Ecology, 13*(5), 643-649. doi:10.1111/j.1530-9290.2009.00182.x
BMU. (2012). *German Resource Efficiency Programme (ProgRess). Programme for the sustainable use and conservation of natural resources*
Bouwmeester, M. C., & Oosterhaven, J. (2013). Specification and Aggregation Errors in Environemntally Extended Input-Output Models. *Environmental and Resource Economics, 56*(3), 307-335. doi:10.1007/s10640-013-9649-8
Bringezu, S., & Moriguchi, Y. (2002). Material Flow Analysis. In A. R.U. & A. L.W. (Eds.), *A Handbook of Industrial Ecology* (pp. 79-90). Cornwall: MPG Books Ltd. (Reprinted from: Not in File).
Bringezu, S., Schütz, H., & Moll, S. (2003). Rationale for and interpretation of economy-wide materials flow analysis and derived indicators. *Journal of Industrial Ecology, 7*(2), 43-64. doi:10.1162/108819803322564343
Bringezu, S., Schütz, H., Steger, S., & Baudisch, J. (2004). International comparison of resource use and its relation to economic growth: the development of total material requirement, direct material inputs and

hidden flows and the structure of TMR. *Ecological Economics, 51*(1-2), 97-124. doi:10.1016/j.ecolecon.2004.04.010

Bruckner, M., Giljum, S., Lutz, C., & Wiebe, K. S. (2012). Materials embodied in international trade - Global material extraction and consumption between 1995 and 2005. *Global Environmental Change-Human and Policy Dimensions, 22*(3), 568-576. doi:10.1016/j.gloenvcha.2012.03.011

Brunner, P. H., & Rechberger, H. (2004). *Practical Handbook of Material Flow Analysis. Advanced Methods in Resource and Waste Management*. Florida: CRC Press LLC.

Cellura, M., Di Gangi, A., Longo, S., & Orioli, A. (2013). An Italian input-output model for the assessment of energy and environmental benefits arising from retrofit actions of buildings. *Energy and Buildings, 62*, 97-106. doi:10.1016/j.enbuild.2013.02.056

Chen, & Chen. (2011). Greenhouse gas emissions and natural resources use by the world economy: Ecological input-output modeling. *Ecological Modelling, 222*(14), 2362-2376. doi:10.1016/j.ecolmodel.2010.11.024

Chen, G., Wiedmann, T., Hadjikakou, M., & Rowley, H. (2016). City Carbon Footprint Networks. *Energies, 9*(8), 602.

Chen, G., Wiedmann, T., Wang, Y., & Hadjikakou, M. Transnational city carbon footprint networks – Exploring carbon links between Australian and Chinese cities. *Applied Energy*. doi:http://dx.doi.org/10.1016/j.apenergy.2016.08.053

Chen, X., Cheng, L., Fung, K., Lau, L., Sung, Y., Zhu, K., Yang, C., Pei, J., & Duan, Y. (2012). Domestic value added and employment generated by Chinese exports: a quantitative estimation. *China Economic Review, 23*(4), 850-864. doi:10.1016/j.chieco.2012.04.003

Cheong, Legoff, Neo, Nimpradit, & Willard. (2012). Input-output tables and household effects of pricing carbon in Australia. *International Input-Output Conference*.

Choi, J. K., Bakshi, B. R., & Haab, T. (2010). Effects of a carbon price in the US on economic sectors, resource use, and emissions: An input-output approach. *Energy Policy, 38*(7), 3527-3536. doi:10.1016/j.enpol.2010.02.029

Christis, Geerken, Vercalsteren, & Vrancken. (2016a). Improving footprint calculations of small open economies: combining local with multi-regional input-output tables. *Economic Systems Research, 29*, 25-47. doi:http://dx.doi.org/10.1080/09535314.2016.1245653

Christis, Vercalsteren, & Hoof, V. (2016b). *Indicatoren voor een groene economie - Update van datafiche en Exceltabellen DMC en RMC*.

Christis, M., Geerken, T., Vercalsteren, A., & Vrancken, K. C. (2015). Value in sustainable materials management strategies for open economies case of Flanders (Belgium). *Resources Conservation and Recycling, 103*, 110-124. doi:10.1016/j.resconrec.2015.07.014

Christis, M., Geerken, T., Vercalsteren, A., & Vrancken, K. C. (2016). Improving footprint calculations of small open economies: combining local with multi-regional input–output tables. *Economic Systems Research*, 1-23. doi:http://dx.doi.org/10.1080/09535314.2016.1245653

Collins, A., Flynn, A., Wiedrnann, T., & Barrett, J. (2006). The environmental impacts of consumption at a subnational level - The ecological footprint of Cardiff. *Journal of Industrial Ecology, 10*(3), 9-24. doi:DOI 10.1162/jiec.2006.10.3.9

Cooper, D. R., & Allwood, J. M. (2012). Reusing steel and aluminum components at end of product life. *Environmental Science & Technology, 46*(18), 10334-10340. doi:10.1021/es301093a

Corsten, M., Worrel, E., Rouw, M., & van Duin, A. (2013). The potential contribution of sustainable waste management to energy use and greenhouse gas emissions reduction in the Netherlands. *Resources, Conservation and Recycling, 77*, 13-21. doi:10.1016/j.resconrec.2013.04.002

Cui, L. B., Peng, P., & Zhu, L. (2015). Embodied energy, export policy adjustment and China's sustainable development: A multi-regional input-output analysis. *Energy, 82*, 457-467. doi:10.1016/j.energy.2015.01.056

Cuypers, Geerken, Gorissen, Lust, Peters, Karstensen, Prieler, Fisher, Hizsnyik, & Van Velthuizen. (2013). *The impact of EU consumption on deforestation: comprehensive analysis of the impact of EU consumption on deforestation* (Technical Report-2013-063)

Daniels, P. L. (2000). Approaches for quantifying the metabolism of phyiscal economies: a comparative survey. Part II: reivew of individual approaches. *Journal of Industrial Ecology, 6*(1), 65-88.

Daniels, P. L., & Moore, S. (2002). Approaches for quantifying the metabolism of physical economies. Part I: methodological overview. *Journal of Industrial Ecology, 5*(4), 69-93.

Dawkins, Paul, Barret, Minx, & Scott. (2008). *Wales' ecological footprint - scenarios to 2020* (Working Paper)

Daxbeck, H., Buschmann, H., Neumayer, S., & Brandt, B. (2009). *Methodology for mapping of physical stocks* (Deliverable 2-3)http://forwast.brgm.fr/Documents/Deliverables/Forwast_D23.pdf

de Bruyn, S. M., Sevenster, M. N., Warringa, G. E. A., van der Voet, E., & van Oers, L. (2004). *Materiaalstromen door de economie en milieubeleid. Een analyse naar indicatoren en beleidstoepassingen van economiebreed materialenbeleid* (04.7612.37). Delft:

De Marco, O., Lagioia, G., Amecarelli, V., & Sgaramella, A. (2009). Constructing physical input-output tables with material flow analysis (MFA) data: bottom-up case studies. In S. S (Ed.), *Handbook of Input-Output Economics in Industrial Ecology* (pp. 161-187). Dordrecht: Springer. (Reprinted from: Not in File).

de Souza, K. B., Ribeiro, L. C. d. S., & Perobelli, F. S. (2016). Reducing Brazilian greenhouse gas emissions: scenario simulations of targets and policies. *Economic Systems Research, 28*(4), 482-496. doi:10.1080/09535314.2016.1230093

Dias, A. C., Lemos, D., Gabarrell, X., & Arroja, L. (2014). Environmentally extended input–output analysis on a city scale – application to Aveiro (Portugal). *Journal of Cleaner Production, 75*, 118-129. doi:http://dx.doi.org/10.1016/j.jclepro.2014.04.012

Dietzenbacher, & Serrano. (2012). *How much would the Kyoto Protocol cost to consumers*

Dietzenbacher, E. (2005). Waste treatment in phyiscal input-output analysis. *Ecological Economics, 55*(1), 11-23. doi:10.1016/j.ecolecon.2005.04.009

Dietzenbacher, E., Giljum, S., Hubacek, K., & Suh, S. (2009). Physical input-output analysis and disposals to nature. In *Handbook of input-output economics in industrial ecology* (pp. 123-137). (Reprinted from: Not in File).

Dietzenbacher, E., Lenzen, M., Los, B., Guan, D., Lahr, M. L., Sancho, F., Suh, S., & Yang, C. (2013a). Input-Output Analysis: the Next 25 Year. *Economic Systems Research, 25*(4), 369-389. doi:10.1080/09535314.2013.846902

Dietzenbacher, E., Los, B., Stehrer, R., Timmer, M., & De Vries, G. (2013b). *The Construction of World Input-Output Tables in the WIOD Project*. Paper presented at the Economic Systems Research.
Dietzenbacher, E., Los, B., Stehrer, R., Timmer, M., & de Vries, G. (2013). The construction of world input–output tables in the WIOD project. *Economic systems research, 25*(1), 71-98. doi:10.1080/09535314.2012.761180
Dils, E., Van der Linden, A., Geerken, T., Christis, M., & Vercalsteren, A. (2012). *Feasibility of integrating data from multi-regional IO models in the Flemish EE-IO model*. Leuven:
Direction Générale Statistique et Information Economique (DGSIE). (2014). Dépenses moyennes par ménage 1978-2010. Retrieved from http://statbel.fgov.be/fr/modules/publications/statistiques/marche_du_travail_et_conditions_de_vie/budget_des_menages_1999-2010.jsp
Dittrich, M., Giljum, S., Lutter, S., & Polzin, C. (2012). *Green economies around the world? Implications of resource use for development and the environment*. Vienna: http://seri.at/wp-content/uploads/2012/06/green_economies_around_the_world.pdf
Druckman, A., & Jackson, T. (2009). The carbon footprint of UK households 1990-2004: A socio-economically disaggregated, quasi-multi-regional input-output model. *Ecological Economics, 68*(7), 2066-2077. doi:10.1016/j.ecolecon.2009.01.013
Duchin, F. (2005). Sustainable consumption of food - A framework for analyzing scenarios about changes in diets. *Journal of Industrial Ecology, 9*(1-2), 99-114. doi:Doi 10.1162/1088198054084707
EC. (2012). *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Roadmap to a Resource Efficient Europe.* (COM/2011/0571 final). Brussels: http://eur-lex.europa.eu/legal-content/NL/TXT/PDF/?uri=CELEX:52012AE0831&from=EN
EC. (2014). *Communication from the commission to the European parliamant, the council, the European economic and social committee and the committee of the regions. In: Toward a circular economy: a zero waste programme for Europe* (398 final)
EC. (2016a). *EU resource efficiency scoreboard 2015* http://ec.europa.eu/environment/resource_efficiency/targets_indicators/scoreboard/pdf/EU%20Resource%20Efficiency%20Scoreboard%202015.pdf
EC. (2016b). *Raw Materials Scoreboard* https://ec.europa.eu/growth/tools-databases/eip-raw-materials/en/content/eip-raw-materials-monitoring-and-evaluation-scheme
Edens, B., Hoekstra, R., Zult, D., Lemmers, O., Wilting, H., & Wu, R. H. (2015). A Method to Create Carbon Footprint Estimates Consistent with National Accounts. *Economic Systems Research, 27*(4), 440-457. doi:10.1080/09535314.2015.1048428
Eder, P., Luis, D., Neuwahl, F., Tukker, A., Huppes, G., van Oers, L., & Heijungs, R. (2006). *Environmentally extended input-output tables and models for Europe* (EUR 22194 EN)
EEA. (1999). *Environmental indicators: Typology and overview* (Technical report No 25/1999). Copenhagen:
EEA. (2007). *Environmental input-output analyses based on NAMEA data: a comparative European study on environmental pressures arising from consumption and production patterns* (ETC/SCP working paper 2/2007). Copenhagen:

