MEASURING MATERIAL FLOWS AND RESOURCE PRODUCTIVITY

Synthesis report

OECD

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ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

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INTRODUCTION

This report[1] is part of the **OECD work programme on material flows (MF) and resource productivity (RP)** that supports the implementation of the OECD Council recommendation on MF and RP adopted in April 2004. It presents a **synthesis** of the work carried out by the OECD with its member countries and international partners since 2005, takes stock of progress made, and adds selected examples from applications of material flow analysis.

The **purpose** of the OECD work programme on material flows (MF) and resource productivity (RP) is to improve the quantitative and analytical **knowledge base** about natural resource and material flows within and among countries, so as to better understand the importance of material resources in member countries' economies and to inform related policy debates. This is done by providing **guidance** on how to measure material flows and resource productivity, paying attention to the "supply side", i.e. how material flow accounts and related indicators can be constructed in a coherent framework that countries can easily implement and further adapt to their own needs, and the "demand side", i.e. how material flow indicators can be selected to suit policy needs and how they can be interpreted and used.

The work has benefited from a **sequence of workshops** hosted by member countries (Helsinki, June 2004; Berlin, May 2005; Rome, May 2006; Tokyo, September 2007), that brought together environmental administrations, statistical services, material flow experts and researchers.

Main outputs include a **series of guidance documents on *Measuring material flows and resource productivity*** that have been drafted in a joint effort by a group of experts from OECD countries led by the OECD Secretariat[2]. They have benefited from contributions by members of the OECD Working Group on Environmental Information and Outlooks and the Working Group on Waste Prevention and Recycling, the Eurostat Task Force on Material Flows, and the London Group on Environmental Accounting. In developing them, the co-operation of environmental administrations, statistical services and material flow experts in countries has been invaluable. Our sincere thanks are therefore extended to all concerned.

The guidance documents reflect the **state of the art** concerning experience with material flow analysis and related indicators in member countries. They are expected to help achieve greater **convergence** of already existing initiatives and to facilitate wider dissemination and **uptake** of existing experience and guidance. The documents may evolve in future as ongoing efforts on methodologies and measurement systems will show results and as more feedback from policy uses will become available. They include:

- ***Volume I. The OECD guide.***

  Volume I describes the full range of MF approaches and measurement tools, with a focus on the national level and emphasis on areas in which practicable indicators can be defined. It is targeted at a non expert audience. It includes (i) an overall framework for material flow analysis (MFA), (ii) a description of different kinds of measurement tools, (iii) a discussion of those issues and policy areas to which MFA and material flow indicators can best contribute, and (iv) guidance on how to interpret material flow indicators. It is

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illustrated with a selection of practical examples from countries' experience and is complemented with a glossary.

- ***Volume II. The accounting framework.***

  Volume II provides a theoretical and technical description of the concepts and methodologies of material flow accounting. It is targeted at an expert audience. It draws upon the Handbook on national accounting - Integrated Environmental and Economic Accounting (the SEEA handbook), developed jointly by the United Nations, the European Commission, the IMF, the OECD, and the World Bank and on the guide published by Eurostat in 2001 Economy-wide material flow accounts and derived indicators – A methodological guide. It has benefited from co-operation with Eurostat and with the London Group on Environmental Accounting, and consultations with the UNSD and its Committee of Experts on Integrated Environmental Economic Accounting.

- ***Volume III. Inventory of country activities***.

  Volume III takes stock of activities related to the measurement and analysis of natural resource and material flows in place or planned in OECD countries and in selected non member economies. It describes the main features that characterise such activities and the extent to which information on material resources is used in environmental reporting and in decision making. It is designed to provide a factual basis for the further exchange of experience and information and for sharing lessons at international level.

- ***Volume IV. Implementing national MF Accounts*** (forthcoming, prepared jointly with Eurostat).

  Volume IV provides practical guidance to assist countries in implementing national material flow accounts. It is targeted at practitioners of material flow accounting. It is constructed in a modular way to reflect several levels of ambition and completeness of accounts, and is being developed stepwise. The first edition will focus on the establishment of simple economy-wide material accounts building on a set of core tables tested and used by Eurostat.

