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A STUDY ON METHODOLOGIES RELEVANT TO THE OECD APPROACH ON SUSTAINABLE MATERIALS MANAGEMENT

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FOREWORD

A consultancy company, Five Winds International, has prepared this document for the OECD. Comments from the OECD Working Group on Waste Prevention and Recycling have further improved the content of the document. This project was made possible through a voluntary contribution from the United States.

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EXECUTIVE SUMMARY

This study provides an overview of ten methodologies used, directly or indirectly, to assess material use in terms of its potential impacts on the environment, benefits to society and value for the economy. The purpose of the study is to promote understanding of the strengths and limitations of the methodologies, in terms of their potential application as part of a strategy to promote more sustainable management of materials. The study does not comprehensively explain every methodology in detail. It does present an overview of each according to its type and scope, points in the part of the life-cycle it covers, data and skill required to conduct it, and potential links to other methodologies in this study. Study findings are based on published literature, and in part, on interview discussions with experts on the different methodologies.

The OECD working definition of a Sustainable Materials Management approach is introduced below, to provide context for how this study contributes to developing that approach. The definition is followed by a list of the ten methodologies which are the focus of this study. **Chapter 1** presents the main study findings and **Chapter 2** presents the description of each methodology in the context of SMM. **Chapter 3** presents discussion on the particular question regarding the focus and orientation of the OECD approach on Sustainable Materials Management.

What Is Sustainable Materials Management?

In December 2005, the OECD agreed on the following working definition for Sustainable Materials Management:[1]

> "Sustainable Materials Management is an approach to promote sustainable materials use, integrating actions targeted at reducing negative environmental impacts and preserving natural capital throughout the life-cycle of materials, taking into account economic efficiency and social equity."

The participants also agreed to the following explanatory notes to the working definition:

- "Materials" include all those extracted or derived from natural resources, which may be either inorganic or organic substances, at all points throughout their life-cycles;
- "Life-cycle of materials" includes all activities related to materials such as extraction, transportation, production, consumption, material/product reuse, recovery and disposal;
- An *economically efficient* outcome is achieved when net benefits to society as a whole are maximised;
- A variety of policy tools can support SMM, such as economic, regulatory and information instruments and partnerships;
- SMM may take place at different levels, including firm/sector and different government levels;
- SMM may cover different geographical areas and time horizons.

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[1] OECD (2007), *Outcome of an OECD Workshop on Sustainable Materials Management,* ENV/EPOC/WGWPR/RD(2005)5/FINAL, OECD, Paris.

The working definition is intended to guide the focus of OECD work on Sustainable Materials Management and can be revised or improved as appropriate, as the work evolves.

Context for This Study

This study contributes to the OECD's work on Sustainable Materials Management in 2006-2008. The objective of the 2006 work was to compile and compare activities carried out by other international organisations, and identify and assess methodologies relevant to the OECD approach on Sustainable Materials Management. In 2007 and 2008, the SMM work will focus on the organisation of the second SMM workshop which should draw conclusions on the SMM work undertaken thus far and initiate possible further work.[2]

Ten Methodologies Studied

Ten methodologies were chosen for investigation in this study:

	Methodology investigated	**Overview**
1	Material Input per Service Unit, MIPS	MIPS measures the amount of materials used (inputs) to generate a unit of service (kg per unit of service), such as a car or a pair of shoes. Results can be used to assess the potential for improving this ratio (i.e., for deriving more service or value from all inputs), but this method does not calculate associated harm to the environment.
2	Life-Cycle Assessment, LCA	LCA measures the environmental and health impacts resulting from the use of materials, energy consumption or emissions generated to produce products or carry out a process or activity. Impacts are measured for example as CO_2 -equivalents, potential to cause eutrophication in water or other potential impact per functional unit.
3	Material Flow Analysis, MFA	MFA measures the amount (kg) of selected materials flowing through the economy, or through different industry sectors.
4	Economic Input/Output Analysis, EIO	EIO measures monetary value of the materials that industries buy and sell, organised by industrial sector or by commodity.
5	Total Cost Assessment, TCA	TCA identifies and quantifies costs associated with activities across the life-cycle of a product, process or activity, aiming to include costs in addition to conventional direct costs to the decision- maker.
6	Cost-Benefit Analysis, CBA	For a given decision or problem, CBA assigns economic value to social and environmental impacts, so that all costs can be evaluated against benefits. Results intended to support decisions to allocate limited resources (i.e. willingness to pay).
7	Ecological Footprint Analysis, EFA	EFA measures land area (or equivalent) that is needed to support a certain level of consumption in a particular population, or to support production of a particular product.
8	Thermodynamic Input/Output Analysis, TIOA	TIOA measures exergy associated with the materials and goods that industries buy and sell (organised by industrial sector or by commodity), essentially adding an energy dimension to the monetary values in Economic Input/Output Analysis.

[2] OECD (2007), *Programme of Work for 2007-2008 on Waste Issues,* ENV/EPOC/WGWPR(2006)3/FINAL, OECD, Paris.

	Methodology investigated	Overview
9	Environmental Impact Assessment, EIA	EIA is very different from the other 9 methodologies. It is a requirement (*e.g.* legislation) to assess and report potential environmental impacts of planned large scale development projects.
10	Computable General Equilibrium, CGE	CGE predicts structural changes that may occur throughout an economy as a result of a change in consumption in one industry sector (*e.g.* shift from one material to another in production of roads), or as a result of a change in technology used, efficiencies, prices, etc.

Each methodology is described according to a selection of features relevant for the OECD approach to Sustainable Materials Management. The features were decided in collaboration with OECD.

The Features	For Instance...
• Is the methodology problem-oriented or systems-oriented?	**Problem-oriented** approaches apply a narrow scope or boundary to examine an issue, reducing complexities and thus focusing effort and resources. Results are specific, directed solutions. **Systems-oriented** approaches apply a broad scope to examine an issue, and can identify interactive effects and uncover co-benefits. Results are helpful to identify relative material intensities, set priorities for further investigation and identify specific problems to later assess with problem-oriented approaches.
• Does the methodology address products, one material or material groups?	
• Can the methodology be conducted at a screening level, or only as a full assessment?	
• What points in the “life-cycle of materials” does the methodology cover?	
• How can results of the methodology be used, and what is its capacity to describe environmental pressure?	Includes discussion on types of users, types of results and decisions, points of application (capital planning, product design, policy development) as well as strengths and weaknesses.
• What time and resource costs are associated with the methodology?	Expressed in person-hours, and simplified due to the “overview” nature of this study.
• What is the status of data availability for the methodology?	
• What skill level is needed to conduct the methodology?	Expressed as requiring basic knowledge and general expertise, or as requiring elaborated knowledge of the methodology and specific expertise.
• Does the methodology complement, or overlap with, other methodologies examined here?	
• What points are of interest to SMM?	Examples of applications, considerations with respect to SMM.

Main Findings

All studied methodologies require general expertise to conduct a screening level assessment, which can be a useful first step and may be all that is necessary to help set priorities for further investigation. More extensive assessments require specific expertise, in particular to interpret and apply results and to determine the geographic scope of impacts. The combination of Cost-Benefit Analysis, Total Cost Assessment and Life-Cycle Analysis is useful for setting policy priorities. The combination which may contribute most to SMM includes Economic Input/Output Analysis, Life-Cycle Analysis and Material Flow Analysis.

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For more general information about the **OECD Environment Programme,** visit our website at: http://www.oecd.org/env/ or send an Email to env.contact@oecd.org

1. STUDY FINDINGS

1. Table 1 presents a summary of how the methodologies described in this study compare according to a selection of defining features. Table 2 presents potential combinations of the ten methodologies in the context of Sustainable Materials Management.

2. T**wo of the methodologies examined can be applied to assess social issues, five assess economic issues and nine assess environmental issues**. All ten methodologies can be used to conduct **screening level** assessments while nine can also be used to conduct full extensive assessments. Eight of the methodologies can be applied to cover all phases of the life-cycle of the product, material or system being assessed. Basic **data** is relatively easy to acquire for all methodologies, with the exception of Cost Benefit Analysis and Environmental Impact Assessment. All methodologies **require general expertise** to conduct a screening level assessment, which can be a useful first step and may be all that is necessary to help set priorities for further investigation. More extensive assessments **require specific expertise**, in particular to interpret and apply results and to determine the geographic scope of impacts. It requires significantly more time and costs to conduct the detailed analysis that is part of more extensive assessments. As shown in Table 2, the combination of CBA/TCA/LCA is useful for setting policy priorities. The combination which may contribute most to SMM includes EIO/LCA/MFA. Of the ten methodologies examined in this study, two methodologies, Cost Benefit Analysis and Total Cost Assessment, are able to assess social, economic and environmental issues associated with the life cycle of materials. However, in practice, both methodologies require a life cycle perspective on the part of the study practitioner in order to incorporate this broader scope

3. For all ten methodologies, there is an element of uncertainty and a degree of subjectivity involved in generating results. Choosing the appropriate methodology to apply in a given situation clearly depends on the scope of the underlying objectives, for instance, whether the objectives are to understand a material, a product or an economy.

4. Based on examination of ten methodologies, it is clear that a combination of methodologies is necessary to gain the most comprehensive picture of social, economic and environmental impacts across the life cycle of materials and thus to foster improved sustainable materials management. No methodology alone is sufficient to promote more sustainable materials management.

Table 1: Summary of Methodologies Assessed.

Method	Type		Scope			Points in Life-cycle			Data		Skills		
	Problem	System	Environment	Economic	Social	Full	Screening	All	Select	Available	Software	Some (screen)	Expert (full)
CBA	X		X	X	X	X	X	X	X			X	X
MFA		X	X			X	X	X	X	X		X	X
LCA	X	X	X			X	X	X	X	X	X	X	X
EIO	X	X	X	X		X	X	X		X	X	X	X
TCA		X	X	X	X	X	X		X	X	X	X	X
EIA	X		X			X	X		X			X	X
TIOA		X	X	X		X	X	X		X	X	X	X
EFA		X	X			X	X	X		X		X	X
MIPS		X	X			X	X	X		X	X	X	X
CGE		X		X		X		X		X	X		X

5. In the context of Sustainable Materials Management it is valuable to combine systems- with problem-oriented approaches. Designed to have a broad scope, systems-oriented approaches provide a context to assist in forming strategies and setting priorities. They complement problem-oriented approaches. Problem-oriented approaches focus on a specific problem within a system and provide detailed results to assist in making tactical decisions and implementing programmes. For example it is valuable to combine the systems-perspective gained from Economic Input/Output Analysis, Material Flow Analysis, Thermodynamic Input/Output Analysis or Computable General Equilibrium with the results from problem-oriented Life-cycle Assessment, Total Cost Assessment, or Cost Benefit Analysis. When combining methodologies it is necessary to ensure that basic geographical and temporal scope, metrics, etc. are compatible, so that the combinations will generate useful results.