EEA. (2009). *Environmental pressures from European consumption and production* (ETC/SCP working paper 1/2009). Copenhagen:
EEA. (2011a). *Key messages on material resource use and efficiency in Europe*. Copenhagen:
EEA. (2011b). *Progress in sustainable consumption and production in Europe - indicators-based report* (ETC/SCP working paper 1/2011). Copenhagen:
EEA. (2013a). *Environmetnal pressures from European consumption and production*. Copenhagen:
EEA. (2013b). *European Union CO2 Emissions: Different Accounting Perspectives*. Copenhagen:
Egilmez, G., Kucukvar, M., & Tatari, O. (2013). Sustainability assessment of U.S. manufacturing sectors: an economic input output-based frontier approach. *Journal of Cleaner Production, 53*, 91-102. doi:10.1016/j.jclepro,2013.03.037
EMF. (2013a). *Towards the circular economy. Economic and business rationale for an accelerated transition*. Cowes:
EMF. (2013b). *Towards the circular economy. Opportunities for the consumer goods sector*. Cowes:
EPA. (2009). *Sustainable Materials Management. The road ahead* (EPA530-R-09-009). Washington DC: http://www3.epa.gov/epawaste/conserve/smm/pdf/vision2.pdf
EPA. (2013). *Analysis of the life cycle impacts and potential for avoided impacts addociated with single family homes.*
EPOC. (2008). *Recommendation of the Council on Resource Productivity*
EREP. (2012). *European Resource Efficiency Platform (EREP) - Manifesto & Policy Recommendations*
EU Regulation. (2013). *No 549/2013* http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2013:174:0001:0727:EN:PDF
European Commission. (2011). *Communication from the commission to the European parliament, the council, the European economic and social committtee an the committtee of the regions. In: roadmap to a Resource Efficient Europe* (571 final)
European Commission, Internationl Monetary Fund, Organisation for Economic Co-operation and Development, & Bank, U. N. W. (2009). *System of National Accounts 2008 (SNA)* (Sales No. E.08.XVII.29). New York: http://unstats.un.org/unsd/nationalaccount/docs/SNA2008.pdf
Eurostat. (2000). *Material flow accounting. Framework and methods. Special Session on Material Flow Accounting*. Paris:
Eurostat. (2001). *Economy-wide material flow accounts and derived indicators. A methodological guide*. Luxembourg: http://ec.europa.eu/eurostat/documents/1798247/6191533/3-Economy-wide-material-flow-accounts...-A-methodological-guide-2000-edition.pdf/9dfae42d-0831-4522-9fe5-571785f8fecf
Eurostat. (2008). *Eurostat Manual of Supply, Use and Input-Output Tables*. Luxembourg: http://ec.europa.eu/eurostat/documents/3859598/5902113/KS-RA-07-013-EN.PDF/b0b3d71e-3930-4442-94be-70b36cea9b39?version=1.0
Eurostat. (2009). *Economy wide material flow accounts: compilation guidelines for reporting to the 2009 Eurostat questionnaire* (Version 01)http://unstats.un.org/unsd/envaccounting/ceea/archive/Framework/Eurostat%20MFA%20compilation%20guide_2009.pdf
Eurostat. (2010). *Environmental statistics and accounts in Europe* (KS-32-10-283-EN-C). Luxembourg:

http://ec.europa.eu/eurostat/documents/3217494/5723037/KS-32-10-283-EN.PDF/22a4889d-e6c9-4583-8d17-fb5104e7eec0?version=1.0
Eurostat. (2013). *Economy-wide material flow accounts (EW-MFA). Compilation guide 2013* http://ec.europa.eu/eurostat/documents/1798247/6191533/2013-EW-MFA-Guide-10Sep2013.pdf/54087dfb-1fb0-40f2-b1e4-64ed22ae3f4c
Eurostat. (2015). *Project: Estimates for Raw Material Consumption (RMC) and Raw Material Equivalents (RME) conversion factors*
Federaal Planbureau. (2007). *Regionale input-outputdata opgesteld doorhet Federaal Planbureau in het kader van eht project 'Vlaams Milieu-IO-model' in oprdacht van de Vlaamse Overheid (2007 data)*
Femia, A., & Vignani, D. (2006). *Economy-wide material flow accounts. Importance and analytical potential of indirect flows* (LG/10/7). New York: http://unstats.un.org/unsd/envaccounting/londongroup/meeting10/LG10_7a.pdf
Fiksel, J. (2006). A framework for sustainable materials management. *The Jounral of The Minerals, Metals & Materials Society, 58*(8), 15-22.
Finnveden, G., & Moberg, A. (2005). Environmental systems analysis tools - an overview. *Journal of Cleaner Production, 13*(12), 1165-1173. doi:10.1016/j.jclepro.2004.06.004
Flanders Investment & Trade. (2013). Flanders is fourth most open economy worldwide. In. http://www.investinflanders.be/EN/news/2013/01/25/Flanders-is-fourth-most-open-economy-worldwide: Government of Flanders.
Foster-McGregor, N., & Stehrer, R. (2013). Value added content of trade: a comprehensive approach. *Economics Letters, 120*(2), 354-357. doi:10.1016/j.econlet.2013.05.003
G., H., & H., S. (2010). *Indirect procedures for estimation of transfer coefficients* (Deliverable 3-3)http://forwast.brgm.fr/Documents/Deliverables/Forwast_D33.pdf
Gemechu, E. D., Butnar, I., Llop, M., Amoras Barrero, M. J., & Castells, F. (2012). *The price impacts of an environmental tax on production of goods in the Spanish economy.* Paper presented at the 20th International Input-Output Conference, Bratislava, Slovakia.
Gerlo, J., & Goeminne, G. (2005). *Material Flow Account-indicatoren voor materiaalgebruik: verkenning van de mogelijkheden voor sectorale opsplitsing en koppeling met milieu-impact* (MIRA/2005/01). Mechelen: http://www.milieurapport.be/upload/main/miradata/MIRA-T/01_sectoren/01_01/2005-01_EVP_eindverslag%20grondstoffen_CDO_0305.pdf
Giljum, S. (2006). Material flow-based indicators for evaluation of eco-efficiency and dematerialisation policies. In L. P. (Ed.), *Sustainability indicators in ecological economics* (pp. 376-398). Cheltenham. (Reprinted from: Not in File).
Giljum, S., Hinterberger, F., Wackernagel, M., & Kitzes, J. (2006). *Resource use indicators in the European Union. Policy processes, indicators sets and criteria for a headline indicator*
Giljum, S., & Hubacek, K. (2001). *International trade, material flows and land use: developing a physical trade balance for the European Union* (IR-01-059). Austria: http://seri.at/wp-content/uploads/2010/06/international-trade-material-flows-and-land-use.pdf
Giljum, S., & Hubacek, K. (2009). Conceptual foundations and applications of physical input-output tables. In S. S. (Ed.), *Handbook of input-output*

economics in industrial ecology (pp. 61-75). Dordrecht: Springer Netherlands. (Reprinted from: Not in File).
Gonzalez-Martinez, A. C., & Schandl, H. (2008). The biophysical perspective of a middle income economy: material flows in Mexico. *Ecological Economics, 68*(1-2), 317-327. doi:10.1016/j.ecolecon.2008.03.013
Graedel, T. E., & van der Voet, E. (2010). *Linkages of sustainability*. Camebridge: MIT Press.
Gravgård, O. P. (2009). *Recording of losses in the physical supply and use tables - Should product output be recorded gross or net of the losses?* (LG/14/3/Supplementary). Canberra: http://unstats.un.org/unsd/envaccounting/londongroup/meeting14/LG14_3a_supp.pdf
Gravgård, O. P., & de Haan, M. (2009). SEEA-2003 and the economic relevance of physical flow accounting at industry and national economy level. In S. S. (Ed.), *Handbook of Input-Output Economics in Industrial Ecology* (pp. 625-652). Dordrecht: Springer. (Reprinted from: Not in File).
Gu, L. P., Zhang, Z. Y., & Kang, J. J. (2006). Patent and R&D resources: the input-output anlaysis of China innovation. *Journal of Industrial Engineering and Engineering Management, 20*, 147-151.
Haas, W., Krausmann, F., Wiedenhofer, D., & Heinz, M. (2015). How circular is the global economy? An assessment of material flows, waste production, and recycling in the European Union and the World in 2005. *Journal of Industrial Ecology, 19*(5), 765-777. doi:10.1111/jiec.12244
Hammer, M., Giljum, S., Bargigli, S., & Hinterberger, F. (2003). *Material flow analysis on the regional level: questions, problems, solutions* (Working Paper No. 2). Hamburg: http://seri.at/en/publications/other-working-papers/2009/09/20/material-flow-analysis-on-the-regional-level-questions-problems-solutions/
Harper, E. M. (2008). A product-level approach to historical material flow analysis. *Journal of Industrial Ecology, 12*(5-6), 768-784. doi:10.111/j.1530-9290.2008.00070.x
Hatfield-Dodds, S., Feeney, K., Shepherd, L., Stephens, J., C., G., & W., P. (2011). *The carbon price and the cost of living: assessing the impacts on consumer prices and households*. Sydney:
Hauknes, J., & Knell, M. (2009). Embodied knowledge and sectoral linkages: An input-output approach to the interaction of high- and low-tech industries. *Research Policy, 38*(3), 459-469. doi:10.1016/j.respol.2008.10.012
Hazari, & Krishnamurty. (1970). Employment implications of India's industrialization: analysis in an input output framework. *The Review of economics and Statistics, 52*, 181-186. doi:http://dx.doi.org/10.2307/1926119
Hendriks, C., Obernosterer, R., Müller, D., Kytzia, S., Baccini, P., & Brunner, P. H. (2000). Material Flow Analysis: A tool to support envionmental policy decision making. Case-studies on the city of Vianna and the Swiss lowlands. *Local Environment: The International Journal of Justice and Sustainability, 5*(3), 311-328. doi:10.1080/13549830050134257
Hernandez-Rodriguez, Beylot, & Villeneuve. (2012). *A numerical approach for compiling full phyiscal supply-use tables (PSUTs) under conflicting information* (hal-00667407). Leiria: https://hal-brgm.archives-ouvertes.fr/hal-00667407/document
Hertwich, E. G., & Peters, G. P. (2009). Carbon Footprint of Nations: A Global, Trade-Linked Analysis. *Environmental Science & Technology, 43*(16), 6414-6420. doi:10.1021/es803496a

Hinterberger, F., Giljum, S., & Hammer, M. (2003). *Material flow accounting and analysis (MFA). A valuable tool for analyses of Society-Nature Interrelations. Entry prepared for the Internet Encyclopedia of Ecological Economics* http://seri.at/wp-content/uploads/2009/09/Material-Flow-Accounting-and-Analysis-MFA.-Encyclopaedia-of-the-International-Society-for-Ecological-Economics-ISEE.pdf
Hoekstra, & Janssen. (2002). *Environmental responsibility and policy in a two country dynamic input-output model*
Hoekstra, R. (2005). *Economic Growth, Material Flows and the Environment. New Applications of Structural Decomposition Analysis and Physical Input-Output Tables*. Cheltenham:
Hoekstra, R. (2010). *Physical input-output tables: developments and future* (2010-136-KOO). Sydney: http://www.rutgerhoekstra.com/publications/2010_Hoekstra-Physical%20input-output%20tabels.pdf
Hoekstra, R., & van den Bergh, J. C. J. M. (2006). Constructing phyiscal input-output tables for environmental modeling and accounting: Framework and illustrations. *Ecological Economics, 59*(3), 375-393. doi:10.1016/j.ecolecon.2005.11.005
Hoekstra, R., Zult, D., Edends, B., Lemmers, O., Wilting, H., & Wu, R. *Producing carbon footprints that are consistent to the Dutch national and environmental accounts*. Paper presented at the 21st International Input-Output Conference, July 9 - 12th 2013, Kitakyushu, Japan & Workshop on the Wealth of Nations in a Globalising World, July 18-19th 2013, University of Groningen, The Netherlands.
Hoffrén, J. (2010). *Economy-wide material flow accounts with hidden flows for Finland: 1945-2008* (253). Helsinki:
Howlett, M., McConnell, A., & Perl, A. (2015). Streams and stages: Reconciling Kingdon and policy process theory. *European Journal of Political Research, 54*(3), 419-434. doi:10.1111/1475-6765.12064
Huang, C. L., Vause, J., Ma, H. W., & Yu, C. P. (2012). Using material/substance flow analysis to support sustainable development assessment: A literature review and outlook. *Resources, Conservation and Recycling, 68*, 104-116.
Hubacek, K., & Giljum, S. (2003). Applying physical input-output analysis to estimate land appropriation (ecological footprints) of international trade activities. *Ecological Economics, 44*(1), 137-151. doi:Doi 10.1016/S0921-8009(02)00257-4
Hubacek, K., Guan, D. B., Barrett, J., & Wiedmann, T. (2009). Environmental implications of urbanization and lifestyle change in China: Ecological and Water Footprints. *Journal of Cleaner Production, 17*(14), 1241-1248. doi:10.1016/j.jclepro.2009.03.011
Huppes, G., de Koning, A., Suh, S., Heijungs, R., van Oers, L., Nielsen, P., & Guinee, J. B. (2006). Environmental impacts of consumption in the European Union - High-resolution input-output tables with detailed environmental extensions. *Journal of Industrial Ecology, 10*(3), 129-146. doi:DOI 10.1162/jiec.2006.10.3.129
Huysman, S., Sala, S., Mancini, L., Ardente, F., Alvarenga, R. A. F., De Meester, S., Mathieux, F., & Dewulf, J. (2015). Toward a systematized framework for resource efficiency indicators. *Resources Conservation and Recycling, 95*, 68-76. doi:10.1016/j.resconrec.2014.10.014
Huysman, S., Schaubroeck, T., & Dewulf, J. (2014). Quantification of Spatially Differentiated Resource Footprints for Products and Services through a

Macro-Economic and Thermodynamic Approach. *Environmental Science & Technology, 48*(16), 9709-9716. doi:10.1021/es500777k
Ibenholt, K. (2002). Materials flow analysis and economic modelling. In A. R.U. & A. L.W. (Eds.), *A handbook of industrial ecology* (pp. 177-184). Cornwall: MPG Books Ltd. (Reprinted from: Not in File).
Inomata, S., & Owen, A. (2014). A Comparative Evaluation of Multi-Regional Input-Output Databases. *Economic Systems Research, 26*(3), 239-244. doi:10.1080/09535314.2014.940856
Jalas, M. (2005). The everyday life context of increasing energy demands - Time use survey data in a decomposition analysis. *Journal of Industrial Ecology, 9*(1-2), 129-145. doi:Doi 10.1162/1088198054084644
Jenkins. (2011). *Modelling the economic and social consequences of drought under future projections of climate change (doctoral thesis)*
Johnson, R. C., & Noguera, G. (2012). Accounting for intermediates: production sharing and trade in value added. *Journal of International Economics, 86*(2), 224-236. doi:10.1016/j.jinteco.2011.10.003
Jungbluth, Nathani, Stucki, & Leuenberger. (2011). *Environmental impacts of Swiss consumption and production. A combination of IO-analysis with LCA*
Jury, C., Rugani, B., Hild, P., May, M., & Benetto, E. (2013). Analysis of complementary methodologies to assess the environmental impact of Luxembourg's net consumption. *Environmental Science & Policy, 27*, 68-80. doi:10.1016/j.envsci.2012.11.014
Kennedy, C., Cuddihy, J., & Engel-Yan, J. (2007). The changing metabolism of cities. *Journal of Industrial Ecology, 11*(2), 43-59. doi:10.1162/jie.2007.1107
Kerkhof, A. C., Nonhebel, S., & Moll, H. C. (2009). Relating the environmental impact of consumption to household expenditures: An input-output analysis. *Ecological Economics, 68*(4), 1160-1170. doi:10.1016/j.ecolecon.2008.08.004
Kitzes, J. (2013). An introduction to environmentally-extended input-output analysis. *Resources, 2*(489), 504. doi:10.3390/resources2040502
Kleijn, R. (2000). Adding it all upp. The sense and non-sense of bulk-MFA. *Journal of Industrial Ecology, 4*(2), 7-8. doi:10.1162/108819800239762
Kleijn, R., & van der Voet, E. (2010). Resource constraints in a hydrogen economy based on renewable energy sources: an explenation. *Renewable Sustainable Energy Review, 14*(9), 2784-2795. doi:10.1016/j.rser.2010.07.066
Konijn, P., de Boer, S., & van Dalen, J. (1997). Input-output analysis of material flows with application to iron, steel and zinc. *Structural Change and Economic Dynamics, 8*(1), 129-153. doi:http://dx.doi.org/10.1016/S0954-349X(96)00063-X
Konijn, P. J. A., & Steenge, A. E. (1995). Compilation of input-output data from the national accounts. *Economic Systems Research, 7*(1), 31-45. doi:10.1080/09535319500000009
Koopman, R., Powers, W., Wang, Z., & Wei, S. J. (2010). *Give credit where credit is due: tracing value added in global production chains* (NBER Working Paper No. 16426)
Kovanda, J., van de Sand, I., Schütz, H., & Bringezu, S. (2012). Economy-wide material flow indicators: overall framework, purposes and uses and comparison of material use and resource intensity of the Czech Republic, Germany and the EU-15. *Ecological Indicators, 17*, 88-98. doi:10.1016/j.ecolind.2011.04.020