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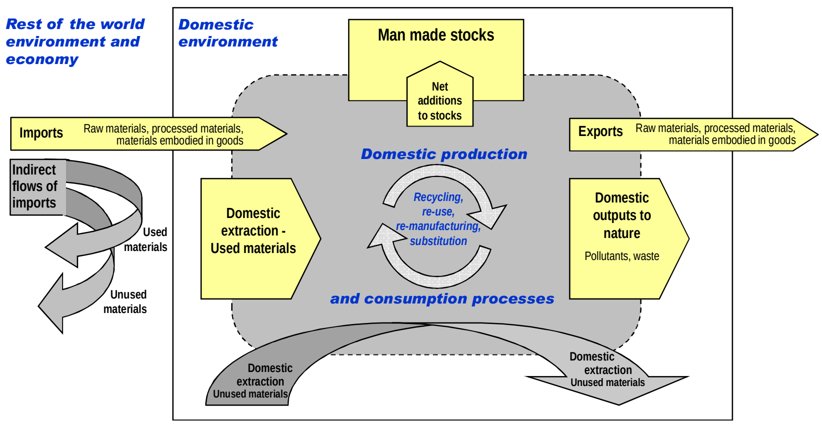
EXECUTIVE SUMMARY

The worldwide use of virtually every significant material has been rising over many years, causing recurrent concerns about shortages of natural resource stocks, the security of supply of energy and other materials, and the environmental effectiveness of their use. A good understanding of the **material basis of the economy** should therefore underpin the formulation of economic, trade, natural resource and environmental policies. The aim of **Material Flow Analysis (MFA)** is to contribute to that understanding.

MFA helps **identify inefficient use** of natural resources, energy and materials in process chains or the economy at large that would go undetected in conventional economic or environmental monitoring systems. It achieves this by using already available production, consumption and trade data in combination with environment statistics, and by improving modelling capacities.

Characteristics of MFA

In essence, MFA comprises two main elements. First, systematic **material flow accounts** in physical units and based on the mass balance principle, provide a structure for information about material flows. Secondly, **material flow indicators** derived from these accounts convey policy-relevant messages to a non-expert audience (general public, high-level decision makers, policy analysts, etc.) about the significance of material flows with respect to economic and environmental issues of concern.



Two further features **distinguish MFA from earlier approaches**. MFA not only shows natural resources flowing into the economy, but also reveals what happens to materials as they move inside and out of the economy, and how this relates to **environmental risks** and impacts, and to resource **productivity**. Moreover, MFA provides information about "hidden" flows associated (i) with the extraction of commodities (e.g. mining overburden, harvest losses), i.e. about materials that do not enter the economy as products, but whose displacement can have adverse environmental effects, and (ii) with the trade of commodities (e.g. pollutants and waste generated upstream in the production process).

Although MFA is only one approach amongst others, it is the **only tool that can**:

- provide an **integrated view** of resource flows through the economy;
- capture **flows that do not enter the economy** as transactions, but that are relevant from an environmental point of view;
- reveal how flows of materials **shift within countries and among countries** and regions, and how this affects the economy and the environment within and beyond national borders.

These characteristics make MFA a useful tool for examining **trade-offs** between policies and for understanding the implications of decisions that depend on **interrelationships** in the economy and the environment. It can be used to analyse issues that **cut across different media and policy areas** and support decisions that have economic, environmental and social implications.

Accounts

MFA can easily be adapted to suit countries' specific circumstances. At the national level, the value of **material flow accounts** is that they present information with the same structure as that of the national economic accounts. Such accounts show how economic performance can be improved by reducing inefficiencies in the use of energy and materials. In the trade area, MFA can show the materials relationships between a country and international markets. Also, MFA complements and enriches conventional environmental information systems. MFA makes it possible, for instance, to identify environmental releases associated with the different stages of a particular material flow (e.g. releases from extraction or production versus use or disposal).