6. It is also valuable to combine screening level assessments with more extensive assessments. As a first step, a screening level assessment of an entire system will help determine which materials or issues to prioritise, and may be all that is needed (e.g. to establish a new policy or programme). Screening level assessments will also help determine priority areas for conducting more detailed assessments, such as detailed assessments of environmental impacts associated with the prioritised issues and measuring costs of addressing (or not addressing) those environmental impacts. For example, conducting Economic Input/Output Analysis, followed by Life-cycle Assessment and Total Cost Assessment would accomplish this. Alone, Economic Input/Output Analysis results can only show the monetary value of materials flowing through the economy, as they are bought and sold by different industry sectors. This “economic intensity” is often used as an indicator of material intensity, but it does not measure specific impacts on the environment or human health. Hence, it can be complemented by Life-cycle Assessment. Total Cost Assessment provides a holistic assessment of potential costs, and is well complemented by Life-cycle

Assessment because the scope of the Life-cycle Assessment can be used to define the scope of activities to assess in the Total Cost Assessment.

7. Potential combinations are described in Table 2. The table also presents combinations of methodologies which may help to set priorities among policy measures. Suggested combinations are based on additional knowledge creation regarding to SMM, technical feasibility, and ease of implementation (e.g., cost and data availability).

Table 2: Combinations of Methodologies for Sustainable Materials Management.

	Methodology combinations which may contribute to Sustainable Materials Management
✓	**Economic Input/Output Analysis & Life-cycle Assessment**
	The combination of Economic Input/Output Analysis and Life-cycle Assessment seems has particularly promising for the OECD SMM initiative. Economic Input/Output Analysis provides the perspective of industrial material flows. These flows may not be otherwise considered in a Life-cycle Assessment, as LCA is based on the perspective of industrial process flows.
✓	**Economic Input/Output Analysis, Life-cycle Assessment & Material Flow Analysis**
	Material Flow Analysis results, when evaluated together with Economic Input/Output Analysis and Life-cycle Assessment, can provide details on how materials flow through the economy at the level of industrial sectors, or different industrial processes.
✓	**Economic Input/Output Analysis, Life-cycle Assessment, Material Flow Analysis & Total Cost Assessment**
	The addition of Total Cost Assessment results to the combinations described above provides a possibility to identify both economic costs and social welfare changes associated with the use of materials in the product or system (LCA would define boundaries of the product or system, and the same boundaries would be used for the TCA).
	Methodology combinations which may help to set priorities among policy measures
✓	**Economic Input/Output Analysis, Material Flow Analysis & Material Input per Service Unit**
	EIO and MFA can be useful in prioritising policies, when combined with MIPS or LCA. The combinations provide both a systems-oriented overview of material flows in the economy or sector under study, as well as a detailed measure of potential associated environmental impacts.
✓	**Cost-Benefit Analysis, Total Cost Assessment & Life-cycle Assessment**
	The combination of CBA and TCA results, together with LCA results, is potentially useful for setting policy priorities to address externalities caused during production of a product (or execution of a process), which would not typically be considered otherwise.
✘	**Environmental Impact Assessment**
	EIA studies, as stand alone assessments, are not particularly useful in prioritising policies in the context of SMM. But combining the results of several EIA studies can be useful in identifying issues common to a sector or type of project, for example, building a new utility plant in a densely populated area.
✘	**Ecological Footprint Analysis**
	EFA studies, while they can provide an upper boundary of activities or indicate overall environmental impacts at a particular time, are less useful in helping prioritise policies. Like EIA studies, EFA studies are more useful when combined with other EFA studies to assess similarities or trends.
?	**Environmentally Weighted Material Consumption, EMC (not covered in this study)**
	Recently developed, the EMC combines data on material flows with information on environmental impacts in an attempt to decouple economic developments from environmental pressures. **EMC should be considered as part of any further investigation into methodology combinations that support**

	SMM.
	Methodology combinations helpful in encompassing economic & social measures
✓	**Material Input per Service Unit & Total Cost Assessment**
	MIPS and TCA provide data to help identify economic efficiency and social equity. MIPS (as well as LCA) provides measures of material intensity, and these measures can be combined with a TCA to identify impacts associated with a particular product or service.
✓	**Economic Input/Output Analysis, Life-cycle Assessment, Material Flow Analysis & Total Cost Assessment**
	MFA, EIO and LCA, provide details on how materials flow through the economy and the resulting environmental impacts. Adding TCA results can identify economic costs and social welfare associated with the use of materials.
✓	**Cost-Benefit Analysis**
	For some specific projects, CBA can help identify economic efficiency and social equity (benefits) associated with material use in a project. It can be combined with a methodology like LCA that defines the activities, or boundaries, of the project to ensure all points in the life-cycle are accounted for.
✓	**Economic Input/Output Analysis**
	For some specific projects, EIO can be used to demonstrate economic efficiency. However EIO does not cover, in its traditional form, social equity.

2. CATALOGUE OF TEN METHODOLOGIES

8. This section presents descriptions for each of the ten methodologies according to the *features* articulated above (Table 2). Descriptions are based on published literature and interview discussions with experts.

2.1 Material Input per Service Unit (MIPS) [3]

Is the methodology problem-oriented or systems-oriented?

9. Material Input per Service Unit, or MIPS, measures the total mass of material inputs to create a unit of service output. MIPS can be applied to whole economies, individual sectors of an economy, companies, as well as to single products and services by taking either a problem or systems-oriented approach. MIPS does not measure potential environmental impacts of the various material inputs.

Does the methodology address products, one material or material groups?

10. The MIPS methodology was designed intentionally to provide "*a simple indictor of the material intensity of a product or service*".[4] As such, it can be used to measures material inputs used to create a product, a single service offering, one type of material or material groups.

Can the methodology be conducted at a screening level, or only as a full assessment?

11. Both screening level and full MIPS assessments can be conducted. Screening level assessments can be done quickly in part because the unit of measure, mass, is readily understood and easily measured. Full assessments can be done as the unit of measure can also be universally applied.

What points in the "life-cycle of materials" are covered?

12. MIPS covers all material inputs at all phases of the life-cycle of the product or service under study, including extraction of materials, manufacturing, transport, use, maintenance, and end-of-life. MIPS does not include energy requirements. The total mass of material inputs across the life-cycle is aggregated to produce a single score for a particular product, and the score is represented per unit of service the product delivers.

13. Inputs are grouped into five categories:

1. Abiotic raw materials;
2. Biotic raw materials;

[3] Summary based on interview with Dr. Stefan Bringezu of the Wuppertal Institute.

[4] Five Winds International (2001), *Eco-efficiency and Materials,* International Council on Metals and the Environment, Ottawa, p. 55.

3. Soil movements in agriculture & silviculture;
4. Water; and
5. Air.

How can results of the methodology be used, and what is its capacity to describe environmental pressure?

14. The results of a MIPS study can be used as a single indicator that represents material intensity across the five categories listed above. The first three, abiotic raw materials, biotic raw materials and soil movements can be combined to a single indicator representing cumulative primary material inputs.

15. MIPS can be used to assess the potential to increase resource productivity and to evaluate the effectiveness of existing or planned policy instruments, such as a resource tax.

Table 3: Examples of Material Input per Service Unit according to Wuppertal Institute.[5]

	Material intensity (t/t)				
Material	**Abiotic material**	**Biotic material**	**Water**	**Air**	**Moved Soil**
Copper (primary)	348		367	1.6	
Copper (secondary)	2.4		85.5	1.3	
Gold	540000				
Platinum	320300		193000	13800	
Portland cement	3.2		16.9	0.3	
Wood - plywood	2	9.13	23.6	0.541	
Drinking Water	0.01		1.3	0.001	

16. The strengths of the MIPS methodology include the comprehensive scope of material inputs across the product life-cycle and that it produces an easy-to-understand indicator (Table 3).

17. A shortcoming for Sustainable Materials Management is that MIPS treats all materials equally. It does not account for the qualities of material flows or environmental impacts of different types of materials, their toxicity, fate, transport, or exposure pathways.[6] Another weakness in this context is that the relative scarcity or abundance of materials is not considered. Resource depletion is implicit in the materials considered as part of the analysis. Also important in the context of materials management is the fact that MIPS favours a recycled content approach and not an end-of-life recycling approach. The result is an assessment that heavily weights the source of feedstock (see difference between primary and secondary copper in Table 3).[7] MIPS does not consider energy requirements for a materials management system.

[5] Wuppertal Institute (2003), *Material Intensity of Materials, Fuels, Transport Services*, Version 2; 28.10.2003, http://www.wupperinst.org/uploads/tx_wibeitrag/MIT_v2.pdf.

[6] Schmidt-Bleek, F. (1994), *How to Reach a Sustainable Economy*, Wuppertal Institute, http://www.factor10-institute.org/pdf/wupp94.pdf.

[7] A recycled content approach does not encourage process improvements and end-of-life materials management techniques that favour recoverability. Further reading on "recycled content" versus an end-of-life approach can be

What time and resource costs are associated with the methodology?

18. The MIPS methodology is relatively less time consuming and less expensive to conduct compared to the other methodologies described below. The cost of conducting a MIPS study is 1-2 persons for 2-3 weeks (similar to the cost of a streamlined or screening Life-cycle Assessment study). Data availability and scope of the MIPS assessment affect costs.

What is the status of data availability for the methodology?

19. Existing life-cycle inventory data can often be used, but typically must be amended for the MIPS format. For example, inputs must be specified on a mass basis (e.g., kg coal / MJ or kg concrete / m^3). Material intensity factors are publicly available from the Wuppertal Institute.

What skill level is needed to conduct the methodology?

20. The methodology requires basic knowledge and general expertise. The MIPS calculations can be performed using spreadsheets and a spreadsheet template is publicly available from the Wuppertal Institute.[8]

Does the methodology complement, or overlap with, other methodologies examined here?

21. MIPS can be complemented by Life-cycle Assessment. Relevant to the OECD Sustainable Materials Management context, the combination of MIPS or Thermodynamic Analysis with Life-cycle Assessment helps determine the level of materials efficiency and is beneficial when combined with Life-cycle Assessment impact information.