Kovanda, J., & Weinzettel, J. (2013). The importance of raw material equivalents in economy-wide material flow accounting and its policy dimension. *Environmental Science & Policy, 29*, 71-80. doi:10.1016/j.envsci.2013.01.005
Kovanda, J., Weinzettel, J., & Hak, T. (2009). Analysis of regional material flows: the case of the Czech Republic. *Resources, Conservation and Recycling, 53*(5), 243-254. doi:10.1016/j.resconrec.2008.12.004
Kronenberg, T., Kuckshinrichs, W., & Hansen, P. (2012). *Macroeconomic effects of the German government's building rehabilitation program* http://www.fz-juelich.de/SharedDocs/Downloads/IEK/IEK-STE/DE/Publikationen/preprints/2012/preprint_17_2012.pdf?__blob=publicationFile
L'Abbate, P. (2012). *Material flow management. Evolution of the analysis of input/output in physical units*
Leamer, E. E. (1988). Measures of Openness. In R. E. Baldwin (Ed.), *Trade Policy Issues and Emperical Analysis* (pp. 145-204): University of Chicago Press.
Lehr, U., Lutz, C., & Edler, D. (2012). Green jobs? Economic impacts of renewable energy in Germany. *Energy Policy, 47*, 358-364. doi:10.1016/j.enpol.2012.04.076
Lenzen, Kanemoto, Moran, & Geschke. (2012). Mapping the structure of the world economy. *Environmental Science & Technology, 46*(15), 8374-8381. doi:10.1021/es300171x
Lenzen, Moran, Kanemoto, & Geschke. (2013). Building Eora: A Global Multi-regional Input-Output Database at High Country and Sector Resolution. *Economic Systems Research, 25*(1), 20-49. doi:10.1080/09535314.2013.769938
Lenzen, M. (1998). Primary energy and greenhouse gases embodied in Australian final consumption: an input-output analysis. *Energy Policy, 26*(6), 495-506. doi:Doi 10.1016/S0301-4215(98)00012-3
Lenzen, M. (2011). Aggregation versus Dissaggregation in Input-Output Analysis of the Environment. *Economic Systems Research, 23*(1), 73-89. doi:10.1080/09535314.2010.548793
Lenzen, M., Kanemoto, K., Moran, D., & Geschke, A. (2012). Mapping the Structure of the World Economy. *Environmental science & technology, 46*, 8374-8381.
Lenzen, M., Pade, L.-L., & Munksgaard, J. (2004). CO2 Multipliers in Multi-region Input-Output Models. *Economic Systems Research, 16*(4), 391-412. doi:10.1080/0953531042000304272
Lenzen, M., & Peters, G. M. (2010). How City Dwellers Affect Their Resource Hinterland. *Journal of Industrial Ecology, 14*(1), 73-90. doi:10.1111/j.1530-9290.2009.00190.x
Lenzen, M., Wood, R., & Foran, B. (2008). Chapter 4 - Direct versus Embodied Energy – The Need for Urban Lifestyle Transitions. In *Urban Energy Transition* (pp. 91-120). Amsterdam: Elsevier.
Lenzen, M., Wood, R., & Wiedmann, T. (2010). Uncertainty Analysis for Multi-Region Input-Output Models - a Case Study of the Uk's Carbon Footprint. *Economic Systems Research, 22*(1), 43-63. doi:10.1080/09535311003661226
Leontief, W. (1966). *Input-output economics*. New York: Oxford University Press.
Lindner, S., Legault, J., & Guan, D. B. (2012). Disaggregating Input-Output Models with Incomplete Information. *Economic Systems Research, 24*(4), 329-347. doi:10.1080/09535314.2012.689954

Loiseau, E., Junqua, G., Roux, P., & Bellon-Maurel, V. (2012). Environmental assessment of a territory: An overview of existing tools and methods. *Journal of Environmental Management, 112*, 213-225. doi:http://dx.doi.org/10.1016/j.jenvman.2012.07.024

Lutz, C., & Lehr, U. (2012). *Economic impacts of energy efficiency and renewable energy in Germany.* Paper presented at the 20th IIOA conference Bratislava.

Mäenpää, I. (2004). *Physical flow accounts Finland 1999*. Oulu:

Mäenpää, I. (2009). *Material flow accounts. IMEA WP5*. Paris: http://www.imea-eu.org/results.html

Markaki, M., Belegri-Roboli, A., Michaelides, P., Mirasgedis, S., & Lalas, D. P. (2013). The impact of clean energy investments on the Greek economy: An input-output analysis (2010-2020). *Energy Policy, 57*, 263-275. doi:10.1016/j.enpol.2013.01.047

Martinez, S. H., van Eijck, J., da Cunha, M. P., Guilhoto, J. J. M., Walter, A., & Faaij, A. (2013). Analysis of socio-economic impacts of sustainable sugarcane-ethanol production by means of inter-regional Input-Output analysis: Demonstrated for Northeast Brazil. *Renewable & Sustainable Energy Reviews, 28*, 290-316. doi:10.1016/j.rser.2013.07.050

Matthews, E., Amann, C., Bringezu, S., Fischer-Kowalski, M., Hüttler, W., Kleijn, R., Moriguchi, Y., Ottke, C., Rodenburg, E., Rogich, D., Schandl, H., Schütz, H., van der Voet, E., & Weisz, H. (2000). *The weight of nations. Material outflows from industrial economies*. Washington, DC: http://pdf.wri.org/weight_of_nations.pdf

Merciai, S., & Schmidt, J. Methodology for the Construction of Global Multi-Regional Hybrid Supply and Use Tables for the EXIOBASE v3 Database. *Journal of Industrial Ecology*, n/a-n/a. doi:10.1111/jiec.12713

Merciai, S., Schmidt, J., Dalgaard, R., Giljum, S., Lutter, S., Usubiaga, A., Acosta, J., Schütz, H., Wittmer, D., & Delahaye, R. (2011). *Report and data Task 4.2: P-SUT* http://www.exiobase.eu/index.php/publications/documentation

Michel, B. (2013). *Is offshoring driven by air emissions? Testing the pollution haven effect for imports of intermediates.* (Working Paper 12-13)http://www.plan.be/publications/publication-1246-en-is+offshoring+driven+by+air+emissions+testing+the+pollution+haven+effect+for+imports+of+intermediates

Miller, R. E., & Blair, P. D. (2009). *Input-Output Analysis. Foundations and Extensions* (2nd ed. ed.). Cambridge: University Press.

Miller, R. E., & Shao, G. (1990). Spatial and sectoral aggregation in the commodity-industry multiregional input-output model. *Environment and Planning A, 22*, 1637-1656.

Minx, J., Creutzig, F., Medinger, V., Ziegler, T., Owen, A., & Baiocchi, G. (2011). *Developing a pragmatic approach to assess Urban Metabolism in Europe - A report to the European Environment Agency prepared by Technische Universität Berlin and Stockholm Environment Institute, Climatecon Working paper 01/2011*. Berlin:

Mohnen, P. (1997). Introduction: input-output analysis of interindustry R1D spillovers. *Economic Systems Research, 9*, 3-8. doi:http://dx.doi.org/10.1080.09535319700000001

Moll, S., Bringezu, S., & Schütz, H. (2005). *Resource Use in European Countries. An estimate of materials and waste streams in the Community, including imports and exports using the instrument of material flows analysis* (Wuppertal Report No. 1). Wuppertal: http://www.personal.ceu.hu/students/06/Lin_Jiaqiao/Research_Focus/pa

pers/ecosystem%20mgmt_natural%20zy/resource%20use%20in%20the%20EU_wuppertal.pdf
Moll, S., Vrgoc, M., Watson, D., Femia, A., Pedersen, O. G., & Villanueva, A. (2006). *Environmental Input-Output Analysis based on NAMEA data. A comparative European study on environmental pressures arising from consumption and production patterns* (ETC/RWM working paper 2007/02). Copenhagen: http://scp.eionet.europa.eu/wp/wp2_2007
Moran, D., & Wood, R. (2014). Convergence between the EORA, WIOD, EXIOBASE, and OPENEU's consumption-based carbon accounts. *Economic systems research, 26*(3), 245-261. doi:10.1080/09535314.2014.935298
Mulalic, I. (2005). *Economy-wide material flow accounts for Denmark*
Müller, D. B., Liu, G., Løvik, A. N., Modaresi, R., Pauliuk, S., Steinhoff, F. S., & Brattebø, H. (2013). Carbon Emissions of Infrastructure Development. *Environmental science & technology, 47*(20), 11739-11746. doi:10.1021/es402618m
Muniz, A. S. G. (2013). Input-output research in structural equivalence: Extracting paths and similarities. *Economic Modelling, 31*, 796-803. doi:10.1016/j.econmod.2013.01.016
Munksgaard, J., Wier, M., Lenzen, M., & Dey, C. (2005). Using input-output analysis to measure the environmental pressure of consumption at different spatial levels. *Journal of Industrial Ecology, 9*(1-2), 169-186. doi:10.1162/1088198054084699
Narayanan, B., Bardi, Aguiar, A., & McDougall, R. (2012). *Global Trade, Assistance, and Production: The GTAP 8 Data Base*. West Lafayette, IN: Center for Global Trade Analysis, Purdue University.
NBB, BISA, IWEPS, & Overheid, V. (2014). *Regionale rekeningen. Regionale verdeling van de Belgische in- en uitvoer van goederen en diensten*. Brussel: https://www.nbb.be/doc/dq/n_method/m_gd_meth2014n.pdf
Neuwahl, F., Loschel, A., Mongelli, I., & Delgado, L. (2008). Employment impacts of EU biofuels policy: Combining bottom-up technology information and sectoral market simulations in an input-output framework. *Ecological Economics, 68*(1-2), 447-460. doi:10.1016/j.ecolecon.2008.04.018
Nijdam, D. S., Wilting, H. C., Goedkoop, M. J., & Madsen, J. (2005). Environmental load from Dutch private consumption - How much damage takes place abroad? *Journal of Industrial Ecology, 9*(1-2), 147-168. doi:Doi 10.1162/1088198054084725
OECD. (2007, 3/2007). OECD programme on material flows and resource productivity. Guidance manual volume II. A theoretical framework for material flow accounts and their applications at the national level. *Presentation.* Retrieved from http://unstats.un.org/unsd/envaccounting/londongroup/meeting11/lg11_9b.pdf
OECD. (2008). *Measuring Material Flows and Resource Productivity Synthesis report*
OECD. (2011). *Policy Instruments for Sustainable Materials Management*. Paris:
OECD. (2012). *Sustainable Materials Management: Making better use of Resources*. Luxembourg:
OECD. (2013). *Interconnected economies: benefitting from global vlaue chains*. Paris:
OECD, UNCTAD, & WTO. (2013). *Implications of global value chains for trade, investment, development and jobs*. Saint Petersburg:

OVAM. (2007). Regionale input-output data opgesteld door het Federaal Planbureau in het kader van het project 'Vlaams Milieu-IO-model' in opdracht van de Vlaamse Overheid. In.
Park, S. H., & Chan, K. S. (1989). A Cross-Country Input-Output-Analysis of Intersectoral Relationships between Manufacturing and Services and Their Employment Implications. *World Development, 17*(2), 199-212. doi:Doi 10.1016/0305-750x(89)90245-3
Parsons, T., & Smelser, N. J. (1984). *Economy and society: a study in the integration of economic and social theory*. London: Routledge & Kegan Paul Ltd.
Parsons, W. (1995). *Public Policy: an introduction to the theory and practice of policy analysis*: Edward Elgar.
Pedersen, O. G., & de Haan, M. (2010). SEEA-2003 and the economic relevance of physical flow accounting at industry and national economy level. In S. S. (Ed.), *Handbook of Input-Output Economics in Industrial Ecology* (pp. 625-652). Dordrecht: Spinger Netherlands. (Reprinted from: Not in File).
Pedersen, O. G., & Devici, N. N. (2014). *Construction of physical supply-use and input-output tables for Denmark*. Copenhagen:
Perese, K. (2010). *Input-output model analysis: pricing carbon dioxide emissions*. Washintong, D.C.:
Peters, G., & Solli, C. (2010). *Global carbon footprints. Methods and import/export corrected results from the Nordic countries in global carbon footprint studies*. Copenhagen:
Peters, G. P., & Hertwich, E. G. (2006). The importance of imports for household environmental impacts. *Journal of Industrial Ecology, 10*(3), 89-109. doi:DOI 10.1162/jiec.2006.10.3.89
Rees, W., & Wackernagel, M. (1996). Urban ecological footprints: Why cities cannot be sustainable - and why they are the key to sustainability. *Environmental Assessment Review, 16*, 223-248.
Reisinger, H., Eisenmenger, N., Ferguson, J., Kanthak, J., Finocchiaro, G., Donachie, G., Maguire, C., Arto, I., & Rotzetter, C. (2009). *Material flow analysis (MFA) for resource policy decision support. Position paper of the Interest Group on the sustainable use of natural resources on the needs for further development of MFA-based indicators*
Remond-Tiedrez, I., & Rueda-Cantuche, J. M. (2016). *The FIGARO project: the EU inter-country supply, use and input-output tables* https://www.iioa.org/conferences/24th/papers/files/2504_20160519071_Item10-12_FIGAROproject.pdf
Rørmose, P. (2011). *Up-to-date input-output tables for environmental accounting and analyses*. Copenhagen:
Rose, A., & Miernyk, W. (1989). Input-Output Analysis: The First Fifty Years. *Economic Systems Research, 1*(2), 229-270.
Rose, A. Z., & Miernyk, W. (1989). Input-output analysis: the first fifty years. *Economic Systems Research, 1*, 229-271. doi:10.1080/09535318900000016
Rugani, B., Roviani, D., Hild, P., Schmitt, B., & Benetto, E. (2014). Ecological deficit and use of natural capital in Luxembourg from 1995 to 2009. *Science of the Total Environment, 468*, 292-301. doi:10.1016/j.scitotenv.2013.07.122
Schandl, H., Hatfield-Dodds, S., Wiedmann, T., Geschke, A., Cai, Y., West, J., Newth, D., Baynes, T., Lenzen, M., & Owen, A. (2016). Decoupling global environmental pressure and economic growth: scenarios for energy use, materials use and carbon emissions. *Journal of Cleaner Production, 132*, 45-56. doi:https://doi.org/10.1016/j.jclepro.2015.06.100

Schmidt, J., Merciai, S., Delahaye, R., Vuik, J., Heijungs, R., de Koning, A., & Sahoo, A. (2012). *Recommendation of terminology, classification, framework of waste accounts and MFA, and data collection guideline*

Schmidt, J., Weidema, B. P., & Suh, S. (2010). *Documentation of the final model used for the scenario analysis* (Deliverable 6-4)http://forwast.brgm.fr/Documents/Deliverables/Forwast_D64.pdf

Schoer, K., & Gravgård, O. P. (2007). *Clarifications and recommendations concerning differences between the OECD guidance manual on material flows and resource productivity, Volume II and the SEEA 2003*

Schütz, H., Moll, S., & Bringezu, S. (2004). *Globalisation and the shifting environmental burden. Material trade flows of the European Union* http://www.wupperinst.org/globalisation/html/shifting_burden.html

Seppala, J., Maenpaa, I., Koskela, S., Mattila, T., Nissinen, A., Katajajuuri, J. M., Harma, T., Korhonen, M. R., Saarinen, M., & Virtanen, Y. (2011). An assessment of greenhouse gas emissions and material flows caused by the Finnish economy using the ENVIMAT model. *Journal of Cleaner Production, 19*(16), 1833-1841. doi:10.1016/j.jclepro.2011.04.021

Sissoko, A. A., & Vandille, G. (2008). *Quantifying environmental leakage for Belgium* (Working Paper 19-08)

Skelton, A., Guan, D., Peters, G. P., & Crawford-Brown, D. (2011). Mapping Flows of Embodied Emissions in the Global Production System. *Environmental Science & Technology, 45*(24), 10516-10523. doi:10.1021/es202313e

Söderholm, P., & Tilton, J. E. (2012). Material efficiency: an economic perspective. *Resources, Conservation and Recycling, 61*, 75-82. doi:10.1016/j.resconrec.2012.01.003

Spangenberg, J. H., Femia, A., Hinterberger, F., & Schütz, H. (1998). *Material flow-based indicators in environmental reporting* (No. 14). Luxembourg: http://web.mit.edu/cron/Backup/project/urban_metabolism/DJQ/Papers_Research_Websites/Indicators+Methods/EU%20MFA%20Indicators%20in%20Environmental%20Reporting.pdf

Stadler, K., Wood, R., Bulavskaya, R., Södersten, C. J., Simas, M., Schmidt, S., Usubiga, A., Acosta-Fernandez, J., Kuenen, J., Bruckner, M., Giljum, S., Lutter, S., S., M., Schmidt, J., Theuri, M. C., Plutzar, C., & Kastner, T. (2017). EXIOBASE 3 - Developing a Time Series of Detailed Environmentally Extended Multi-Regional Input-Output Tables. *Journal of Industrial Ecology, in press*.

Stahmer, C. (2000). *The magic triangle of I-O tables*. Macerata: https://www.iioa.org/conferences/13th/files/StahmerMagicTriangle.pdf

Stahmer, C., Kuhn, M., & Braun, N. (1996). *Phyiscal input-output tables. German experiences.* Stockholm:

Statistics Austria, & SERI. (2011). *Physical input-output tables for austria 2005. Final report on technical implementation*

Steen-Olsen, K., Owen, A., Hertwich, E. G., & Lenzen, M. (2014). Effects of Sector Aggregation on CO2 Multipliers in Multiregional Input-Output Tables. *Economic Systems Research, 26*(3), 284-302. doi:10.1080/09535314.2014.934325

Stehrer, R. (2012). *Trade in Value Added and the Valued Added in Trade* (81). Vienna: http://www.wiiw.ac.at/trade-in-value-added-and-the-valued-added-in-trade-dlp-2620.pdf

Strassert, G. (2000). *Phiscal input-output accounting and analysis: new perspectives*. Macerata: https://www.iioa.org/conferences/13th/files/Strassert_GermanyPhysicalFlows.pdf

Su, B., & Ang, B. W. (2010). Input-output analysis of CO2 emissions embodied in trade: The effects of spatial aggregation. *Ecological Economics, 70*(1), 10-18. doi:10.1016/j.ecolecon.2010.08.016

Su, B., Huan, H. C., Ang, B. W., & Zhou, P. (2010). Input-output analysis of CO2 emissions embodied in trade: The effects of sector aggregation. *Energy Economics, 32*(1), 166-175. doi:10.1016/j.eneco.2009.07.010

Su, Y.-W., Yang, H.-Y., & Lin, C.-H. (2017). Increase of electricity price and energy efficiency: analysis using the macroeconomic interindustry model of Taiwan. *Economic Systems Research, 29*(3), 430-451. doi:10.1080/09535314.2017.1323726

Suh, S. (2009). *Handbook of input-output economics in industrial ecology*. Dordrecht: Springer.

SuMMa. (2011). *Policy research centre sustainable materials management (SuMMa). Multiannual programme*. Leuven:

Sun, L., Giljum, S., & Hubacek, K. (2004). Beyond the simple material balance: a reply to Sangwong Suh's note on physical input-output analysis. *Ecological Economics, 48*(1), 19-22. doi:10.1016/j.ecolecon.2003.09.004

Tarancón, M. M. Á., & del Río, G. P. (2007). A combined input–output and sensitivity analysis approach to analyse sector linkages and CO2 emissions. *Energy Economics, 29*(3), 578-597. doi:http://dx.doi.org/10.1016/j.eneco.2006.02.004

ten Raa, T. (2005). *The economics of input-output analysis*. Cambridge: University Press.

Thomas, B. A., & Azevedo, I. L. (2013). Estimating direct and indirect rebound effects for US households with input-output analysis Part 1: Theoretical framework. *Ecological Economics, 86*, 199-210. doi:10.1016/j.ecolecon.2012.12.003

Timmer, M. P. (2012). *The World Input-Output Database (WIOD): Contents, Sources and Methods* http://www.wiod.org/publications/source_docs/WIOD_sources.pdf

Timmer, M. P., Dietzenbacher, E., Los, B., Stehrer, R., & de Vries, G. J. (2015). An Illustrated User Guide to the World Input-Output Database: the Case of Global Automotive Production. *Review of International Economics, 23*(3), 575-605. doi:10.1111/roie.12178

Timmer, M. P., Erumban, A. A., Los, B., Stehrer, R., & de Vries, G. J. (2014). Slicing up global value chains. *Journal of Economic Perspectives, 28*(2), 99-118. doi:10.1257/jep.28.2.99

Timmers, M. P. (2012). *The World Input-Output Database (WIOD): Contents, Sources and Methods* http://www.wiod.org/publications/source_docs/WIOD_sources.pdf

Toye, R. (2017, 8 June 2017). Doughnut Economics by Kate Rawortsh review - forget growth, think survivial. *The Guardian*.

TRITEL, & CE Delft. (2013). *Onderzoek naar de mogelijkheden voor het opstellen van materiaalrekeningen. Eindrapport*. Mechelen: https://www.vlaanderen.be/nl/publicaties/detail/onderzoek-naar-de-mogelijkheden-voor-het-opstellen-van-materiaalrekeningen

Tukker, A., Bouwmeester, M., Oosterhaven, J., de Koning, A., & Heijungs, R. (2011). *Policy impact assessment - resources, products and imports and exports* (Exiopol deliverable IV.2.b)

Tukker, A., Bulavskaya, T., Giljum, K., de Koning, A., Lutter, S., Simas, M., Stadler, K., & Wood, R. (2014). *The global resource footprint of Nations: carbon, water, land and materials embodied in trade and final consumption*. Leiden/Delft/Vienna/Trondheim:

Tukker, A., Bulavskaya, T., Giljum, S., de Koning, A., Lutter, S., Simas, M., Stadler, K., & Wood, R. (2016). Environmental and resource footprints in a global context: Europe’s structural deficit in resource endowments. *Global Environmental Change, 40*, 171-181. doi:https://doi.org/10.1016/j.gloenvcha.2016.07.002

Tukker, A., de Koning, A., Wood, R., Hawkins, T., Lutter, S., Acosta, J., Cantuche, J. M. R., Bouwmeester, M., Oosterhaven, J., Drosdowski, T., & Kuenen, J. (2013). Exiopol - Development and Illustrative Analyses of a Detailed Global Mr Ee Sut/Iot. *Economic Systems Research, 25*(1), 50-70. doi:10.1080/09535314.2012.761952

Tukker, A., de Koning, A., Wood, R., Moll, S., & Bouwmeester, M. (2012). Price corrected domestic technology assumption - a method to assess pollution embodied in trade using primary official statistics only. With a case on CO2 emissions embodied in imports to Europe. *Environmental Science & Technology, 47*, 1775-1783. doi:dx.doi.org/10.1021/es303217f

Tukker, A., & Dietzenbacher, E. (2013). Global Multiregional Input-Output Frameworks: An Introduction and Outlook. *Economic Systems Research, 25*(1), 1-19. doi:10.1080/09535314.2012.761179

Tukker, A., G., H., van Oers, L., & Heijungs, R. (2005). *Environmentally extended input-output tables and models for Europe* http://ftp.jrc.es/EURdoc/eur22194en.pdf

Tukker, A., Poliakov, E., Heijungs, R., Hawkins, T., Neuwahl, F., Rueda-Cantuche, J. M., Giljum, S., Moll, S., Oosterhaven, J., & Bouwmeester, M. (2009). Towards a global multi-regional environmentally extended input-output database. *Ecological Economics, 68*(7), 1928-1937. doi:10.1016/j.ecolecon.2008.11.010

Tukker, A., Poliakov, E., Heijungs, R., Hawkins, T., Neuwahl, F., Rueda-Cantuche, J. M., Giljum, S., Moll, S., Oosterhaven, J., & Bouwmeester, M. (2009). *Towards a global multi-regional environmentally extended input-output database*. Paper presented at the Ecological Economics.