Indicators

Some examples of **material flow indicators** in use are:

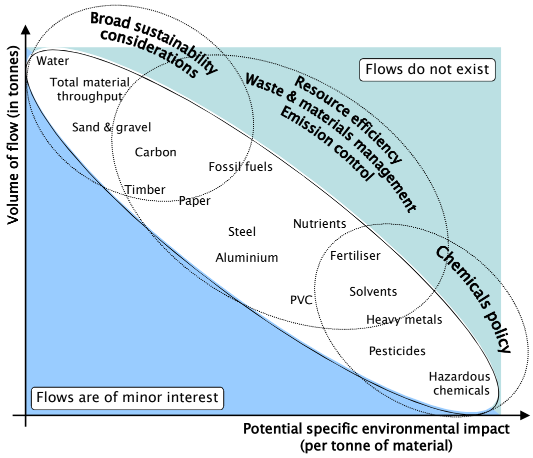
Domestic extraction used (DEU)	DEU measures the flows of materials that originate from the environment and that physically enter the economic system for further processing or direct consumption (they are "used" by the economy).
Direct Material Input (DMI)	DMI represents materials supply. It measures the direct input of materials for use into the economy, i.e. all materials that are of economic value and are used in production and consumption activities.
Total Material Requirement (TMR)	TMR includes, in addition to TMI, the (indirect) material flows that are associated to imports but that take place in other countries. It measures the total 'material base' of an economy. Adding indirect flows converts imports into their 'primary resource extraction equivalent'.
Domestic Material Consumption (DMC)	DMC represents materials use. DMC measures the total amount of material directly used in an economy (i.e. the direct apparent consumption of materials, excluding indirect flows). DMC is defined in the same way as other key physical indictors such as gross inland energy consumption.
Total Material Consumption (TMC)	TMC measures the total material use associated with domestic production and consumption activities, including indirect flows imported (see TMR) but less exports and associated indirect flows of exports.
Physical Trade Balance (PTB)	The PTB reflects the physical trade surplus or deficit of an economy. It is defined as imports minus exports (excluding or including their hidden flows).
Total Domestic Output (TDO)	TDO represents the environmental burden of materials use, i.e. the total quantity of material outputs to the environment caused by economic activity.

It is also possible to define **resource productivity indicators** that can be used in parallel with those describing labour or capital productivity. For instance, total material productivity (GDP/TMR) is defined as the ratio between gross value added and the total material requirements of a country. It describes the total amount of materials extracted, moved or used to generate one unit of gross domestic product.

Environmental aspects of materials use

The **environmental pressures** associated with resource use are different for each stage of the resource life cycle. They can also be widely distributed geographically when materials are traded internationally, either in the form of raw materials or as products embodying them. The pressures of the extraction phase necessarily remain in the extracting country. If resources are exported, however, the other pressures will take place where the materials are further transformed and where they reach the end of their life in the socio-economic system.

When considering the environmental pressures associated with the flow of materials and substances, it is useful to distinguish between "**bulk**" and "**toxic**" flows. The former generally have low environmental impact per unit of mass, but their overall impact can be significant because large amounts of material are involved. Toxic flows, on the other hand, have high specific impact coupled with small volumes, and the overall impact can still be significant, though of a different nature. The management issues associated with various materials and substances will therefore differ, depending on the position of a material in the diagram shown here.



Examples of applications

This synthesis report contains some examples of the **types of analysis made possible by MFA**. It does so by briefly considering each of the four broad classes of materials that make up worldwide material flows, which amounted to some 55 billion tonnes in 2002. These are, in order of importance by weight: i) Construction and industrial minerals (22.9 billion tonnes in 2002); ii) biomass (15.6 billion tonnes); iii) fossil fuels (10.6 billion tonnes); and iv) metal ores (5.8 billion tonnes).