Points of Interest with respect to SMM

22. The MIPS methodology is inherently focussed on providing information on the efficiency of material use across the life-cycle of a product or service offered. Although it does not capture direct measures of environmental impact or resource depletion, it can be used as a relatively efficient and comprehensive screening tool to identify areas of concern.

2.2 Life-cycle Assessment (LCA)

Is the methodology problem-oriented or systems-oriented?

23. The LCA methodology is most widely applied as a problem-oriented approach and results are used to support identification and selection of environmentally preferable alternatives.

Does the methodology address products, one material or material groups?

24. The LCA methodology can address a single product, a material or material groups. It is comprised of four phases – goal and scope definition, inventory analysis, impact assessment and interpretation analysis.

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found in: Atherton, J. (2006), *Declaration by the Metals Industry on Recycling Principles*, International Journal on Life-cycle Assessment (Online First), http://www.dx.doi.org/10.1065/lca2006.11.283.

8 Additional information and a MIPS calculations spreadsheet can be found at: http://www.wupperinst.org/en/projects/topics_online/mips/index.html.

Can the methodology be conducted at a screening level, or only as a full assessment?

25. Both screening level and full assessments are possible for LCA studies.

What points in the "life-cycle of materials" are covered?

26. LCA studies can include all life-cycle stages of materials, including their associated emissions and energy requirements (raw material extraction, manufacturing, distribution, use, and end-of-life management). The practitioner also has the option to conduct a truncated or partial LCA study with a narrower scope, covering for instance only product manufacture and its delivery to the retail store, but not including its use or disposal.

How can results of the methodology be used, and what is its capacity to describe environmental pressure?

27. The LCA methodology enables comparison of environmental impacts associated with alternatives that provide the same or a similar function. This concept of function in LCA allows for the direct analysis of the value a product provides and is expressed as a service that provides value, as opposed to the physical product that delivers a service.[9] As such, LCA can be used to establish a base case and identify preferable alternatives under multiple scenarios that consider a range of environmental and human health impacts. LCA can be used by manufacturers during the design of a new product for comparing alternative product design options.

28. The LCA results are presented in common, comparable units. To generate comparable units, resources used, energy consumed and emissions generated are classified according to a pre-defined life-cycle impact assessment methodology. For example, contributions to impacts related to climate change are measured in kilograms carbon dioxide (kg CO_2) equivalent, primary energy demand in mega joules, acidification potential in kilograms sulphur dioxide (kg SO_2) equivalent, etc. LCA results are useful for identifying the highest potential relative environmental impacts of a process or a product, and also to determine key contributors to those impacts. Impacts can be prioritised with the addition of weighting factors.[10] (Table 4)

29. A traditional LCA study typically assesses the processes involved in the direct production of a product *and* the processes to produce the materials that go into the product. In the event that the product under study has an associated co-product or by-product, LCA can include the materials used, energy consumed and emissions generated associated with the additional product.[11] Indirect items, items not directly consumed or entrained in the product, and their associated production processes are typically not included. Indirect items include "overhead" items (e.g., lighting and non-process heating, long-term capital used to produce the product but not consumed such as buildings, roads, and other infrastructure). Numerous assumptions about data and models are required and data availability can be an issue, although data is being generated at an increasing rate (e.g., European Commission Joint Research Centre *LCA*

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[9] Five Winds International (2001), *Eco-efficiency and Materials*, International Council on Metals and the Environment, Ottawa, p. 55.

[10] An example of weighting scheme used for LCA can be found in the Building for Environmental and Economic Sustainability (BEES) programme, http://www.bfrl.nist.gov/oae/software/bees.html.

[11] There are two methods of analysis: one termed "system expansion" and a second termed "allocation" (which allocates environmental impacts on the basis of mass, economic value, physical properties, among others). The interested reader is referred to ISO 14040 (2006), *Environmental management – Life-cycle assessment - principals and framework*, International Organization for Standardization, Geneva.

Platform project[12]; voluntary market driven efforts of individual material producers[13], product manufacturers and industry associations[14]).

Table 4. Impact Assessment Methodologies

State of the Practice on Impact Assessment Methodologies
The state of the practice on impact assessment methodologies in LCA include both midpoint indicators (global warming potential, stratospheric ozone depletion potential, primary energy demand, acidification potential, eutrophication potential, photo oxidant chemical potential (smog formation), human health toxicity potential, ecological toxicity potential, and resource use) and measures of damage (human health as a measure of disability adjusted life years, biotic natural environment and abiotic natural resources). Internationally accepted methodologies, such as measures of primary energy demand and global measures of global warming potential and ozone depletion, are widely accepted and used. Regionally specific impact assessment methodologies (acidification potential, eutrophication potential and smog formation), although they provide greater accuracy, are only available for Western Europe and North America. The state-of-the-science of human health toxicity and ecological toxicity life-cycle impact assessment methodologies are less developed and are currently unsuitable as a basis for business or policy decision-making.[15]

<u>What time and resource costs are associated with the methodology?</u>

30. Simple LCA studies can be done with a fairly low level of effort (2-3 persons 4-8 weeks) by using existing databases (either public or purchased with LCA software) or if the user has primary data readily available (e.g. from product bill of materials). Costs to conduct LCA studies increase considerably if the scope of the study expands from direct operations of one manufacturer, to also include operations beyond the boundaries of that manufacturer (suppliers, transporters, end users, recyclers). The latter requires a larger boundary and greater quantification. The level of effort of studies at this higher level of sophistication can be of the order of 3-5 persons for 6-18 months.

<u>What is the status of data availability for the methodology?</u>

31. Various commercially available software tools and databases are available that provide the user with data to model material flows, energy flows and pollution from many industrial systems. Typically the databases provide average information on common materials (various plastics, metals and chemicals), energy supply options (coal, nuclear), major components (circuit boards), industrial processes (painting metal, tanning leather), transportation options and end-of-life management options (incineration, recycling). Some publicly available data exist but most data must be purchased.

<u>What skill level is needed to conduct the methodology?</u>

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12 Details can be found at: http://www.lca.jrc.ec.europa.eu/EPLCA/.

13 Kennecott Utah Copper, (2005), *Copper Environmental Profile,* http://www.kennecott.com/pdf/Copper_Environmental_Profile_Declaration.pdf.

14 An example is the work done by APME (Association of Plastic Manufacturers in Europe) on plastics, http://www.plasticseurope.org/.

15 Ligthart T, et al. (2004), *Declaration of Apeldoorn on LCIA of Non-Ferro Metals,* Apeldoorn, NL, http://www.uneptie.org/pc/sustain/reports/lcini/Declaration of Apeldoorn_final.pdf.

32. For simple studies, the methodology requires basic knowledge and general expertise. Studies intended for public audiences require extensive knowledge of the methodology and experience defining the proper study scope, and interpreting and communicating results.

Does the methodology complement, or overlap with, other methodologies examined here?

33. As a primarily problem-oriented approach, the LCA methodology complements Material Flow Analysis (a systems-oriented approach) in the understanding of material intensities and contribution to environmental and human health impacts. As such, it follows that the MIPS methodology is an overlapping approach, as material intensities can be assessed within LCA.

34. Economic Input/Output Analysis (EIO), when combined with emissions data, can also complement LCA, particularly when a process based on LCA methodology is used that does not capture indirect effects associated with overhead and infrastructure. Combined EIO and LCA studies, also known as hybrid-LCA, can be used to capture a broader boundary of influence related to a product system.

35. When combined with Total Cost Assessment (TCA), LCA can be used more effectively as a sustainability tool, capturing economic value and associated costs along with environmental burdens. The result is the basis of eco-efficiency computations.

Points of Interest with respect to SMM

36. In 2002 the United Nations Environment Programme (UNEP) and the Society of Environmental Toxicology and Chemistry (SETAC) conjointly launched the Life-cycle Initiative to promote life-cycle approaches worldwide. Jointly they work to enhance the application of sound life-cycle tools, communicate achievements and establish training activities. The initiative has mobilized an established and growing network of over 1000 members interested in advancing life-cycle approaches. One key objective is to facilitate life-cycle approaches in four key consumption clusters: housing, food, mobility and consumer products. Additional activities associated with developing and promoting LCA include the European Commission Directorate General Joint Research Centre Life-cycle European Platform on Life-cycle Assessment, formed to increase the use of LCA in both the public and private sectors. Relevant to Sustainable Materials Management, materials used in building construction applications may be influenced by the growing use of LCA within the building and construction sector:

- The current mandate of CEN (European Committee for Standardization) to harmonise the use of LCA and Environmental Product Declarations for building construction products (TC350 and TC351);[16]
- The US Green Building Council is integrating LCA into the next version of its environmental building evaluation scheme, Leadership in Energy and Environmental Design (LEED);[17]
- The Building Research Establishment Environmental Assessment Method (BREEAM) and the incorporation of life-cycle assessment measures;[18] and
- The Building for Economic and Environmental Sustainability (BEES) programme of the US National Institute of Standards and Technology.[19]

[16] More information can be found at: http://www.cen.eu.

[17] More information can be found at www.usgbc.org/LEED.

[18] More information can be found at: http://www.breeam.org.

[19] More information can be found at: www.bfrl.nist.gov/oae/software/bees.html.

2.3 Material Flow Analysis (MFA)

Is the methodology problem-oriented or systems-oriented?

37. The MFA methodology is a systems-oriented approach. MFA focuses on the relationships among energy and material flows, economic and trade developments and environmental changes.[20] There are many different types of MFA studies and these studies can be conducted at macro, meso, or micro-level. MFA studies can focus on the whole economy (Economy-wide MFA), economic sectors (e.g., the National Accounting Matrix with Environmental Accounts (NAMEA)), or individual materials, products, or substances. Material Flow *Accounts* track the movement of materials from extraction to manufacturing, use in a product, reuse, recycling and eventual disposal, and show emissions to the environment at each step.

Does the methodology address products, one material or material groups?

38. The MFA methodology can address one material or material groups, including products.

Can the methodology be conducted at a screening level, or only as a full assessment?

39. Full or screening level MFA assessments can be conducted. Since material flows tend to extend beyond political boundaries, the geographic scope of MFA can also be on a global scale. Impacts of these flows on the economy, environment (including emissions/pollution) and energy demands are also taken into account during the analysis.

What points in the "life-cycle of materials" are covered?

40. All points in the life-cycle of a material (i.e., extraction, production, transport, use, recycling and disposal) are considered in a full assessment; screening level assessments may focus on specific stages in the life-cycle to obtain basic information on material flows at that stage. In Economy-wide MFA studies, Total Material Requirement (TMR) is typically calculated. TMR comprises all primary materials except air and water[21] and it is important to note that TMR is an input oriented methodology and does not include associated emissions.