Turner, K., Lenzen, M., Wiedmann, T., & Barrett, J. (2007). Examining the global environmental impact of regional consumption activities - Part 1: A technical note on combining input-output and ecological footprint analysis. *Ecological Economics, 62*(1), 37-44. doi:10.1016/j.ecolecon.2006.12.002

UN. (1999). *Handbook of input-output table. Compilation and analysis.* New York:

UNEP. (2011). *Decoupling natural resource use and environmental impacts from economic growth, A Report of the Working Group on Decoupling to the International Resource Panel*

UNEP. (2014). *Decoupling 2: technologies, opportunities and policy options. A report of the Working Group on Decoupling to the International Resource Panel*

UNEP. (2015). *International Trade in Resources: A Biophysical Assessment, Report of the International Resource Panel*

Union, C. o. t. E. (2010). *Council conclusions on sustainable materials mangement and sutainable production and consumption: key contribution to a resource-efficient Europe*. Brussels:

Union, E. P. a. t. C. o. t. E. (2011). *Regulation No. 691/2011 of the European Parliament and of the counil of 6 July 2011 on European envionmental economic accounts*. Luxembourg: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2011:192:0001:0016:EN:PDF

United Nations, European Commission, Food and Agriculture Organization of the United Nations, Internationl Monetary Fund, Organisation for Economic Co-operation and Development, & The World Bank. (2014). *System of Environmental-Economic Accounting 2012 (SEEA) central framework* (Sales No. E.12.XVII.12)http://unstats.un.org/unsd/envaccounting/seeaRev/SEEA_CF_Final_en.pdf
van den Bergh, J. C. J. M., Verbruggen, H., & Janssen, M. (2002). Belastend materiaal. *Economsich Statische Berichten, 87*(4381), 783-785.
van der Voet, E., Kleijn, R., Huele, R., Ishikawa, M., & Verkuijlen, E. (2002). Predicting future emissions based on characteristics of stocks. *Ecological Economics, 41*(2), 223-234. doi:10.1016/S0921-8009(02)00028-9
van der Voet, E., van Oers, L., & Nikolic, I. (2004). Dematerialization: not just a matter of weight. *Journal of Industrial Ecology, 8*(4), 121-137. doi:10.1162/1088198043630432
Velazquez, E. (2006). An input-output model of water consumption: Analysing intersectoral water relationships in Andalusia. *Ecological Economics, 56*(2), 226-240. doi:10.1016/j.ecolecon.2004.09.026
Vercalsteren, A., Jansen, B., Moorkens, I., Van der Linden, A., & Vercaemst, P. (2008). *Opstellen en opvullen van de milieu-extensietabel van een Vlaams milieu input-outputmodel [in Dutch]*
Vercalsteren, A., Van der Linden, A., Dils, E., Geerken, T., Moorkens, I., Vanhulsel, M., & Vangeel, S. (2011). *Het Vlaams uitgebreid milieu input-outputmodel: update van de milieu-extensietabellen [in Dutch]*
Vercalsteren, A., Van der Linden, A., Geerken, T., & Christis, M. (2015). *Onderzoek naar beleidstoepassingen van milieu input-output tabellen. Studie uitgevoerd in opdracht van de Vlaamse Milieumaatschappij* (MIRA/2015/06). Mechelen:
Walz, R. (2011). Employment and structural impacts of material efficiency strategies: results from five caste studies. *Journal of Cleaner Production, 19*, 805-815. doi:10.1016.j.jclepro.2010.06.023
Wang, Y. F., Zhao, H. Y., Li, L. Y., Liu, Z., & Liang, S. (2013). Carbon dioxide emission drivers for a typical metropolis using input-output structural decomposition analysis. *Energy Policy, 58*, 312-318. doi:10.1016/j.enpol.2013.03.022
Wang, Z., Huang, K., Yang, S., & Yu, Y. (2013). An input-output approach to evaluate the water footprint and virual water trade of Beijing, China. *Journal of Cleaner Production, 42*, 172-179. doi:j.jclepro.2012.11.007
Watson, D., & Moll, S. (2008). Environmental benefits and disadvantages of economic specialisation within global markets, and implications for SCP monitoring. In T. Geerken, A. Tukker, C. Vezzoli, & F. Ceschin (Eds.), *Sustainable Consumption and Production: Framework for Action. 2nd Conference of the Sustainable Consumption Research Exchange (SCORE!) Network* (pp. 375-394). Brussels: Sustainalbe Consumption Research Exchanges (SCORE). (Reprinted from: Not in File).
WEF. (2014). *Towards the circular economy: accelerating the scale-up across global supply chains. Prepared in collaboration withthe Ellen MacArthur Foundation and McKinsey & Company*. Geneva:
Weidema, B. P., Wesnæs, M., Hermansen, J., Kristensen, T., & Halberg, N. (2008). *Environmental improvement potential of meat and dairy products*. Luxembourg:

Weinzettel, J., & Kovanda, J. (2011). Structural Decomposition Analysis of Raw Material Consumption. *Journal of Industrial Ecology, 15*(6), 893-907. doi:10.1111/j.1530-9290.2011.00378.x
Weisz, H., & Duchin, F. (2006). Physical and monetary input-output analysis: What makes the difference? *Ecological Economics, 57*(3), 534-541. doi:10.1016/j.ecolecon.2005.05.011
Weisz, H., Krausmann, F., Amann, C., Eisenmenger, N., Erb, K. H., Hubacek, K., & Fischer-Kowalski, M. (2006). The physical economy of the European Union: cross-country comparison and determinants of material consumption. *Ecological Economics, 58*(4), 676-698. doi:10.1016/j.ecolecon.2005.08.016
Weisz, H., Schandl, H., & Fischer-Kowalski, M. (1998). OMEN - An operating matrix for material interrelations between the economy and nature. How to make material balances consistent. In K. R., B. S., F.-K. M., & P. V. (Eds.), *Ecologizing societal metabolism: designing scenarios for sustainable materials management* (pp. 160-165). Leiden: Centre of Environmental Science. (Reprinted from: Not in File).
Wenz, L., Willner, S. N., Radebach, A., Bierkandt, R., Steckel, J. C., & Levermann, A. (2015). Regional and Sectoral Disaggregation of Multi-Regional Input-Output Tables - a Flexible Algorithm. *Economic Systems Research, 27*(2), 194-212. doi:10.1080/09535314.2014.987731
Wernick, I. K., & Irwin, F. H. (2005). *Material flows accounts. A tool for making environmental policy*. Washington, DC: http://pdf.wri.org/WRI_MFA_Policy.pdf
Wiebe, Bruckner, Giljum, Lutz, & Polzin. (2012a). Carbon and Materials Embodied in the International Trade of Emerging Economies A Multiregional Input-Output Assessment of Trends Between 1995 and 2005. *Journal of Industrial Ecology, 16*(4), 636-646. doi:10.1111/j.1530-9290.2012.00504.x
Wiebe, Bruckner, M., Giljum, & Lutz. (2012b). Calculating Energy-Related Co2 Emissions Embodied in International Trade Using a Global Input-Output Model. *Economic Systems Research, 24*(2), 113-139. doi:10.1080/09535314.2011.643293
Wiebe, K., & Yamano, N. (2016). *Estimating CO2 emissions embodied in final demand and trade using the OECD ICIO 2015: methodology and results*. Paris:
Wiedmann, T. (2009). A first empirical comparison of energy Footprints embodied in trade - MRIO versus PLUM. *Ecological Economics, 68*(7), 1975-1990. doi:10.1016/j.ecolecon.2008.06.023
Wiedmann, T. (2016). Impacts Embodied in Global Trade Flows. In R. Clift & A. Druckman (Eds.), *Taking Stock of Industrial Ecology* (pp. 159-180). Cham: Springer International Publishing.
Wiedmann, T., & Barrett, J. (2011). A greenhouse gas footprint analysis of UK Central Government, 1990-2008. *Environmental Science & Policy, 14*(8), 1041-1051. doi:10.1016/j.envsci.2011.07.005
Wiedmann, T., & Barrett, J. (2013). Policy-Relevant Applications of Environmentally Extended Mrio Databases - Experiences from the Uk. *Economic Systems Research, 25*(1), 143-156. doi:10.1080/09535314.2012.761596
Wiedmann, T., Lenzen, M., Turner, K., & Barrett, J. (2007). Examining the global environmental impact of regional consumption activities - Part 2: review of input-output models for the assessment of environmental impacts embodied in trade. *Ecological Economics, 61*, 15-26. doi:10.1016/j.ecolecon.2006.12.003

Wiedmann, T., Minx, J., Barrett, J., & Wackernagel, M. (2006). Allocating ecological footprints to final consumption categories with input-output analysis. *Ecological Economics, 56*(1), 28-48. doi:10.1016/j.ecolecon.2005.05.012

Wiedmann, T., Wood, R., Lenzen, M., Minx, J., Guan, D., & Barrett, J. (2008). *Development of an Embedded Carbon Emission Indicator*. London, UK:

Wiedmann, T., Wood, R., Minx, J. C., Lenzen, M., Guan, D. B., & Harris, R. (2010). A Carbon Footprint Time Series of the Uk - Results from a Multi-Region Input-Output Model. *Economic Systems Research, 22*(1), 19-42. doi:Pii 922183656

10.1080/09535311003612591

Wiedmann, T. O., Chen, G., & Barrett, J. (2015). The Concept of City Carbon Maps: A Case Study of Melbourne, Australia. *Journal of Industrial Ecology*, n/a-n/a. doi:10.1111/jiec.12346

Wiedmann, T. O., Schandl, H., Lenzen, M., Moran, D., Suh, S., West, J., & Kanemoto, K. (2015). The material footprint of nations. *Proceedings of the National Academy of Sciences of the United States of America, 112*(20), 6271-6276. doi:10.1073/pnas.1220362110

Wilting, H., Faber, A., & Idenburg, A. M. (2004). *Exploring technology scenarios with an input-output model.* Paper presented at the International Conference of Input-Output and General Equilibrium: Data Modeling and Policy Analysis, Brussels, Belgium.

Wolsky, A. M. (1984). Disaggregating Input-Output Models. *Review of Economics and Statistics, 66*(2), 283-291. doi:Doi 10.2307/1925829

Wood, R., Lenzen, M., & Foran, B. (2009). A Material History of Australia. *Journal of Industrial Ecology, 13*(6), 847-862. doi:10.1111/j.1530-9290.2009.00177.x

Wood, R., Stadler, K., Bulavskaya, T., Lutter, S., Giljum, S., de Koning, A., Kuenen, J., Schutz, H., Acosta-Fernandez, J., Usubiaga, A., Simas, M., Ivanova, O., Weinzettel, J., Schmidt, J. H., Merciai, S., & Tukker, A. (2015a). Global Sustainability Accounting-Developing EXIOBASE for Multi-Regional Footprint Analysis. *Sustainability, 7*(1), 138-163. doi:10.3390/su7010138

Wood, R., Stadler, K., Bulavskaya, T., Lutter, S., Giljum, S., de Koning, A., Kuenen, J., Schütz, H., Acosta-Fernandez, J., Usubiaga, A., Simas, M., Ivanova, O., Weinzettel, J., Schmidt, J. H., Merciai, S., & Tukker, A. (2015b). Global sustainability accounting-developing EXIOBASE for multi-regional footprint analysis. *Sustainability, 7*(1), 138-163. doi:10.3390/su7010138

WRI, & WBCSD. (2011). *Corporate value chain (scope 3) accounting and reporting standard* http://www.wri.org/sites/default/files/pdf/ghgp_corporate_value_chain_scope_3_standard.pdf

Wullt, J. (2008). *Supply and use tables - An indispensable tool for producing reliable national accounts* http://ec.europa.eu/eurostat/statistics-explained/index.php/Archive:Supply_and_use_tables_-_An_indispensable_tool_for_producing_reliable_national_accounts

WWF. (2008). *EU consumption, global pollution*

Wyckoff, A. W., & Roop, J. M. (1994). The Embodiment of Carbon in Imports of Manufactured Products - Implications for International Agreements on Greenhouse-Gas Emissions. *Energy Policy, 22*(3), 187-194. doi:Doi 10.1016/0301-4215(94)90158-9

Zbranek, J., & Sixta, J. (2011). *Analysis of the labour inputs in the input-output framework.* Paper presented at the International Input-Output Conference, Bratislava.
Zhang, Y., Yang, Z., & Yu, X. (2015). Urban Metabolism: A Review of Current Knowledge and Directions for Future Study. *Environmental science & technology, 49*(19), 11247-11263. doi:10.1021/acs.est.5b03060

Appendix 1: Flemish RIOT 2003 sector classification

SUTTAK 2003	DESCRIPTION [IN DUTCH]
01A1a	Akkerbouw
01A1b	Tuinbouw
01A1c	Veeteelt
02A1	Bosbouw, bosexploitatie en aanverwante diensten
05A1	Visserij en het kweken van vis en schaal- en schelpdieren
10A1	Winning van steenkool, bruinkool en turf
11A1	Winning van aardolie en aardgas en aanverwante diensten
12A1	Winning van uranium- en thoriumerts
13A1	Winning van metaalertsen
14A1	Overige winning van delfstoffen
15A1	Productie en verwerking van vlees en vleesproducten
15B1	Verwerking en conservering van vis en vervaardiging van visproducten
15C1	Verwerking en conservering van groenten en fruit
15D1	Vervaardiging van plantaardige en dierlijke oliën en vetten
15E1	Zuivelnijverheid
15F1 + 15G1 + 15H1	Maalderijen en vervaardiging van zetmeel en zetmeelproducten, diervoeders, brood, vers banketbakkerswerk, beschuit en koekjes
15I1	Vervaardiging van suiker, chocolade en suikerwerk
15J1	Vervaardiging van deegwaren, koffie en thee, en overige voedingsmiddelen -
15K1 + 15L1 + 16A1	Vervaardiging van dranken en tabaksproducten
17A1	Bewerken en spinnen van textielvezels, weven van textiel en textielveredeling -
17B1	Vervaardiging van geconfectioneerde artikelen van textiel excl. kleding, overige textielproducten, gebreide en gehaakte stoffen en artikelen
18A1	Vervaardiging van kleding en bontnijverheid
19A1	Leernijverheid en vervaardiging van schoeisel
20A1	Houtindustrie en vervaardiging van artikelen van hout, kurk, riet en vlechtwerk -
21A1	Papier- en kartonnijverheid
22A1	Uitgeverijen
22B1	Drukkerijen en aanverwante diensten en reproductie van opgenomen media
23A1	Vervaardiging van cokes, geraffineerde aardolieproducten en splijt- en kweekstoffen
24A1	Vervaardiging van chemische basisproducten
24B1	Vervaardiging van verdelgingsmiddelen en van chemische producten voor de landbouw
24C1	Vervaardiging van verf, vernis en drukinkt
24D1	Farmaceutische nijverheid
24E1	Vervaardiging van zeep, was- en poetsmiddelen, parfums en kosmetische artikelen
24F1 + 24G1	Vervaardiging van overige chemische producten en synthetische en kunstmatige vezels
25A1	Rubbernijverheid
25B1	Vervaardiging van producten van kunststof
26A1	Vervaardiging van glas en glaswerk
26B1 + 26D1	Vervaardiging van keramische producten en artikelen van beton, gips en cement, natuursteen en overige niet-metaalhoudende producten