How can results of the methodology be used, and what is its capacity to describe environmental pressure?

41. Results are often used as the basis for policy formation regarding material use, or for making choices that will improve material efficiency or prevent pollution (Table 5). MFA provides data on quantities of material flows throughout life-cycle of various materials. The advantage of an Economy-wide MFA is the ability to link environmental impacts with activity in a national economy. Weaknesses of MFA include the varying levels of data quality at country levels, which make comparative assessments at the country level difficult. MFA also does not enable assessment of potential impacts on human health and the environment, nor does it include energy consumption requirements.[22]

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[20] OECD (2008), *Measuring Material Flows and Resource Productivity*, *Volume I, The OECD Guide*, OECD, Paris, http://www.oecd.org/dataoecd/46/48/40485853.pdf.

[21] Bringezu, S., H. Schutz, and S. Moll (2003), "Rationale for and Interpretation of Economy-Wide Material Flow Analysis and Derived Indicators", *Journal of Industry Ecology* 7(2).

[22] Bringezu, S., H. Schutz, and S. Moll (2003), Rationale for and Interpretation of Economy-Wide Material Flow Analysis and Derived Indicators, *Journal of Industry Ecology* 7(2).

Table 5: MFA Results as an Input to Decision Making.[23]

Material Flow Accounts
MFA can provide additional information to decision makers regarding supply of, and demand for materials, government policies and tradeoffs between policies. Environmental policy is one example of such a government policy (i.e. understanding the flows of toxic substances). Land management is another example. MFA can help inform land managers about how the land is, and may be used and why (e.g., demand for forest products). Public understanding of resource issues is also a possible application for MFA. Material flow accounts do not necessarily lead to any government policies, but can help organise information collected by government agencies and others in order to gain new insights, improve communication, set priorities and track progress.

What time and resource costs are associated with the methodology?

42. The costs of MFA studies are highly variable, and depend on the complexity and data availability of the materials assessed. Some materials may be straightforward to track, such as metals used in construction, whereas others, specifically those used in smaller amounts, such as a chemical that is more dispersed, may be more difficult to track. The level of effort can be 1-2 persons for 2-4 weeks for minor products and 3-5 persons for several months for major economic flows (e.g. zinc or copper). Some estimates reach $1 million to $1.5 million USD and 4 full-time equivalent staff to create material flow accounts for "a few" materials.[24]

What is the status of data availability for the methodology?

43. For both screening and full level assessments, information for MFA's must be gathered from a broad range of sources (from statistics as well as stakeholders), specifically key members of the material's supply chain (e.g., extractors, manufactures, recyclers, etc.). Data availability and quality is generally best for direct flows and for input and consumption variables (e.g. tonnes/year). Output variables are less well covered. Gaps remain in the coverage of international flows of resources and materials and in the coverage of hidden or indirect flows. Little coherent information is available on flows of secondary raw (recycled) materials.[25] The important role of government in data collection has been emphasised, as well as the need for government to engage the business and environmental communities in data collection.[26]

What skill level is needed to conduct the methodology?

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[23] *Institutionalizing Material Flow Accounts in the Federal Government*, Meeting Report. 20 July 2004, White House Conference Center (www.epa.gov/innovation/pdf/mfaworkshop.pdf). Meeting attended by nine federal agencies and departments, the environmental and natural resources research community, the private sector.

[24] *Institutionalizing Material Flow Accounts in the Federal Government*, Meeting Report. 20 July 2004, White House Conference Center (www.epa.gov/innovation/pdf/mfaworkshop.pdf). Meeting attended by nine federal agencies and departments, the environmental and natural resources research community, the private sector.

[25] OECD (2008), *Measuring Material Flows and Resource Productivity, Volume III, Inventory of Country Activities,* OECD, Paris, http://www.oecd.org/dataoecd/47/28/40486068.pdf.

[26] *Institutionalizing Material Flow Accounts in the Federal Government*, Meeting Report. 20 July 2004, White House Conference Center. Meeting attended by nine federal agencies and departments, the environmental and natural resources research community, the private sector.

44. MFA is typically undertaken on a large scale over a long period of time which requires elaborated knowledge of the methodology and specific expertise.

Does the methodology complement, or overlap with, other methodologies examined here?

45. Economy-wide Material Flow Accounting is increasingly used to estimate the total material input (including hidden flows such as ancillary and excavated material flows) for a national economy.[27] Economy-wide MFA uses physical units such as tonnes per year and is complementary to National Accounting Systems.[28] MFA is also conceptually similar to ecological footprint studies.[29] OECD has identified a need to position MFA within a broader architecture of accounts and indicators, such as linking it with other indicators derived from natural and other resource accounts (water, forest, land and energy), and other environmental accounts and information tools (air emissions and waste statistics).[30] Although not mentioned by the OECD, one combination of methodologies that is particularly useful to the Sustainable Materials Management approach is the combination of MFA with impact category indicators of Life-cycle Assessment. MFA describes where the materials are from and where they are being used, while Life-cycle Assessment describes the impacts of the materials over the life-cycle.

Points of Interest with respect to SMM

46. Since MFAs provide detailed information regarding material flows including the creation of unused materials, pollution, energy use and economic impacts, they allow for a holistic assessment of the overall potential impacts of individual materials throughout the entire life-cycle. This information, if combined with social life-cycle impacts, provides one input for decision-making on sustainable materials management.

2.4 Economic Input/Output Analysis (EIO)

Is the methodology problem-oriented or systems-oriented?

47. Economic Input/Output Analysis (EIO) is a methodology with a variety of applications that can be problem or systems-oriented. EIOs measure the monetary value of what industries buy and sell, to identify direct and indirect impacts of interaction between economic sectors, as well as how changes in one sector affect the other sectors. When combined with environmental data from other methodologies, the environmental impact of economic activities (e.g. consumption expenditures) can be evaluated.

Does the methodology address products, one material or material groups?

48. EIOs can be used to assess a specific material (e.g., steel) or an entire industry (e.g., automobile industry) but cannot be used to assess differences at the product level. Assessments can be of varying geographical sizes, from municipal to national and global level.

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27 United Nations, European Commission, International Monetary Fund, Organisation for Economic Co-operation and Development, World Bank (2003), *Handbook of National Accounting,* Integrated Environmental and Economic Accounting.

28 Sustainability A-Test, http://www.sustainabilitya-test.net.

29 OECD (2008), *Measuring Material Flows and Resource Productivity, Volume I, The OECD Guide,* OECD, Paris, http://www.oecd.org/dataoecd/46/48/40485853.pdf.

30 OECD (2004), "OECD Workshop on Material Flows and Related Indicators" – Chair's Summary", OECD, Paris, http://www.oecd.org/dataoecd/34/49/32367214.pdf.

Can the methodology be conducted at a screening level, or only as a full assessment?

49. EIOs are typically conducted at the screening level for macro-level planning, but also more detailed assessments can be conducted. However, as the number of sectors modelled increase, the data requirements can increase exponentially in order to fully capture the indirect economic activities.

What points in the "life-cycle of materials" are covered?

50. EIO is able to assess the impacts at all industrial points of the life-cycle of a material, as it captures the infinite rounds of production to produce material goods and services within an economic system. EIOs incorporate a broader boundary than traditional process-level LCA studies, as process-level LCA studies typically do not capture indirect effects associated with overhead and infrastructure. However, EIO typically does not capture the use phase of materials and it has limited resolution of recycling loops and no account of waste flows. Broader applications of EIO have been proposed to incorporate the full life-cycle of materials.[31]

How can results of the methodology be used, and what is its capacity to describe environmental pressure?

51. Similar to MFA and Footprint analyses, EIO can be used to identify major flows of goods and services throughout an economy, and it is most useful in the discovery of unforeseen interindustry dependencies by varying final demand (typically by setting the material of interest to a set amount and all other final demand purchases to zero).

52. EIO is a static model and, therefore, it should only be applied in a limited fashion when conducting comparative static assessments that involve structural changes of the Input/Output table, as non-linearities are not captured by the model. Increased model sophistication, such as the formulation of marginal and dynamic Input/Output tables requires expertise in economic systems modelling.

53. The EIO methodology can be used to measure direct and indirect energy use and emissions generated by an industry activity within an economy. EIO data are typically organised by standard industrial classifications. When combined with national emissions and energy data sets or emissions datasets that utilize the same industrial classification codes,[32,33] and further combined with Life-Cycle Impact Assessment methodologies, such as the US EPA's Tool for the Reduction and Assessment of Chemical and other Environmental Impacts (TRACI),[34] EIO can be used to generate a screening level environmental assessment across a variety of impact categories. However, national reporting data sets, when used to compile an inventory, can present uncertainties, either by underestimation (small firms may not be required to report emissions if they emit less than threshold reporting requirements) or overestimated (inventories typically do not provide information on actual emission).

What time and resource costs are associated with the methodology?

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[31] Duchin, Faye (1998), *Structural Economics: Measure Change in Technology, Lifestyles and the Environment*, Island Press.

[32] Standard Industrial Classification (SIC) and North American Industry Classification System (NAICS).

[33] Examples: US Environmental Protection Agency (EPA) Toxic Release Inventory (TRI), US Department of Energy, Energy Information Administration Manufacturing Energy Consumption Survey (MECS) data.

[34] More information about TRACI can be found at: http://www.epa.gov/nrmrl/std/sab/traci/.

54. National level Input/Output economic data is generally publicly available in electronic format. Screening environmental LCA (EIO-LCA) studies can be performed free of charge online (www.eiolca.net). This level of effort of this type of analysis is minimal (1-2 persons for 1 week). For more sophisticated EIO analysis the costs are variable depending on data requirements. The initial investment to compile Input/Output tables can be quite significant, especially if specialized data is required. Regional data sets extrapolated from national economic surveys are available commercially. The level of effort for this type of analysis can be of the order of 3-5 experts in this field for 6-12 months.

What is the status of data availability for the methodology?

55. EIO has been a part of the United Nations System of National Accounts since 1968. Broad based economic data is typically reported on a multi-year basis and it is available 3-4 years after the reference year, such as in the case of the US Bureau of Economic Analysis Input/Output Benchmark Accounts.[35] However, studies have shown that previous Input/Output benchmark accounts can be fairly accurate predictors of current and future accounts.[36]

56. The OECD compiles its own EIO database, which is in its second revision. The OECD database covers 28 OECD and 9 non-OECD countries.[37,38] Data supplied by the National Standard Institutes (NSIs) representing the countries that contribute to the OECD database are publicly available.[39] Data reported are harmonised under the International Standard Industrial Classification of all Economic Activities (ISIC). Currently the OECD database covers 66% of the global population and over 90% of the global Gross Domestic Product (95% of OECD GDP). The OECD 2006 database covers 48 product and service industries.

What skill level is needed to conduct the methodology?

57. When conducting screening level EIO studies, such as using the EIO-LCA tool, specialized training is not required, although some understanding of the Input/Output tables and methodology is important. However, when conducting more sophisticated studies that involve dynamic analysis or structural changes in the economy modelled, the methodology requires elaborated knowledge of the methodology and specific expertise.

Does the methodology complement, or overlap with, other methodologies examined here?

58. EIOs can be used with Life-cycle Assessment (EIO-LCA) to measure the overall environmental impact of producing a certain monetary amount of a commodity or service. When Input/Output analysis is linked to Material Flow data or to Physical Input/Output Tables (PIOT), environmental aspects can be included. EIO can be used to organize environmental accounting data; an example is the generation of a hybrid Input/Output analysis through National Accounting Matrix with Environmental Accounts

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35 http://www.bea.gov/industry/index.htm#benchmark_io.

36 Polenske, K. R.,(1980), The U.S. Multiregional Input/Output Accounts and Model, D.C. Heath and Company, Lexington, MA.

37 United Nations (1999), *Handbook of National Accounting*, Studies in Methods Series F, No. 74, Handbook of Input/Output Table, Compilation and Analysis, United Nations, New York.

38 The OECD Input/Output Database, 2006 Edition, DSTI/DOC (2006)8, STI Working Paper 2006/8 Statistical Analysis of Science, Technology and Industry, Directorate for Science, Technology and Industry, Paris, France, 2006.

39 Tables for Singapore are available within the OECD only.

(NAMEA). The Input/Output can be combined with a screening level Life-cycle Assessment to help incorporate additional indirect activities typically not captured by process level Life-cycle Assessment.

Points of Interest with respect to SMM

59. EIO can be used to evaluate the economic impact of material choices and use in industry. In the past, EIO has been used to measure impact of tariff rates on international trade of automobiles (and therefore tariff rates of all inputs, for example steel). EIO can be used to assess export changes, consumption and investment due to policy decisions.[40]

2.5 Total Cost Assessment (TCA)

Is the methodology problem-oriented or systems-oriented?

60. Total Cost assessment (TCA) is a problem-oriented methodology primarily used by businesses as a tool to capture the comparative total costs associated with selecting one alternative option over another. TCA can be used to identify preferable materials, process designs, product designs, or capital expenditures. In addition to direct and indirect costs typically tracked by traditional accounting techniques, TCA also considers contingent liability costs, intangible internal costs, and external costs borne by society.

Does the methodology address products, one material or material groups?

61. TCA studies can be used to compare product alternatives or to conduct a baseline study of products and processes.

Can the methodology be conducted at a screening level, or only as a full assessment?

62. TCA studies can be conducted at screening level and as a full assessment. At their simplest, screening level assessments are often conducted as brainstorming sessions that bring together people from multiple disciplines (marketing, engineering, manufacturing, personnel, accounting, health and safety, and environment) to identify significant potential costs early in the project planning process. Full assessments are typically conducted to justify large expenditures that would not be selected if only direct costs were considered.

What points in the "life-cycle of materials" are covered?

63. TCA can be used to capture costs associated with all points in the life-cycle of materials examined (raw material extraction, manufacturing, distribution, use and end-of-life options). Costs for product manufacturing, such as purchasing materials and operating equipment, are typically captured as direct costs. TCA also includes costs not directly associated with manufacturing, such as capital investments and overhead costs. Contingent liability costs associated with TCA captures risks associated with all aspects of the life-cycle of a product or process life. This includes costs associated with accidents or chemical spills, the risks of exposure to humans, and future liability costs associated with end-of-life disposal.

How can results of the methodology be used, and what is its capacity to describe environmental pressure?

[40] United Nations (2000), *Integrated Environmental and Economic Accounting*, An Operational Manual, Handbook of National Accounting Series F, No. 78.

64. The results of a TCA study can be used to compare costs of alternative materials or product designs, or to assess pollution prevention options.[41] The primary strength of TCA is the ability to capture costs associated with environmental liabilities, both contingent liability costs associated with internal operations (e.g., chemical spills and accidents), and external costs borne by society (e.g., emissions of green house gasses). Estimates of contingent liability costs and intangible external costs can be difficult to determine due to the lack of empirical data (e.g., the costs associated with contributing to climate change), or inability to determine a monetary value (e.g., the value of maintaining an open space in a community versus the economic value of building a factory).[42]

What time and resource costs are associated with the methodology?

65. The costs to conduct a TCA can be minimal and are primarily associated with personnel resources to identify major direct and indirect costs (1-2 analysts for 2-3 weeks and a panel of experts for 1 day). The resources necessary to capture contingent liability costs, internal intangible costs and external costs can be on the order of 1-2 analysts for 1-2 months depending on the boundary and scope of the task, and the accessibility and existence of the data associated with the alternatives to be assessed.

What is the status of data availability for the methodology?

66. Data for TCA is generally available, since primary input is financial and economic data of a company or government. TCA calculation can be done on spreadsheets, but some software programmes also exist in the public domain (e.g., Tellus Institute P2/Finance[43]).

What skill level is needed to conduct the methodology?

67. The methodology requires basic knowledge and general expertise of accounting principles, net present values, risk estimation, economic estimation techniques (contingent valuation and willingness to pay) and Life-cycle Assessment to effectively conduct the TCA. Skills to coordinate the multi-disciplinary participants can greatly enhance the value of applying the methodology.

Does the methodology complement, or overlap with, other methodologies examined here?

68. As a type of Environmental Accounting or Full Cost Accounting with a focus on environmental costs and savings in capital budgets,[44] TCA complements Life-cycle Assessment. TCA can be performed in conjunction with Life-Cycle Assessment. Also, TCA can use Life-Cycle Inventory data to understand what activities are occurring and thus determine the scope of activities to cover within the TCA study.

Points of Interest with respect to SMM

69. The TCA methodology is of interest to Sustainable Materials Management due to its inherent multidisciplinary approach and comprehensive scope which captures conventional costs, as well as

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41 GEMI (Global Environmental Management Initiative) (1994), *Finding Cost-Effective Pollution Prevention Initiatives: Incorporating Environmental Costs into Business Decision Making*, GEMI, Washington, D.C., USA

42 GEMI (Global Environmental Management Initiative) (1994), *Finding Cost-Effective Pollution Prevention Initiatives: Incorporating Environmental Costs into Business Decision Making*, GEMI, Washington, D.C., USA

43 Information on Tellus Institute and the P2/Finance tool can be found at: www.tellus.org and http://es.epa.gov/techinfo/finance/finance2.html.

44 EPA (1995), *An Introduction to Environmental Accounting as a Business Management Tool: Key Concepts and Terms*, EPA 742-R-95-001.

potential risk based costs. This scope incorporates aspects of environment, economics and consideration of societal burdens.

2.6 Cost-Benefit Analysis (CBA)

Is the methodology problem-oriented or systems-oriented?

70. Cost-Benefit Analysis (CBA) is a problem-oriented approach which attempts to put an economic value on social and environmental impacts that are typically not having a monetary market value. CBAs are typically used to evaluate whether a specific project is worth implementing for society. The methodology is based on welfare economics, which deals with the best possible allocation of resources (assumed to be limited) in society. CBA is sometimes referred to as 'applied welfare economics' as the optimal allocation of resources is defined as the allocation that provides the most welfare for society.[45]

Does the methodology address products, one material or material groups?

71. CBA can be applied to assess the costs and benefits of undertaking a policy measure, a project or a process. Benefits and costs are broadly defined as increases in human wellbeing and reductions in human wellbeing respectively.[46,47]

Can the methodology be conducted at a screening level, or only as a full assessment?

72. Both full and screening level assessments of a project can be conducted.

What points in the "life-cycle of materials" are covered?

73. Depending on the scope, CBA of a project can consider the entire life-cycle of a project (raw material extraction, manufacturing, distribution, use and end-of-life options), or focus on a specific part of the life-cycle, e.g. a CBA of an Extended Producer Responsibility programme may only measure costs and benefits of measures taken to manage end-of-life products. Similarly, a much more expansive CBA could measure costs and benefits of a material from its extraction/production through to the end of its useful life.

How can results of the methodology be used, and what is its capacity to describe environmental pressure?

74. Results can be used to inform decisions on whether benefits outweigh costs of an activity, and to redesign plans in order to optimise or redistribute benefits and costs across actors. Benefits are aggregated across different social groups or nations by summing willingness to pay for benefits, or willingness to accept compensation for losses, regardless of the circumstances of the beneficiaries or losers. Further aggregation does account for the circumstances of beneficiaries or losers by giving higher weight (value) to benefits and costs borne by disadvantaged groups. For a project or policy to be considered superior to another based on cost-benefit analysis, its social benefits must exceed its social costs.

75. CBAs allow for economic value to be attributed to goods and services that typically are not assigned market value and subsequently factored into to economic decision-making processes. The

[45] European Environment Agency (2005), *Paper and cardboard — recovery or disposal? Review of life-cycle assessment and cost-benefit analysis on the recovery and disposal of paper and cardboard*, EEA, p.94.

[46] OECD (2006), *Cost-Benefit Analysis and the Environment - Recent Developments*, OECD, Paris, p.16.

[47] OECD (2006), *Cost-Benefit Analysis and the Environment - Recent Developments,* OECD, Paris, p.17.

capacity to describe environmental pressure includes ability of CBA to assign monetary value to activities without a market price. However, assumptions of value must be done transparently to account for biases of influential stakeholders and those conducting the assessment.

76. Weaknesses of CBA include the many assumptions made in order to conduct a CBA which, as with any assumptions, include a potential risk of inaccuracy in practice. CBA measures costs and benefits on the basis of (subjective) individual preferences given objective resource constraints and technological possibilities.[48] It can therefore be challenging to determine if a product or policy is sustainable as preferences vary across populations.

What time and resource costs are associated with the methodology?

77. Costs of conducting a CBA depend on the scope and depth of analysis, and expected output. In general, a basic analysis which focuses on the well defined costs and benefits of perhaps three to four case studies of existing projects could be conducted with a level of effort of 1-2 persons for 2-4 months. More in-depth studies will increase the costs in line with increasing time and expertise required. In-depth studies can have a level of effort of up to 2-3 persons for as much as 6 months.

What is the status of data availability for the methodology?