26C1	Vervaardiging van cement, kalk en gips -
27A1	Vervaardiging van ijzer en staal, ferro-legeringen (EGKS), en buizen
27B1	Eerste verwerking van staal, productie van niet-EGKS-ferro legeringen en non-ferro metalen, en gieten van metalen
28A1	Vervaardiging van metalen constructiewerken, metalen recipiënten, radiatoren en ketels voor centrale verwarming, stoomketels; smeden, persen, stampen en profielwalsen van metaal
28B1	Oppervlaktebehandeling en bekleding van metaal; algemene metaalbewerking -
28C1	Vervaardiging van scharen, messen, bestekken, gereedschap en ijzerwaren, en overige producten van metaal
29A1	Vervaardiging van motoren en mechanisch drijfwerk, exclusief motoren voor luchtvaartuigen, motorvoertuigen en -rijwielen
29B1	Vervaardiging van machines voor algemeen gebruik
29C1	Vervaardiging van machines voor de landbouw en de bosbouw, en gereedschapswerktuigen
29D1	Vervaardiging van huishoudapparaten
30A1	Vervaardiging van kantoormachines en computers
31A1	Vervaardiging van elektromotoren en elektrische generatoren en transformatoren, schakel- en verdeelinrichtingen, en geïsoleerde kabels en draad
31B1	Vervaardiging van accumulatoren en elektrische batterijen, elektrische lampen en verlichtingsapparaten, en elektrische benodigdheden
32A1	Vervaardiging van audio-, video- en telecommunicatieapparatuur
33A1	Vervaardiging van medische apparatuur, van precisie- en optische instrumenten en van uurwerken
34A1	Vervaardiging en assemblage van auto's
34B1	Vervaardiging van carrosserieën, aanhangwagens en caravans, en van onderdelen en accessoires voor auto's
35A1	Scheepsbouw- en -reparatie, vervaardiging van rollend materieel voor spoor- en tramwegen en van lucht- en ruimtevaartuigen
35B1	Vervaardiging van motorrijwielen en rijwielen, en overige transportmiddelen, n.e.g
36A1	Vervaardiging van meubels
36B1	Bewerking van edelstenen en vervaardiging van juwelen
36C1	Vervaardiging van muziekinstrumenten, sportartikelen, spellen en speelgoed, en overige industrie
37A1	Recuperatie
40A1	Productie en distributie van elektriciteit, gas, stoom en warm water
41A1	Winning, zuivering en distributie van water
45A1	Het bouwrijp maken van terreinen
45B1	Algemene bouwkundige en civieltechnische werken, dakbedekking en bouw van dakconstructies
45C1	Aanleg van spoorwegen, wegen, straten, vliegvelden en sportaccommodaties, waterbouw, en overige werkzaamheden in de bouw
45D1	Bouwinstallatie
45E1	Afwerking van gebouwen, en verhuur van machines voor de bouwnijverheid met bedieningspersoneel
50A1	Handel in auto's, onderhoud en reparatie van auto's, handel in onderdelen en accessoires van auto's, handel in en reparatie van motorrijwielen
50B1	Kleinhandel in motorbrandstoffen
51A1	Groothandel en handelsbemiddeling
52A1	Kleinhandel, reparatie van consumentenartikelen
55A1	Hotels en overige accommodaties voor kortstondig verblijf, markt
55B1	Restaurants, drankgelegenheden, kantines en catering

60A1 + 60B1 + 60B3 + 60C1	Vervoer per spoor, personenvervoer te land volgens een dienstregeling, taxi’s, overig vervoer van personen te land, goederenvervoer over de weg en verhuisdiensten en vervoer via pijpleidingen
61A1	Zee- en kustvaart
61B1	Binnenvaart
62A1	Luchtvaart
63A1	Reisbureaus en touroperators
63B1	Vrachtbehandeling en opslag, overige vervoer ondersteunende activiteiten, organisatie van het vrachtvervoer, markt
63B3	Vervoer ondersteunende activiteiten, niet-markt
64A1 + 64B1	Postactiviteiten en telecommunicatie
65A2	Financiële instellingen
66A2	Verzekeringswezen
67A1	Hulpbedrijven i.v.m. financiële instellingen en het verzekeringswezen
70A1	Verhuur en handel in onroerende goederen
71A1	Verhuur van auto's en overige transportmiddelen
71B1	Verhuur van machines en werktuigen, en overige roerende goederen
72A1	Informatica en aanverwante activiteiten
73A1	Speur- en ontwikkelingswerk, markt
73A5	Speur- en ontwikkelingswerk, niet-markt
74A1	Rechtskundige dienstverlening, en accountants, boekhouders en belastingconsulenten, markt- en opinieonderzoekbureaus
74B1	Adviesbureaus op het gebied van bedrijfsvoering en beheer, managementactiviteiten van holdings en coördinatiecentra
74C1	Technisch advies, architecten en ingenieurs, technische testen en analyses -
74D1	Reclamewezen
74E1	Selectie en terbeschikkingstelling van personeel
74F1	Opsporings- en beveiligingsdiensten, industriële reiniging, en diverse dienstverlening aan bedrijven
75A3 + 75B3	Openbaar bestuur, excl. verplichte sociale verzekering
75C3	Verplichte sociale verzekering
80A1	Onderwijs, markt
80A3	Openbaar onderwijs
80A5	Onderwijs, ander niet-markt
85A1 + 85B1	Gezondheidszorg en veterinaire diensten
85C1	Maatschappelijke dienstverlening, markt
85C5	Maatschappelijke dienstverlening, niet-markt
90A1	Afvalwater- en afvalverzameling; straatreiniging, markt
90A3	Afvalwater- en afvalverzameling; straatreiniging, niet-markt
91A1	Diverse verenigingen, markt
91A5	Diverse verenigingen, niet-markt
92A1	Activiteiten op het gebied van film en video, radio en televisie, markt
92A3	Activiteiten op het gebied van film en video, radio en televisie, niet-markt
92B1	Overige activiteiten op het gebied van amusement, markt
92B5	Overige activiteiten op het gebied van amusement, niet-markt
92C1	Persagentschappen, en overige culturele activiteiten, markt
92C5	Overige culturele activiteiten, niet markt
92D1	Sport en overige recreatie, markt
92D5	Sport, niet markt
93A1	Overige diensten
95A4	Particuliere huishoudens met werknemers

Appendix 2: Flemish RIOT 2007 sector classification

SUTTAK 2003	DESCRIPTION [IN DUTCH]
01a	Landbouw, jacht en aanverwante diensten - akkerbouw
01b	Landbouw, jacht en aanverwante diensten – tuinbouw
01c	Landbouw, jacht en aanverwante diensten - veeteelt
02	Bosbouw, bosexploitatie en aanverwante diensten
05	Visserij en het kweken van vis en schaal- en schelpdieren
10	Winning van steenkool, bruinkool en turf
11	Winning van aardolie en aardgas en aanverwante diensten
12	Winning van uranium- en thoriumerts
13	Winning van metaalertsen
14	Overige winning van delfstoffen
15.1	Productie en verwerking van vlees en vleesproducten
15.2 + 15.85 t/m 15.89	Verwerking en conservering van vis en vervaardiging van visproducten; Vervaardiging van deegwaren, koffie en thee, en overige voedingsmiddelen
15.3	Verwerking en conservering van groenten en fruit
15.4	Vervaardiging van plantaardige en dierlijke oliën en vetten
15.5	Zuivelnijverheid
15.6 + 15.7	Maalderijen en vervaardiging van zetmeel en zetmeelproducten, diervoeders,
15.81 + 15.82	Brood, vers banketbakkerswerk, beschuit en koekjes
15.83 + 15.84	Vervaardiging van suiker, chocolade en suikerwerk
15.9	Vervaardiging van dranken
16	Vervaardiging van tabaksproducten
17.1 t/m 17.3	Bewerken en spinnen van textielvezels, weven van textiel en textielveredeling -
17.4 t/m 17.7	Vervaardiging van geconfectioneerde artikelen van textiel excl. kleding, overige textielproducten, gebreide en gehaakte stoffen en artikelen
18	Vervaardiging van kleding en bontnijverheid
19	Leernijverheid en vervaardiging van schoeisel
20	Houtindustrie en vervaardiging van artikelen van hout, kurk, riet en vlechtwerk -
21	Papier- en kartonnijverheid
22.1	Uitgeverijen
22.2 t/m 22.3	Drukkerijen en aanverwante diensten en reproductie van opgenomen media
23	Vervaardiging van cokes, geraffineerde aardolieproducten en splijt- en kweekstoffen
24.1	Vervaardiging van chemische basisproducten
24.2 + 24.3	Vervaardiging van verdelgingsmiddelen en van chemische producten voor de landbouw ;verf, vernis en drukinkt
24.4	Farmaceutische nijverheid
24.5	Vervaardiging van zeep, was- en poetsmiddelen, parfums en kosmetische artikelen
24.6	Vervaardiging van overige chemische producten
24.7	Vervaardiging van synthetische en kunstmatige vezels
25.1	Rubbernijverheid
25.2	Vervaardiging van producten van kunststof
26.1	Vervaardiging van glas en glaswerk
26.2 t/m 26.5	Vervaardiging van keramische producten en cement, kalk en gips
26.6 t/m 26.8	Vervaardiging van artikelen van beton, gips en cement, natuursteen en overige niet-metaalhoudende producten

27.1 t/m 27.2	Vervaardiging van ijzer en staal, ferro-legeringen (EGKS), en buizen
27.3 t/m 27.5	Eerste verwerking van staal, productie van niet-EGKS-ferrolegeringen en non-ferro metalen, en gieten van metalen
28.1 t/m 28.4	Vervaardiging van metalen constructiewerken, metalen recipiënten, radiatoren en ketels voor centrale verwarming, stoomketels; smeden, persen, stampen en profielwalsen van metaal
28.5	Oppervlaktebehandeling en bekleding van metaal; algemene metaalbewerking -
28.6 t/m 28.7	Vervaardiging van scharen, messen, bestekken, gereedschap en ijzerwaren, en overige producten van metaal
29.1	Vervaardiging van motoren en mechanisch drijfwerk, exclusief motoren voor luchtvaartuigen, motorvoertuigen en -rijwielen
29.2	Vervaardiging van machines voor algemeen gebruik
29.3 t/m 29.6	Vervaardiging van machines voor de landbouw en de bosbouw, en gereedschapswerktuigen
29.7	Vervaardiging van huishoudapparaten
30	Vervaardiging van kantoormachines en computers
31.1 t/m 31.3	Vervaardiging van elektromotoren en elektrische generatoren en transformatoren, schakel- en verdeelinrichtingen, en geïsoleerde kabels en draad
31.4 t/m 31.6	Vervaardiging van accumulatoren en elektrische batterijen, elektrische lampen en verlichtingsapparaten, en elektrische benodigdheden
32	Vervaardiging van audio-, video- en telecommunicatieapparatuur
33	Vervaardiging van medische apparatuur, van precisie- en optische instrumenten en van uurwerken
34.1	Vervaardiging en assemblage van auto's
34.2 t/m 34.3	Vervaardiging van carrosserieën, aanhangwagens en caravans, en van onderdelen en accessoires voor auto's
35.1 t/m 35.3	Scheepsbouw- en -reparatie, vervaardiging van rollend materieel voor spoor- en tramwegen en van lucht- en ruimtevaartuigen
35.4 t/m 35.5	Vervaardiging van motorrijwielen en rijwielen, en overige transportmiddelen, n.e.g
36.1	Vervaardiging van meubels
36.2	Bewerking van edelstenen en vervaardiging van juwelen
36.3 t/m 36.6	Vervaardiging van muziekinstrumenten, sportartikelen, spellen en speelgoed, en overige industrie
37	Recuperatie
40	Productie en distributie van elektriciteit, gas, stoom en warm water
41	Winning, zuivering en distributie van water
45.1	Het bouwrijp maken van terreinen
45.21 t/m 45.22	Algemene bouwkundige en civieltechnische werken, dakbedekking en bouw van dakconstructies
45.23 t/m 45.25	Aanleg van spoorwegen, wegen, straten, vliegvelden en sportaccommodaties, waterbouw, en overige werkzaamheden in de bouw
45.3	Bouwinstallatie
45.4 t/m 45.5	Afwerking van gebouwen, en verhuur van machines voor de bouwnijverheid met bedieningspersoneel
50.1 t/m 50.4	Handel in auto's, onderhoud en reparatie van auto's, handel in onderdelen en accessoires van auto's, handel in en reparatie van motorrijwielen
50.5	Kleinhandel in motorbrandstoffen
51	Groothandel en handelsbemiddeling
52	Kleinhandel, reparatie van consumentenartikelen
55.1 t/m 55.2	Hotels en overige accommodaties voor kortstondig verblijf, markt
55.3 t/m 55.5	Restaurants, drankgelegenheden, kantines en catering
60.1 t/m 60.23	Vervoer per spoor, personenvervoer te land volgens een dienstregeling, taxi’s, overig vervoer van personen te land