78. Data to conduct a basic CBA includes operational costs, market prices and calculations of "benefit" or "well-being". Simple analyses can therefore be done with data on market costs and benefits, and data availability varies depending on the system being assessed. More in-depth studies require the expertise of an economist to assess costs or benefits that have no market price (or to assess externalities not fully reflected in the current market price, such as the cost of building infrastructure in an environmentally sensitive area). An economist's expertise would be needed to assign "Shadow Prices" to costs and benefits that do not have a market price so they can be assessed alongside those with well defined market prices. Shadow Prices can be determined through a variety of methodologies, including stakeholder consultation (to gather data from stakeholders on their "willingness to pay") and proxy which looks at cost differentials between associated items (e.g., the difference in market price between a 4 room house on a small lake, and a similar 4 room house not on a lake can indicate, in part, the market's willingness to pay for preserving a lake).

What skill level is needed to conduct the methodology?

79. Skills required to conduct a CBA is the major factor in calculating the cost and time required to conduct the assessment. A basic CBA, which simply takes account of all market costs and benefits, requires basic knowledge and general expertise. More in-depth studies require elaborated knowledge of the methodology and specific expertise.

Does the methodology complement, or overlap with, others examined here?

80. CBA studies can incorporate life-cycle data and be used in Environmental Impact Assessment and Total Cost Assessment studies. The combination of CBA with life-cycle perspectives (not necessarily a formal life-cycle assessment) can be useful in addressing the cost and social welfare of a project/decision in a holistic manner.

Points of Interest with respect to SMM

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[48] Advanced Tools for Sustainability Assessment, (2006) Vrije Universiteit Amsterdam Instituut voor Milieu Vraagstukken (IVM), Amsterdam, The Netherlads, Webbook: http://ivm5.ivm.vu.nl/sat/.

81. CBA has the capacity to help establish priorities and determine the optimal scale of a project, where net benefits are maximized, as costs and benefits are assigned the same unit, therefore CBA can allow for comparison of otherwise not comparable consequences of the project.[49] CBA considers social elements, but assigns higher weights to benefits (or costs) realized by lower income groups. With respect to supporting Sustainable Materials Management, data on social impacts and technical environmental aspects could be used to help define the benefits and costs which CBA uses to quantify the impacts in economic terms.

2.7 Ecological Footprint Analysis (EFA)

Is the methodology problem-oriented or systems-oriented?

82. Ecological Footprint Analysis (EFA) is a systems-oriented approach which quantifies "the total ecosystem area that the population effectively 'appropriates' to meet its demand for economic goods and services, including the area it needs to provide its share of certain (usually free) land- and water-based services of nature such as the carbon sink function."[50] EFA attempts to answer the question "how large an area is required to support a particular population" at its current level of consumption, including areas that are effectively 'imported' through trade.[51] EFA does not address environmental or health impacts.

Does the methodology address products, one material or material groups?

83. EFA can be applied to a specific location, country, or region (footprint to support the population's current consumption) or to products or processes (footprint to create one airplane or air conditioner). It identifies material flows, where they come from, where they are going and their associated impacts. At the local level, this could include local ecological consequences often caused by consumption of materials and energy. At a national level this could include information on trade corrected data, where consumption equals that which is produced locally in addition to imports minus exports.[52] The area of a population's theoretical ecological footprint depends on four factors:[53]

1. The population size;
2. The average material standard of living;
3. The average productivity of land/water ecosystems; and
4. The efficiency of resource harvesting, processing, and use.

Can the methodology be conducted at a screening level, or only as a full assessment?

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[49] European Environment Agency, (2005), *Paper and cardboard — recovery or disposal? Review of life-cycle assessment and cost-benefit analysis on the recovery and disposal of paper and cardboard* No 5/2006, EEA and Office for Official Publications of the European Communities, p.94.

[50] Rees, W. (2006) "Ecological Footprints and Bio-Capacity: Essential Elements in Sustainability Assessment" in Dewulf, J and Van Langenhove, H (eds.), *Renewables-Based Technology: Sustainability Assessment*, John Wiley and Sons, Chichester, UK, Chapter 9.

[51] Rees, W. (2006) "Ecological Footprints and Bio-Capacity: Essential Elements in Sustainability Assessment" in Dewulf, J and Van Langenhove, H (eds.), *Renewables-Based Technology: Sustainability Assessment*, John Wiley and Sons, Chichester, UK, Chapter 9.

[52] Personal communication with William Rees. University of British Columbia. 2006

[53] Rees, W. (2006) "Ecological Footprints and Bio-Capacity: Essential Elements in Sustainability Assessment" in Dewulf, J and Van Langenhove, H (eds.), *Renewables-Based Technology: Sustainability Assessment*, John Wiley and Sons, Chichester, UK, Chapter 9

84. The EFA methodology can be conducted at both a screening level or as a full assessment. A screening level EFA would analyse one material flow within a small region. A full assessment could include studies of material flows at a national or international level with greater sophistication of accounting detail (e.g., consideration of imports and exports and multiple resource types and materials).

What points in the "life-cycle of materials" are covered?

85. EFA primarily focuses on the production of goods and services (raw material extraction, manufacturing, and distribution).

How can results of the methodology be used, and what is its capacity to describe environmental pressure? [54]

86. An EFA can be used to compare the total biophysical demand of a population with the bio-capacity of its domestic land-base. This information can then be used to assess if (and potentially by how much) a population may be living beyond what its local ecology can support. EFA can also be used to assess if consumption patterns are 'decoupling' from nature—i.e. EFA time series can reveal whether a population's lifestyle and material choices are reducing or increasing the amount of land area required to sustain it.

87. EFA can show that a population is consuming more goods, materials or energy than they can produce themselves which is often the case in more developed countries. This can spark criticism and discussion regarding the capacity to support a certain level of consumption of human populations (a controversial topic that may detract from the impact of the analysis). Similarly these limits based on the bio-productivity of a specific area are often met with criticism from those who believe that populations can expand their bio-productivity through importing the needed goods and materials.[55]

What time and resource costs are associated with the methodology?

88. The main costs to conduct an EFA lie in the collection of the data and are therefore highly variable depending on the systems being assessed. At a local level it may be difficult to assess imports and exports, as this data is not always tracked, whereas at the national level this data is easily available. For specific industries, comparing different systems can require intensive data collection, e.g. comparing the impacts of greenhouse versus field production of vegetables.[56] Based on the sophistication of the study and data availability, the level of effort can range widely from 1-2 persons for 2-4 weeks, to 2-3 persons for 6 months.

What is the status of data availability for the methodology?

89. Data availability varies depending on the system being assessed. See above.

What skill level is needed to conduct the methodology?

[54] Rees, W. (2006) "Ecological Footprints and Bio-Capacity: Essential Elements in Sustainability Assessment" in Dewulf, J and Van Langenhove, H (eds.), *Renewables-Based Technology: Sustainability Assessment*, John Wiley and Sons, Chichester, UK, Chapter 9

[55] Rees, W. (2006) "Ecological Footprints and Bio-Capacity: Essential Elements in Sustainability Assessment" in Dewulf, J and Van Langenhove, H (eds.), *Renewables-Based Technology: Sustainability Assessment*, John Wiley and Sons, Chichester, UK, Chapter 9

[56] Personal communication with William Rees. University of British Columbia, 2006.

90. The methodology requires basic knowledge and general expertise. The skills required are the ability to collect quantitative data and conduct in-depth research into material flows. Skills in economics, ecology and physical and biophysical flows will assist the researchers to collect appropriate data and analysing the data effectively.[57]

Does the methodology complement, or overlap with, other methodologies examined here?

91. EFA is complementary to Material Flow Analysis.

Points of Interest with respect to SMM

92. EFA is the only methodology that compares the availability of resources with consumption levels. This can be shown for example by average consumption versus availability of the resources. It addresses the bio-productivity of specific areas and can assess the impacts of consumption per capita, or by country or geographical region. EFA differs from MFA, which identifies material flows in terms of where they came from and where they are going, since it includes the impacts of the actual flows as well.

2.8 Thermodynamic Input/Output Analysis (TIOA)[58]

Is the methodology problem-oriented or systems-oriented?

93. Thermodynamic Input/Output Analysis (TIOA) is a systems-oriented approach to study interactions between economic and ecological systems and to evaluate available energy flows in the economic system. Unlike other methodologies based on energy flow, TIOA considers exergy, which is the ability of an energy stream to do work, and combines Cumulative Exergy Consumption Analysis (CECA) with Economic Input/Output analysis. TIOA analyses the observed inputs of natural resources to and emissions from industrial activities to determine their thermodynamic basis.[59]

Does the methodology address products, one material or material groups?

94. TIOA can be applied at the macro level, such as considering environmental policy effects on energy flow. However, the methodology is limited by the granularity of the Input/Output tables employed, and is better suited to assess an entire industry (e.g., automobile industry) than a specific material (e.g., steel).

Can the methodology be conducted at a screening level, or only as a full assessment?

95. TIOA can be conducted at the screening level for macro-level planning. More detailed assessments can be conducted, but similar to Economic Input/Output, the data requirements can increase exponentially in order to fully capture the indirect economic activities, as the number of sectors modelled increase.

What points in the "life-cycle of materials" are covered?

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[57] Personal communication with William Rees. University of British Columbia, 2006.

[58] Summary based on interview with Dr. Nandan Ukidwe of Solutia Inc., unless noted otherwise.

[59] Bakshi, B.R. and Ukidwe, N.U., (2006), "The Role of Thermodynamics in Life-cycle Assessment of Existing and Emerging Technologies" in *Electronics and the Environment, 2006. Proceedings of the 2006 IEEE International Symposium*, ISSN: 1095-2020, ISBN: 1-4244-0351-0, pp 15- 20.

96. TIOA can be applied to assess any or all points in the life-cycle of a material (raw material extraction, manufacturing, distribution, use of materials and end-of-life options). TIOA captures various quality aspects of material streams, such as their mass, energy, concentration, velocity and location.[60]

How can results of the methodology be used, and what is its capacity to describe environmental pressure?

97. TIOA, through exergy analysis, measures thermodynamic efficiencies of a process and many processes can be combined to show efficiencies of supply chains, economic systems or ecosystems. Other applications of the methodology include hierarchal thermodynamic metrics that can further assess multiple technologies. Such metrics are shown to be robust, stackable, communicable to diverse audiences and protective of proprietary information. Similar to Economic Input/Output Analysis, TIOA can support environmentally conscious decision making by evaluating life-cycle environmental impacts of economic activities and by juxtaposing economic and natural capital flows through them.

98. Accuracy of TIOA depends, like other methodologies, on the quality of the data. To address this, rigorous statistical methodologies (and necessary resources) are required to obtain reliable results.[61]

What time and resource costs are associated with the methodology?

99. Cost will be highly variable depending on the scope and data availability in the geographic region of the study. TIOA is currently not widely applied as such, the community of practitioners is not well established and the ability to incorporate data and metadata from previously studies is limited. The basic model to conduct TIOA is available for free, and software called ThermoLCA is currently under development at the Center for Resilience at Ohio State University and will be distributed on CD, keeping the cost low. ThermoLCA would enable users to readily conduct TIOA without any specialized training, thereby greatly reducing costs.

100. If a specific process or product is to be analysed, resources would be required to collect that data as well. If TIOA is to be done for a system that has not been studied, it may take several months to develop the relevant model. Therefore the level of effort to conduct a TIOA could range from 1-2 persons for 1 week to assess a minimal set of data with the assistance of a dedicated software application to 2-3 persons for 3-6 months for more sophisticated studies.[62]

What is the status of data availability for the methodology?

101. Much of the research on TIOA to date has been based on the US economic systems and data from the US government agencies (US Department of Energy, Agriculture, EPA Toxic Release Inventory, Department of Commerce, etc.). However, TIOA could be applied more widely as long as sufficient resources are available to collect the appropriate data.

What skill level is needed to conduct the methodology?

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[60] Bakshi, B.R. and Ukidwe, N.U., (2004) "Thermodynamic Accounting of Ecosystem Contribution to Economic Sectors with Application to 1992 US Economy" in *Environmental Science and Technology*, 38 (18), 4810 -4827, 2004. 10.1021/es035367t S0013-936X(03)05367-7, American Chemical Society.

[61] Bakshi, B.R. and Ukidwe, N.U., (2004) "Thermodynamic Accounting of Ecosystem Contribution to Economic Sectors with Application to 1992 US Economy" in *Environmental Science and Technology*, 38 (18), 4810 -4827, 2004. 10.1021/es035367t S0013-936X(03)05367-7, American Chemical Society.

[62] Personal communication with Dr. Bhavik Bakshi,

102. The methodology requires basic knowledge and general expertise. A project team focusing on comparing or evaluating alternative products or processes should include experts with product- or process-specific knowledge and experience. Similarly, for the macro-scale applications, data regarding resource consumption and emissions would be required at the appropriate national or regional level. Once appropriate data has been collected the actual analysis is relatively easy to conduct. In addition, with the development of the Thermo-LCA tool users will be able to conduct TIOA without specialized training.[63]

Does the methodology complement, or overlap with, other methodologies examined here?

103. TIOA can add additional information to Life-cycle Assessment and Material Flow Analysis studies. The combination of TIOA with Life-cycle Assessment can indicate the level of materials efficiency and is beneficial when combined with Life-cycle Assessment impact information. It is possible, for more expert users to incorporate the end-point impact characterization factor of energy consumption from TIOA into the Life-cycle Impact Assessment structure of Life-cycle Assessment.

Points of Interest with respect to SMM

104. Material flow-based analyses tend to look at material flows through economic systems, but don't consider energy inputs to the system or the quality difference between materials (e.g. 1 tonne of coal vs. 1 tonne of iron ore). Energy based methodologies, mainly developed during the 1970's energy crisis, account for energy flows rather than materials, but can't account for quality differences between energy streams and also only account for the first law of thermodynamics (i.e. conservation of mass and energy).

105. The main interest of the TIOA is to capture the contribution of ecosystems to industrial activity. Ecosystem services include: sunlight for photosynthesis; hydro potential for power generation, geothermal heat for power generation, wind energy for power generation and fertile soil used to generate biogenic materials.

2.9 Environmental Impact Assessment (EIA)

Is the methodology problem-oriented or systems-oriented?

106. Environmental Impact Assessment (EIA) methodology is a problem-oriented tool to assess potential environmental, social, and economic impacts of proposed development projects. In many countries (including the EU countries, Canada, the US and China) an EIA is required through laws to be conducted prior to project authorization. A screening evaluation is usually performed to determine if a complete EIA is necessary. EIA is best performed during initial stages of a project, when the project owners are still open to considering alternative ideas and solutions (i.e., before large capital costs have been invested).

Does the methodology address products, one material or material groups?

107. The EIA methodology is particularly targeted to assess the implications of large development projects and not used to assess products, materials or material groups.

Can the methodology be conducted at a screening level, or only as a full assessment?

[63] Personal communication from Dr. Nandan Ukidwe.

108. A screening step is a required as a part of an EIA study and it is done to determine if a full EIA must be conducted. EIAs address landscape and environmental issues of specific projects. Full EIA study must address alternatives to the proposed project, including a scenario in which the project is not conducted at all (a null option).

What points in the "life-cycle of materials" are covered?

109. The scope of an EIA methodology includes an estimation of actual environmental impacts of development projects. It does not address impacts upstream (e.g., impacts associated with raw materials required for building) or impacts downstream (e.g., impacts associated with use of products manufactured at the plant being proposed for building).

How can results of the methodology be used, and what is its capacity to describe environmental pressure?

110. EIA results are used to determine if a project may be approved as is, or if modifications are required to mitigate adverse impacts. Governments, businesses and occasionally private citizens use EIA studies as a means to document the associated potential impacts of a project. Since EIA studies are required for most projects, with specific criteria determining which projects may go forth without an EIA, this methodology is very different from the other methodologies discussed in this document. The primary strength of an EIA is that it ensures environmental impacts are considered at some point in decision making process. In addition, private citizens are given the opportunity to comment on EIA studies.

What time and resource costs are associated with the methodology?

111. The cost for EIA studies vary depending on the scope of project. The level of effort for large-scale projects can require an expert team of professionals, 5-10 persons for 1-2 years. Smaller-scale projects can be completed by 1-2 experienced analysts in 6-12 months.

What is the status of data availability for the methodology?

112. Primary data is collected at the study site to identify the specific potential impacts. Information from similar EIA studies can be used as reference information in developing a new EIA.

What skill level is needed to conduct the methodology?

113. The methodology is readily understood, however the ability to successfully conduct EIA studies is an acquired skill, particularly requiring familiarity with local environmental conditions and the technology of the project to be assessed. Therefore this methodology requires basic knowledge of the methodology, and specific expertise on the application as well.

Does the methodology complement, or overlap with, other methodologies examined here?

114. EIA can incorporate Cost-Benefit Analysis or Life-cycle Assessment data for comparing the alternatives and supporting decision making.

Points of Interest with respect to SMM

115. Construction projects and mining operations require EIA before initiation of a project. Overall, EIA is not very useful for the OECD's Sustainable Materials Management, since it neither addresses materials nor is very informative as such in this respect.

2.10 Computable General Equilibrium (CGE) [64]

Is the methodology problem-oriented or systems-oriented?

116. Computable General Equilibrium (CGE) models are a systems-oriented methodology. CGE consists of numerical models for many industry sectors to allow quantitative analyses of resource allocation and related policy issues in a regional, national, multi-national or global economy.[65] The models are used to show how changes in conditions in one sector of the economy affect other sectors and the economic system as a whole. CGE models have become practical in the last few decades as computers became capable of solving multiple non-linear equations simultaneously.

Does the methodology address products, one material or material groups?

117. CGE can be used to evaluate materials or material groups. A partial equilibrium model is simply a supply and demand curve, where changes in the equilibrium are assumed to be independent of other related factors and commodity markets. That is, the effects of these changes are not modelled beyond the sector being studied. CGE models expand on this scope to account for how shifts in one sector affect the equilibriums of other sectors. This broader methodology of modelling can be focused on a set of specific sectors, throughout various regions, countries or multiple countries, depending on the desired scope of the model. CGE models can either calculate a new general equilibrium (i.e., comparative static models), or they can model changing equilibriums over time (i.e., dynamic models).[66]

Can the methodology be conducted at a screening level, or only as a full assessment?

118. In context of SMM and relative to other methodologies examined in this study, current state-of-the-art models can be coarse and thus the methodology can only be applied at the screening level.

What points in the "life-cycle of materials" are covered?

119. CGE models can be applied to the industrial activities associated with a material or product at the sector level (raw material extraction, manufacturing, distribution). It does not typically include the use phase or the end-of-life options.

How can results of the methodology be used, and what is its capacity to describe environmental pressure?

120. CGE models show the interactions of sectors throughout the supply chain, they can also be applied to environmental attributes (e.g. energy consumption). However, it can be difficult to get sufficient data on some environmental attributes, depending on the scope of the study, as gaps and inconsistencies in the data may exist between sectors, regions or countries.

121. CGE models do however have the ability, if sufficient data can be collected, to show effects of changes throughout various sectors and have therefore become the dominant methodology to analyse

64 Summary based on interview with Carl Pasurka of the US EPA unless noted otherwise.

65 EEE (Ecological and Environmental Economics Programme) and CEEPA (Centre for Environmental Economics and Policy in Africa), (2005), "Joint EEE-CEEPA First Training of Trainers Workshop" programme of proceedings held 5-16 December 2005 at International Centre for Theoretical Physics, Trieste, Italy.

66 In the US, CGE model results in a retrospective study of the Clean Air Act Amendments allowed both an economy wide analysis of the effects of the regulations along with an industry-level view of the effects of the regulations (http://yosemite.epa.gov/EE/epa/eerm.nsf/vwRepNumLookup/EE-0295?OpenDocument)

proposed changes to taxes and trade barriers. Unfortunately it is somewhat inevitable that several key assumptions are required to fully specify the model (e.g. elasticities of substitution). As with any assumption this can result in a risk of reduced accuracy, but this can be minimised through extensive data collection and careful sensitivity analysis.

122. As with other methodologies, the strength of CGE relies heavily on the strength of the assumptions made at the initiation of the process. Since CGE is a modelling methodology which attempts to predict complex interactions across markets, assumptions are often inter-related and as such, accuracy of the initial assumptions is crucial. CGE is recognized as a tool to assess the structure of economic systems. CGE is an interesting methodology for increased understanding of economic systems but not useful for detailed studies or material flows.

What time and resource costs are associated with the methodology?

123. The level of effort to conduct an analysis using CGE models requires 1-2 experts for 6-12 months depending on the level of detail required for the final results. Major areas of effort include the gathering of data and writing of the analysis. Once sufficient data is collected, the coding is primarily done through various software applications (e.g. GAMS/MINOS and GAMS/MPSGE) which have greatly reduced the cost of creating CGE models.

What is the status of data availability for the methodology?

124. Availability of data depends on which materials, sectors, and countries are being studied as reporting frequency varies by sector and country.