60.24 + 60.3	Goederenvervoer over de weg en verhuisdiensten; vervoer via pijpleidingen
61.1	Zee- en kustvaart
61.2	Binnenvaart
62	Luchtvaart
63.3	Reisbureaus en touroperators
63.1 + 63.2(partim). 63.4	Vrachtbehandeling en opslag, overige vervoerondersteunende activiteiten, organisatie van het vrachtvervoer, markt
63.2 (partim)	Vervoerondersteunende activiteiten, niet-markt
64	Postactiviteiten en telecommunicatie
65	Financiële instellingen
66	Verzekeringswezen
67	Hulpbedrijven i.v.m. financiële instellingen en het verzekeringswezen
70	Verhuur en handel in onroerende goederen
71.1 t/m 71.2	Verhuur van auto's en overige transportmiddelen
71.3 t/m 71.4	Verhuur van machines en werktuigen, en overige roerende goederen
72	Informatica en aanverwante activiteiten
73.1 (partim). 73.2.(partim)	Speur- en ontwikkelingswerk, markt
73.1 (partim). 73.2.(partim)	Speur- en ontwikkelingswerk, niet-markt
74.11 t/m 74.13	Rechtskundige dienstverlening, en accountants, boekhouders en belastingconsulenten, markt- en opinieonderzoekbureau 's
74.14 t/m 74.15	Adviesbureaus op het gebied van bedrijfsvoering en beheer, managementactiviteiten van holdings en coördinatiecentra
74.2 t/m 74.3	Technisch advies, architecten en ingenieurs, technische testen en analyses -
74.4	Reclamewezen
74.5	Selectie en terbeschikkingstelling van personeel
74.6 t/m 74.8	Opsporings- en beveiligingsdiensten, industriële reiniging, en diverse dienstverlening aan bedrijven
75.1 t/m 75.2	Openbaar bestuur, excl. verplichte sociale verzekering
75.3	Verplichte sociale verzekering
80 (partim)	Onderwijs, markt
80 (partim)	Openbaar onderwijs
80 (partim)	Onderwijs, ander niet-markt
85.1	Gezondheidszorg
85.2	Veterinaire diensten
85.3 (partim)	Maatschappelijke dienstverlening, markt
85.3 (partim)	Maatschappelijke dienstverlening, niet-markt
90 (partim)	Afvalwater- en afvalverzameling; straatreiniging, markt
90 (partim)	Afvalwater- en afvalverzameling; straatreiniging, niet-markt
91.11 + 91.12 (partim)	Diverse verenigingen, markt
91.12 (partim) + 91.2 t/m 91.3	Diverse verenigingen, niet-markt
92.1(partim) t/m 92.2 (partim)	Activiteiten op het gebied van film en video, radio en televisie, markt
92.1(partim) t/m 92.2 (partim)	Activiteiten op het gebied van film en video, radio en televisie, niet-markt
92.3 (partim)	Overige activiteiten op het gebied van amusement, markt
92.3 (partim)	Overige activiteiten op het gebied van amusement, niet-markt
92.4 + 92.5 (partim)	Persagentschappen, en overige culturele activiteiten, markt
92.5 (partim)	Overige culturele activiteiten, niet markt
92.6 (partim) + 92.7	Sport en overige recreatie, markt
92.6 (partim)	Sport, niet markt

93	Overige diensten
95	Particuliere huishoudens met werknemers

Appendix 3: Flemish RIOT 2010 sector classification

SUTTAK 2008	DESCRIPTION [IN DUTCH]
01A_1	Teelt van akkerbouwgewassen plus suikerbieten en suikerbietenzaad
01A_2	Teelt van tuinbouwgewassen, planten & fruit
01A_3	Veeteelt, diensten ivm veeteelt behalve veterinaire diensten & jacht
02A	Bosbouw en de exploitatie van bossen
03A	Visserij en aquacultuur
05A	Winning van steenkool en bruinkool
06A	Winning van aardolie en aardgas
07A	Winning van metaalertsen
08A	Overige winning van delfstoffen
09A	Ondersteunende activiteiten in verband met de mijnbouw
10A	Verwerking en conservering van vlees en vervaardiging van vleesproducten
10B	Verwerking en conservering van vis en van schaal- en weekdieren
10C	Verwerking en conservering van groenten en fruit
10D	Vervaardiging van plantaardige en dierlijke oliën en vetten
10E	Vervaardiging van zuivelproducten
10F	Vervaardiging van maalderijproducten, zetmeel en zetmeelproducten
10G	Vervaardiging van bakkerijproducten en deegwaren
10H	Vervaardiging van suiker, cacao, chocolade en suikerwerk
10I	Vervaardiging van andere voedingsmiddelen
10J	Vervaardiging van diervoeders
11A + 11B	Vervaardiging van dranken
12A	Vervaardiging van tabaksproducten
13A	Bewerken en spinnen van textielvezels, weven van textiel en textielveredeling
13B	Vervaardiging van andere textielproducten
14A	Vervaardiging van kleding
15A	Vervaardiging van leer en van producten van leer
16A	Houtindustrie en vervaardiging van artikelen van hout en van kurk, exclusief meubelen; vervaardiging van artikelen van riet en van vlechtwerk
17A	Vervaardiging van papier en papierwaren
18A	Drukkerijen, reproductie van opgenomen media
19A	Vervaardiging van cokes en van geraffineerde aardolieproducten
20A + 20B	Vervaardiging van chemische basisproducten, kunstmeststoffen en stikstofverbindingen en van kunststoffen en synthetische rubber in primaire vormen, excl. vervaardiging van andere anorganische chemische basisproducten
20C+20F	Vervaardiging van verdelgingsmiddelen en van andere chemische producten voor de landbouw; Vervaardiging van andere chemische producten
20D	Vervaardiging van verf, vernis e.d., drukinkt en mastiek
20E	Vervaardiging van zeep, wasmiddelen, poets- en reinigingsmiddelen, parfums en toiletartikelen
20G	Vervaardiging van synthetische en kunstmatige vezels
21A	Vervaardiging van farmaceutische grondstoffen en producten
22A+22B	Vervaardiging van producten van rubber en kunststof
23A	Vervaardiging van glas en glaswerk
23B +23C +23D	Vervaardiging van vuurvaste producten; Vervaardiging van producten voor de bouw, van klei; Vervaardiging van andere keramische producten; Vervaardiging van cement, kalk en gips;

	Vervaardiging van artikelen van beton, cement en gips; Houwen, bewerken en afwerken van natuursteen; Vervaardiging van andere schuurmiddelen en niet-metaalhoudende minerale producten n.e.g.
24A + 24B	Vervaardiging van ijzer en staal en van ferrolegeringen; Vervaardiging van buizen, pijpen, holle profielen en fittings daarvoor, van staal; Vervaardiging van andere producten van de eerste verwerking van staal; Productie van edele metalen en van andere non-ferrometalen; Gieten van metalen
25A	Vervaardiging van metalen constructiewerken; Vervaardiging van tanks, reservoirs en bergingsmiddelen, van metaal; Vervaardiging van stoomketels, exclusief warmwaterketels voor centrale verwarming; Vervaardiging van wapens en munitie; Smeden, persen, stampen en profielwalsen van metaal; poedermetallurgie
25B	Oppervlaktebehandeling van metalen; verspanend bewerken van metalen
25C	Vervaardiging van scharen, messen, bestekken, gereedschap en ijzerwaren; Vervaardiging van andere producten van metaal
26A + 26C	Vervaardiging van elektronische onderdelen en printplaten; vervaardiging van computers en randapparatuur; Vervaardiging van meet-, controle- en navigatie-instrumenten en -apparatuur; vervaardiging van uurwerken, bestralingsapparatuur en van elektromedische en elektrotherapeutische apparatuur, optische instrumenten en van foto- en filmapparatuur, magnetische en optische media
26B	Vervaardiging van communicatieapparatuur; vervaardiging van consumentenelektronica
27A	Vervaardiging van elektromotoren, van elektrische generatoren en transformatoren en van schakel- en verdeelinrichtingen, batterijen en accumulatoren, kabels en van schakelaars, stekkers, stopcontacten e. d.; Vervaardiging van lampen en verlichtingsapparaten
27B	Vervaardiging van huishoudapparaten, andere elektrische apparatuur
28A + 28B	Vervaardiging van machines en apparaten voor algemeen gebruik; Vervaardiging van machines en werktuigen voor de landbouw en de bosbouw; Vervaardiging van niet-verspanende machines voor de metaalbewerking en van gereedschapswerktuigen; Vervaardiging van andere machines, apparaten en werktuigen voor specifieke doeleinden
29A	Vervaardiging en assemblage van motorvoertuigen
29B	Vervaardiging van carrosserieën voor motorvoertuigen; vervaardiging van aanhangwagens en opleggers; Vervaardiging van delen en toebehoren voor motorvoertuigen
30A + 30B	Scheepsbouw; Vervaardiging van rollend materieel voor spoorwegen
30C	Vervaardiging van lucht- en ruimtevaartuigen en van toestellen in verband daarmee
30D	Vervaardiging van militaire gevechtsvoertuigen; Vervaardiging van transportmiddelen, n.e.g.
31A	Vervaardiging van meubelen
32A	Bewerken van edelstenen en vervaardiging van sieraden en dergelijke artikelen
32B	Vervaardiging van muziekinstrumenten, sportartikelen, spellen en speelgoed, medische en tandheelkundige instrumenten en benodigdheden, en overige industrie
33A	Reparatie en installatie van machines en apparaten
35A + 35B	Productie en distributie van elektriciteit, stoom en gekoelde lucht; Productie en distributie van gas
36A	Winning, behandeling en distributie van water
37A	Afvalwaterafvoer
38A	Inzameling van afval; Verwerking en verwijdering van afval

38B	Terugwinning
39A	Sanering en ander afvalbeheer
41A	Bouw van gebouwen; ontwikkeling van bouwprojecten
42A	Weg- en waterbouw
43A	Slopen; Bouwrijp maken van terreinen; Proefboren en boren
43B	Elektrische installatie, loodgieterswerk en overige bouwinstallatie
43C	Afwerking van gebouwen
43D	Overige gespecialiseerde bouwactiviteiten
45A	Groot- en detailhandel in en onderhoud en reparatie van motorvoertuigen en motorfietsen
46A	Groothandel en handelsbemiddeling, met uitzondering van de handel in motorvoertuigen en motorfietsen en in vaste, vloeibare en gasvormige brandstoffen en aanverwante producten
46B	Groothandel in vaste, vloeibare en gasvormige brandstoffen en aanverwante producten
47A	Detailhandel, met uitzondering van de handel in auto's en motorfietsen en in motorbrandstoffen
47B	Detailhandel in motorbrandstoffen in gespecialiseerde winkels
49A + 49B	Vervoer per spoor; Overig personenvervoer te land
49C	Goederenvervoer over de weg en verhuisbedrijven; vervoer via pijpleidingen
50A + 50B	Personen- en goederenvervoer over zee- en kustwateren; Personen- en goederenvervoer over binnenwateren
51A	Luchtvaart
52A	Opslag en vervoerondersteunende activiteiten
53A +61A	Posterijen en koeriers; Telecommunicatie
55A	Verschaffen van accommodatie
56A	Eet- en drinkgelegenheden
58A	Uitgeverijen
59A	Productie van films en video- en televisieprogramma's, maken van geluidsopnamen en uitgeverijen van muziekopnamen
60A	Programmeren en uitzenden van radio- en televisieprogramma's
62A	Ontwerpen en programmeren van computerprogramma's, computerconsultancy-activiteiten en aanverwante activiteiten
63A	Dienstverlenende activiteiten op het gebied van informatie
64A + 64B +64C + 64D	Geldscheppende financiële instellingen; Holdings; Beleggingstrusts en -fondsen en vergelijkbare financiële instellingen; Overige financiële dienstverlening, exclusief verzekeringen en pensioenfondsen
65A	Verzekeringen, herverzekeringen en pensioenfondsen, exclusief verplichte sociale verzekeringen
66A + 66B + 66C	Ondersteunende activiteiten in verband met financiële diensten, exclusief verzekeringen en pensioenfondsen; Ondersteunende activiteiten in verband met verzekeringen en pensioenfondsen; Vermogensbeheer
68A	Exploitatie van en handel in onroerend goed uitgez. de huurwaarde van door de eigenaar bewoonde bewoningen
68B	huurwaarde van door de eigenaar bewoonde bewoningen
69A	Rechtskundige en boekhoudkundige dienstverlening
70A	Activiteiten van hoofdkantoren; adviesbureaus op het gebied van bedrijfsbeheer
71A	Architecten en ingenieurs; technische testen en toetsen
72A	Speur- en ontwikkelingswerk op wetenschappelijk gebied
73A	Reclamewezen en marktonderzoek
74A	Overige gespecialiseerde wetenschappelijke en technische activiteiten
75A	Veterinaire diensten
77A	Verhuur en lease van motorvoertuigen
77B	Verhuur en lease van consumentenartikelen
77C	Verhuur en lease van andere machines en werktuigen en andere materiële goederen; Lease van intellectuele eigendom en

	vergelijkbare producten, met uitzondering van werken onder auteursrecht
78A	Terbeschikkingstelling van personeel
79A	Reisbureaus, reisorganisatoren, reserveringsbureaus en aanverwante activiteiten
80A	Beveiligings- en opsporingsdiensten
81A	Diverse ondersteunende activiteiten ten behoeve van voorzieningen; landschapsverzorging
81B	Reiniging
82A	Administratieve en ondersteunende activiteiten ten behoeve van kantoren en overige zakelijke activiteiten
84A + 84B + 84C	Openbaar bestuur, defensie, sociale zekerheid
85A	Onderwijs
86A	Ziekenhuizen
86B	Praktijken van artsen
86C	Tandartspraktijken
86D	Overige menselijke gezondheidszorg
87A	Maatschappelijke dienstverlening met huisvesting
88A	Maatschappelijke dienstverlening zonder huisvesting
90A	Creatieve activiteiten, kunst en amusement
91A	Bibliotheken, archieven, musea en overige culturele activiteiten
92A	Loterijen en kansspelen
93A	Sport, ontspanning en recreatie
94A	Verenigingen
95A	Reparatie van computers en consumentenartikelen
96A	Overige persoonlijke diensten
97A	Huishoudens als werkgever van huishoudelijk personeel