What skill level is needed to conduct the methodology?

125. The methodology requires elaborated knowledge of the methodology and specific expertise. Ideally the CGE model to conduct a study would be created by a project team that includes an economist with speciality in CGE modelling and solid skills of microeconomics. The team should also include an expert with familiarity of relevant data and policy implications. Various software applications are available to conduct the mathematical analysis.

Does the methodology complement, or overlap with, other methodologies examined here?

126. CGE is similar to Economic Input/Output Analysis, but goes to the next level in understanding the economy-wide implications of changes in material use in one sector. Results of an Input/Output model can be viewed as the first iteration of a CGE model, which then requires more information on certain economic parameters (e.g., price elasticities of demand, elasticities of substitution between domestically produced goods and imports). If one has the data on emissions and materials to undertake an Input/Output analysis, then one also has the necessary data to undertake a CGE analysis, and depending on the depth of information needed, EIO may be sufficient. CGE can be combined with Cost-Benefit Analysis and with data collected as part of environmental accounting efforts.

Points of Interest with respect to SMM

127. The greatest value of CGE models is their ability to predict how changes in one industry sector will influence other sectors and what those influences may be. The models are commonly used to model the effects trade barriers or taxes will have on different industry sectors. Recently the modelling methodology has been used to model the effects that environmental and natural resource problems and

policies (e.g. climate change policies) may have on various sectors.[67] CGE is an interesting methodology to understand economic systems but not useful for studying specific products, processes or material flows.

[67] EEE (Ecological and Environmental Economics Programme) and CEEPA (Centre for Environmental Economics and Policy in Africa), (2005), "Joint EEE-CEEPA First Training of Trainers Workshop" programme of proceedings held 5-16 December 2005 at International Centre for Theoretical Physics, Trieste, Italy.

3. FOCUS AND ORIENTATION OF SMM

128. In addition to the above descriptions of each methodology, it is useful for the OECD to know **w*hat are the advantages and disadvantages of focusing the OECD Sustainable Materials Management approach on material streams, material groups, all materials, industrial branches, the whole economic system or having another focus entirely?*** The advantages and disadvantages of different focuses are discussed below:

Material Streams?
• Focusing SMM on the management on material streams or flows provides a greater understanding of the relative intensity that a particular material has across the supply chain and the associated relative environmental impacts. A limitation to focussing on material streams is the lack of information on the overall context of the material intensity observed, and the associated impact at each step along the supply chain

Material Groups?
• The advantage of examining material groups is the ability to see combined and interactive effects as part of an assessment and decision-making process. Particularly some materials when combined or grouped, provide distinct added functional value. For example, zinc combined with steel, produces a highly durable material – galvanized steel. Examining only the iron in the steel would limit the sustainable aspects of combining zinc with steel.

All Materials?
• Examining all materials in a product system, industry sector or economy captures a systems perspective that provides insights into the relative intensities of materials across a supply chain or an entire economy. This comprehensive view has the benefit of capturing not only the materials that dominate an economic system, but also the de minimis-materials that may be relatively small on a mass basis, but provide a high economic value, or likewise relatively high risk of environmental impact. Examples of such materials are the use of lubricating oils and machinery and industrial catalysts, which have high value in manufacturing processes.
• While including all materials in a study may provide a comprehensive perspective, a broad scope also creates the risk of producing too much information that may diminish the ability to prioritise problems and definitive alternative solutions.

Industrial Branches?
• Focusing material management on an Industrial Branch provides a "real world view" of how materials interact within the economy. In an Industrial Branch, interested stakeholders can be engaged and work together to identify issues and implement solutions. The Industrial Branches perspective brings focus on a sub-group of the economy that allows industries with similar values and vision to work together. A disadvantage is the lack of perspective of material issues in one industrial brand versus the others.

Whole Economic Systems?
• A Whole Economic System approach is similar to an All Materials approach as both are comprehensive in scope. The Whole Economic System approach can provide valuable information regarding inter-industry relationships to better understand secondary and tertiary relationships of

material flows. As a systems-oriented approach, this will help to flag products and/or materials and prioritise those for more focused studies on materials. However, it should be recognized that whole economic systems approaches as proxies to material flows have inherent inaccuracies due to price and cost variability.

GLOSSARY OF ACRONYMS

CBA	Cost-Benefit Analysis
CECA	Cumulative Exergy Consumption Analysis
CEN	European Committee for Standardization
CGE	Computable General Equilibrium Model
CO_2	Carbon dioxide
DfE	Design for Environment
EFA	Ecological Footprint Analysis
EIA	Environmental Impact Assessment
EIO-LCA	Economic Input/Output-Life-cycle Assessment
EMC	Environmentally Weighted Material Consumption
EPA	Environmental Protection Agency
GDP	Gross domestic product
GHG	Greenhouse gases
HS&E	Health, Safety and Environment
ICMM	International Council on Mining & Metals
EIO	Economic Input/Output Analysis
ISIC	International Standard Industrial Classification
Kg	Kilogram (unit of mass)
LCA	Life-cycle Assessment
LCI	Life-cycle Inventory
m^3	Cubic meter (unit of volume)
MECS	Manufacturing Energy Consumption Survey
MFA	Material Flow Analysis
MIPS	Material Input per Service Unit
MIT	Material intensity
MJ	Mega joule (unit of energy)
NAMEA	National Accounting Matrix including Environmental Accounts
NSI	National Standard Institute
OECD	Organisation for Economic Co-operation and Development
PIOT	Physical Input/Output Table
SETAC	Society of Environmental Toxicology and Chemistry
SMM	Sustainable Materials Management
SO_2	Sulphur dioxide
TCA	Total Cost Assessment
TIOA	Thermodynamic Input/Output Analysis
TMR	Total Material Requirement
TRACI	Tool for the Reduction and Assessment of Chemical and other Environmental Impacts
TRI	Toxics Release Inventory
WGWPR	Working Group on Waste Prevention and Recycling (OECD)
UNEP	United Nations Environment Programme
USD	United States dollars

INFORMATION SOURCES

Useful Reading

Material Input per Service Unit, MIPS:
Additional information and a MIPS calculations spreadsheet can be found at:
http://www.wupperinst.org/en/projects/topics_online/mips/index.html.

Life-cycle Assessment, LCA:
Life-cycle Assessment Handbook (2002), *Operational Guide to the ISO Standards*, Guniée, J, 9ed.), Kluwer Academic Publishers, The Netherlands, http://www.leidenuniv.nl/cml/ssp/projects/lca2/lca2.html.

Material Flow Analysis, MFA:
OECD (2007), *Measuring Material Flows and Resource Productivity,* An OECD Guide, OECD, Paris (forthcoming).

National Academy of Sciences / National Research Council (NAS) (2003), *Materials Count: The Case for Material Flow Analysis*, Washington, available at: http://books.nap.edu/books/0309089441/html/index.html (this is the original report that lead into the meeting on *Institutionalizing Material Flow Accounts in the Federal Government*, 20 July 2004, White House Conference Center, http://www.epa.gov/innovation/pdf/mfaworkshop.pdf).

Economic Input/Output Analysis, EIO:
Input/Output Analysis (1985), *Foundations and Extensions,* Miller, R. and P. Blair. Prentice Hall.

Structural Economics (1988), *Measuring Change in Technology, Lifestyles and the Environment,* Duchin, F., Island Press.

Total Cost Assessment, TCA:
American Institute of Chemical Engineers (2000), *Total Cost Assessment,* http://www.earthshift.com/Total Cost Assessment Methodology.pdf.

Cost-Benefit Analysis, CBA:
OECD (2006), "Cost Benefit Analysis and Other Decision-making Procedures" Chapter 19 in: *Cost Benefit Analysis and the Environment, Recent Development*, OECD, Paris. 2006 ISBN 92-64-01004-1

Ecological Footprint Analysis, EFA:
Rees, W. (2006), "Ecological Footprints and Bio-Capacity: Essential Elements in Sustainability Assessment", Chapter 9 in: Jo Dewulf and Herman Van Langenhove, eds., *Renewables-Based Technology: Sustainability Assessment,* Chichester, UK: John Wiley and Sons.

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Ukidwe, N. (2005), *Thermodynamic Input/Output analysis of economic and ecological systems for sustainable engineering,* Ohio State University, http://www.ohiolink.edu/etd/view.cgi?osu1117555725.

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Computable General Equilibrium Models, CGE:
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Shoven, J. B. and J. Whalley (1992), *Applying general equilibrium*, MIT Press.

Other

Birat, J. P., J. S. Thomas and M. Chiappini (2006), *SOVAMAT Social Value of Materials, Version 3*. December 23, 2006.

European Commission Directorate General Joint Research Centre Life-cycle European Platform on Life-cycle Assessment, http://lca.jrc.ec.europa.eu/EPLCA/.

Maximising Value, guidance document on implementation of materials stewardship. International Council on Mining and Metals, http://www.icmm.com/library_pub_detail.php?rcd=199.

Ecological Benefits Assessment Strategic Plan The plan was developed to guide future research and institutional actions for improving ecological benefits assessments conducted by the US EPA, http://www.greenbiz.com/toolbox/reports_third.cfm?LINKADVID=74684.

Proceedings of the US and Canadian EPA international workshop on Benefits Transfer and Valuation Databases: Are We Heading in the Right Direction? http://yosemite.epa.gov/EE/epa/eed.nsf/webpages/btworkshop.html.

Experts Consulted

A number of people contributed their time and ideas to the catalogue of methodologies examined in this study. The OECD wish to thank them for their insights.

Material Input per Service Unit, MIPS:
Dr. Stefan Bringezu, Wuppertal Institute, interviewed on October 30, 2006.

Material Flow Analysis, MFA:
Paul Bailey, ICF Consulting, interviewed on October 30, 2006.

Ecological Footprint Analysis, EFA:
William E. Rees, PhD. University of British Columbia. School of Community and Regional Planning, interviewed on October 27, 2006.

Thermodynamic Input/Output Analysis, TIOA:
Dr. Nandan Ukidwe. Research Engineer, Solutia Inc., Doctor of Philosophy (Advisor: Prof. Bhavik Bakshi), Sustainable and Efficient Process Engineering Group, Department of Chemical & Biomolecular Engineering, The Ohio State University, Columbus, Ohio, interviewed on October 23, November 27 and 28, 2006.

Prof. Bhavik R. Bakshi, Faculty Advisor, The Ohio State University, Columbus, Ohio, interviewed on October 27, 2006.

Computable General Equilibrium Models, CGE:
Carl Pasurka, US EPA, interviewed on October 24 and 26, 2006.