Appendix 4: EXIOBASE 1 sector classifications

No.	Description
1	Cultivation of paddy rice
2	Cultivation of wheat
3	Cultivation of cereal grains nec
4	Cultivation of vegetables, fruit, nuts
5	Cultivation of oil seeds
6	Cultivation of sugar cane, sugar beet
7	Cultivation of plant-based fibers
8	Cultivation of crops nec
9	Cattle farming
10	Pigs farming
11	Poultry farming
12	Meat animals nec
13	Animal products nec
14	Raw milk
15	Wool, silk-worm cocoons
16	Forestry, logging and related service activities
17	Fishing, operating of fish hatcheries and fish farms; service activities incidental to fishing
18	Mining of coal and lignite; extraction of peat
19	Extraction of crude petroleum and services related to crude oil extraction, excluding surveying
20	Extraction of natural gas and services related to natural gas extraction, excluding surveying
21	Extraction, liquefaction, and regasification of other petroleum and gaseous materials
22	Mining of uranium and thorium ores
23	Mining of iron ores
24	Mining of copper ores and concentrates
25	Mining of nickel ores and concentrates
26	Mining of aluminium ores and concentrates
27	Mining of precious metal ores and concentrates
28	Mining of lead, zinc and tin ores and concentrates
29	Mining of other non-ferrous metal ores and concentrates
30	Quarrying of stone
31	Quarrying of sand and clay
32	Mining of chemical and fertilizer minerals, production of salt, other mining and quarrying n.e.c.
33	Processing of meat cattle
34	Processing of meat pigs
35	Processing of meat poultry
36	Production of meat products nec
37	Processing vegetable oils and fats
38	Processing of dairy products
39	Processed rice
40	Sugar refining
41	Processing of Food products nec
42	Manufacture of beverages
43	Manufacture of fish products
44	Manufacture of tobacco products
45	Manufacture of textiles
46	Manufacture of wearing apparel; dressing and dyeing of fur
47	Tanning and dressing of leather; manufacture of luggage, handbags, saddlery, harness and footwear
48	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials

49	Manufacture of pulp, paper and paper products
50	Publishing, printing and reproduction of recorded media
51	Manufacture of coke oven products
52	Manufacture of motor spirit (gasoline)
53	Manufacture of kerosene, including kerosene type jet fuel
54	Manufacture of gas oils
55	Manufacture of fuel oils n.e.c.
56	Manufacture of petroleum gases and other gaseous hydrocarbons, except natural gas
57	Manufacture of other petroleum products
58	Processing of nuclear fuel
59	Manufacture of chemicals and chemical products
60	Manufacture of rubber and plastic products
61	Manufacture of glass and glass products
62	Manufacture of ceramic goods
63	Manufacture of bricks, tiles and construction products, in baked clay
64	Manufacture of cement, lime and plaster
65	Manufacture of other non-metallic mineral products n.e.c.
66	Manufacture of basic iron and steel and of ferro-alloys and first products thereof
67	Precious metals production
68	Aluminium production
69	Lead, zinc and tin production
70	Copper production
71	Other non-ferrous metal production
72	Casting of metals
73	Manufacture of fabricated metal products, except machinery and equipment
74	Manufacture of machinery and equipment n.e.c.
75	Manufacture of office machinery and computers
76	Manufacture of electrical machinery and apparatus n.e.c.
77	Manufacture of radio, television and communication equipment and apparatus
78	Manufacture of medical, precision and optical instruments, watches and clocks
79	Manufacture of motor vehicles, trailers and semi-trailers
80	Manufacture of other transport equipment
81	Manufacture of furniture; manufacturing n.e.c.
82	Recycling of metal waste and scrap
83	Recycling of non-metal waste and scrap
84	Production of electricity by coal
85	Production of electricity by gas
86	Production of electricity by nuclear
87	Production of electricity by hydro
88	Production of electricity by wind
89	Production of electricity nec, including biomass and waste
90	Transmission of electricity
91	Distribution and trade of electricity
92	Manufacture of gas; distribution of gaseous fuels through mains
93	Steam and hot water supply
94	Collection, purification and distribution of water
95	Construction
96	Sale, maintenance, repair of motor vehicles, motor vehicles parts, motorcycles, motor cycles parts and accessoiries
97	Retail sale of automotive fuel
98	Wholesale trade and commission trade, except of motor vehicles and motorcycles
99	Retail trade, except of motor vehicles and motorcycles; repair of personal and household goods
100	Hotels and restaurants
101	Transport via railways
102	Other land transport
103	Transport via pipelines
104	Sea and coastal water transport
105	Inland water transport

106	Air transport
107	Supporting and auxiliary transport activities; activities of travel agencies
108	Post and telecommunications
109	Financial intermediation, except insurance and pension funding
110	Insurance and pension funding, except compulsory social security
111	Activities auxiliary to financial intermediation
112	Real estate activities
113	Renting of machinery and equipment without operator and of personal and household goods
114	Computer and related activities
115	Research and development
116	Other business activities
117	Public administration and defence; compulsory social security
118	Education
119	Health and social work
120	Collection and treatment of sewage
121	Collection of waste
122	Incineration of waste
123	Landfill of waste
124	Sanitation, remediation and similar activities
125	Activities of membership organisation n.e.c.
126	Recreational, cultural and sporting activities
127	Other service activities
128	Private households with employed persons
129	Extra-territorial organizations and bodies

Appendix 5: EXIOBASE 2 sector classification

No.	Description
1	Cultivation of paddy rice
2	Cultivation of wheat
3	Cultivation of cereal grains nec
4	Cultivation of vegetables, fruit, nuts
5	Cultivation of oil seeds
6	Cultivation of sugar cane, sugar beet
7	Cultivation of plant-based fibers
8	Cultivation of crops nec
9	Cattle farming
10	Pigs farming
11	Poultry farming
12	Meat animals nec
13	Animal products nec
14	Raw milk
15	Wool, silk-worm cocoons
16	Manure treatment (conventional), storage and land application
17	Manure treatment (biogas), storage and land application
18	Forestry, logging and related service activities
19	Fishing, operating of fish hatcheries and fish farms; service activities incidental to fishing
20	Mining of coal and lignite; extraction of peat
21	Extraction of crude petroleum and services related to crude oil extraction, excluding surveying
22	Extraction of natural gas and services related to natural gas extraction, excluding surveying
23	Extraction, liquefaction, and regasification of other petroleum and gaseous materials
24	Mining of uranium and thorium ores
25	Mining of iron ores
26	Mining of copper ores and concentrates
27	Mining of nickel ores and concentrates
28	Mining of aluminium ores and concentrates
29	Mining of precious metal ores and concentrates
30	Mining of lead, zinc and tin ores and concentrates
31	Mining of other non-ferrous metal ores and concentrates
32	Quarrying of stone
33	Quarrying of sand and clay
34	Mining of chemical and fertilizer minerals, production of salt, other mining and quarrying n.e.c.
35	Processing of meat cattle
36	Processing of meat pigs
37	Processing of meat poultry
38	Production of meat products nec
39	Processing vegetable oils and fats
40	Processing of dairy products
41	Processed rice
42	Sugar refining
43	Processing of Food products nec
44	Manufacture of beverages
45	Manufacture of fish products
46	Manufacture of tobacco products
47	Manufacture of textiles
48	Manufacture of wearing apparel; dressing and dyeing of fur
49	Tanning and dressing of leather; manufacture of luggage, handbags, saddlery, harness and footwear

50	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials
51	Re-processing of secondary wood material into new wood material
52	Pulp
53	Re-processing of secondary paper into new pulp
54	Paper
55	Publishing, printing and reproduction of recorded media
56	Manufacture of coke oven products
57	Petroleum Refinery
58	Processing of nuclear fuel
59	Plastics, basic
60	Re-processing of secondary plastic into new plastic
61	N-fertiliser
62	P- and other fertiliser
63	Chemicals nec
64	Manufacture of rubber and plastic products
65	Manufacture of glass and glass products
66	Re-processing of secondary glass into new glass
67	Manufacture of ceramic goods
68	Manufacture of bricks, tiles and construction products, in baked clay
69	Manufacture of cement, lime and plaster
70	Re-processing of ash into clinker
71	Manufacture of other non-metallic mineral products n.e.c.
72	Manufacture of basic iron and steel and of ferro-alloys and first products thereof
73	Re-processing of secondary steel into new steel
74	Precious metals production
75	Re-processing of secondary preciuos metals into new preciuos metals
76	Aluminium production
77	Re-processing of secondary aluminium into new aluminium
78	Lead, zinc and tin production
79	Re-processing of secondary lead into new lead
80	Copper production
81	Re-processing of secondary copper into new copper
82	Other non-ferrous metal production
83	Re-processing of secondary other non-ferrous metals into new other non-ferrous metals
84	Casting of metals
85	Manufacture of fabricated metal products, except machinery and equipment
86	Manufacture of machinery and equipment n.e.c.
87	Manufacture of office machinery and computers
88	Manufacture of electrical machinery and apparatus n.e.c.
89	Manufacture of radio, television and communication equipment and apparatus
90	Manufacture of medical, precision and optical instruments, watches and clocks
91	Manufacture of motor vehicles, trailers and semi-trailers
92	Manufacture of other transport equipment
93	Manufacture of furniture; manufacturing n.e.c.
94	Recycling of waste and scrap
95	Recycling of bottles by direct reuse
96	Production of electricity by coal
97	Production of electricity by gas
98	Production of electricity by nuclear
99	Production of electricity by hydro
100	Production of electricity by wind
101	Production of electricity by petroleum and other oil derivatives
102	Production of electricity by biomass and waste
103	Production of electricity by solar photovoltaic
104	Production of electricity by solar thermal

105 Production of electricity by tide, wave, ocean
106 Production of electricity by Geothermal
107 Production of electricity nec
108 Transmission of electricity
109 Distribution and trade of electricity
110 Manufacture of gas; distribution of gaseous fuels through mains
111 Steam and hot water supply
112 Collection, purification and distribution of water
113 Construction
114 Re-processing of secondary construction material into aggregates
115 Sale, maintenance, repair of motor vehicles, motor vehicles parts, motorcycles, motor cycles parts and accessoiries
116 Retail sale of automotive fuel
117 Wholesale trade and commission trade, except of motor vehicles and motorcycles
118 Retail trade, except of motor vehicles and motorcycles; repair of personal and household goods
119 Hotels and restaurants
120 Transport via railways
121 Other land transport
122 Transport via pipelines
123 Sea and coastal water transport
124 Inland water transport
125 Air transport
126 Supporting and auxiliary transport activities; activities of travel agencies
127 Post and telecommunications
128 Financial intermediation, except insurance and pension funding
129 Insurance and pension funding, except compulsory social security
130 Activities auxiliary to financial intermediation
131 Real estate activities
132 Renting of machinery and equipment without operator and of personal and household goods
133 Computer and related activities
134 Research and development
135 Other business activities
136 Public administration and defence; compulsory social security
137 Education
138 Health and social work
139 Incineration of waste: Food
140 Incineration of waste: Paper
141 Incineration of waste: Plastic
142 Incineration of waste: Metals and Inert materials
143 Incineration of waste: Textiles
144 Incineration of waste: Wood
145 Incineration of waste: Oil/Hazardous waste
146 Biogasification of food waste, incl. land application
147 Biogasification of paper, incl. land application
148 Biogasification of sewage slugde, incl. land application
149 Composting of food waste, incl. land application
150 Composting of paper and wood, incl. land application
151 Waste water treatment, food
152 Waste water treatment, other
153 Landfill of waste: Food
154 Landfill of waste: Paper
155 Landfill of waste: Plastic
156 Landfill of waste: Inert/metal/hazardous
157 Landfill of waste: Textiles
158 Landfill of waste: Wood
159 Activities of membership organisation n.e.c.
160 Recreational, cultural and sporting activities
161 Other service activities

162	Private households with employed persons
163	Extra-territorial organizations and bodies

Appendix 6: EXIOBASE 1 Country/region classification

No.	Countries	Abr.
1	Austria	AT
2	Belgium	BE
3	Bulgaria	BG
4	Cyprus	CY
5	Czech Republic	CZ
6	Germany	DE
7	Denmark	DK
8	Estonia	EE
9	Spain	ES
10	Finland	FI
11	France	FR
12	Greece	GR
13	Hungary	HU
14	Ireland	IE
15	Italy	IT
16	Lithuania	LT
17	Luxembourg	LU
18	Latvia	LV
19	Malta	MT
20	Netherlands	NL
21	Poland	PL
22	Portugal	PT
23	Romania	RO
24	Sweden	SE
25	Slovenia	SI
26	Slovak Republic	SK
27	United Kingdom	GB
28	United States	US
29	Japan	JP
30	China	CN
31	Canada	CA
32	South Korea	KR
33	Brazil	BR
34	India	IN
35	Mexico	MX
36	Russian Federation	RU
37	Australia	AU
38	Switzerland	CH
39	Turkey	TR
40	Taiwan	TW
41	Norway	NO
42	Indonesia	ID
43	South Africa	ZA
44	Rest of World	WW

Appendix 7: EXIOBASE 2 Country/region classification

No.	Countries
1	Austria
2	Belgium
3	Bulgaria
4	Cyprus
5	Czech Republic
6	Germany
7	Denmark
8	Estonia
9	Spain
10	Finland
11	France
12	Greece
13	Hungary
14	Ireland
15	Italy
16	Lithuania
17	Luxembourg
18	Latvia
19	Malta
20	Netherlands
21	Poland
22	Portugal
23	Romania
24	Sweden
25	Slovenia
26	Slovakia
27	UK
28	US
29	Japan
30	China
31	Canada
32	South Korea
33	Brazil
34	India
35	Mexico
36	Russia
37	Australia
38	Switzerland
39	Turkey
40	Taiwan
41	Norway
42	Indonesia
43	South Africa
44	ROW Asia & Pacific
45	ROW America
46	ROW Europe
47	ROW Africa
48	ROW Middle East