Looking ahead

Over the past decade, a **considerable amount of work** on MFA has been carried out, much of it in developing methodologies and doing the necessary "spade work" (i.e. setting up and populating accounts) required before the more visible MF indicators can be calculated. About **two-thirds of OECD countries** have made various degrees of progress with a wide range of MFA initiatives. Differences of approach among countries are due to individual countries initially focussing on the resources or materials of greatest economic and environmental importance to them. Nevertheless, the guidance material developed by international agencies and research institutes has helped countries achieve a degree of methodological harmonisation. Remaining differences point to the need for additional clarification and **convergence**. Also, not all economy-wide indicators are yet widely understood. More is therefore needed to review and explain the added value of MFA compared to other monitoring and measurement tools and to appropriately position MFA within a broader architecture of environmental and economic accounts and indicators. The work done by the OECD since 2005 is a **first step** in this direction.

Actual use of MF information in national **policy debates and policy-making** has remained limited, but this should change now that an increasing number of countries are incorporating MF indicators into national indicator sets, while some are also formulating broad national goals, quantitative objectives, and even time-bound numerical targets in terms of MF indicators. Feedback on the policy relevance of these indicators is still seen by some as insufficient and further insights are needed to guide their refinement, to agree on common **indicator sets** and to promote their systematic use.

Further work in developing MFA as a practical analytical tool must be aimed at better understanding the **environmental impacts and costs** of resource use throughout the entire life cycle of materials and the products that embody them (i.e. from natural resource extraction, manufacturing, use/consumption to end-of-life management). Required also are the implementation of compatible databases for **key material flows** (e.g. flows of importance to the 3R initiative, flows of particular importance to the environment and the economy), and the sharing of **good practices** within countries, among countries and among enterprises. As to the **dissemination and uptake of guidance**, OECD governments should co-operate with **industry and non-member economies** to strengthen their capacity on measurement and analysis of material flows and the associated environmental impacts.

MEASURING MATERIAL FLOWS AND RESOURCE PRODUCTIVITY

1. NATURAL RESOURCES, MATERIALS AND THE ECONOMY[3]

The material basis of economies

Natural resources are fundamental for the economy and prosperity. They provide raw materials, energy, food, water and land, as well as environmental and social services.

Economic, social and environmental aspects of natural resource use

The use of materials from natural resources in human activities and the attendant production and consumption processes have many economic, social and environmental consequences that often extend beyond the borders of single countries or regions:

- From an economic perspective, the manner in which natural resources are used and managed affects (i) short-term costs and long-term economic sustainability; (ii) the supply of strategically important materials; and (iii) the productivity of economic activities and industrial sectors.
- From a social point of view, the exploitation and use of natural resources and materials affects employment, human health, and a population's recreational access to particular resources, landscapes and ecosystems. Natural resources also are a basic element of the cultural heritage of many people, notably of indigenous cultures. Furthermore, social equity considerations play a role in the way revenues and other financial flows associated with resource production and supply are managed, particularly in resource-rich countries.
- From an environmental perspective, the use of natural resources and materials needs to be considered in terms of (i) the rate of extraction and depletion of renewable and non-renewable resource stocks; (ii) the extent of harvest and the reproductive capacity and natural productivity of renewable resources; and (iii) the associated environmental burden (e.g. pollution, waste, habitat disruption), and its effects on environmental quality (e.g. air, water, soil, biodiversity, landscape) and on related environmental services.

Managing resources well and efficiently

Making sure that natural resources and materials are managed well and used efficiently through their life cycle is key to economic growth, environmental quality and sustainable development. It helps reduce the negative environmental impacts associated with the production, consumption and end-of-life management of natural resources, a concern that has long been on the policy agenda of OECD countries. It also helps indirectly reduce demand pressures on natural resources in the context of the global economy. This is particularly important in a world where the prices of many natural resources are rising fast; and where there are often concerns about the long-term security of supply of natural resources. Supply security is a strategic concern for governments and businesses alike; efficient management of the environmental impacts associated with using these resources will increase their long-term availability (and quality) for everyone.

[3] Based on OECD (2008), *Measuring material flows and resource productivity – Volume I. The OECD Guide*, *Chapter 1*, OECD, Paris.

Over the past two decades, worldwide use of virtually every significant material has been rising. Growing economic and trade integration among countries has enlarged the size of markets, allowed greater specialisation and mobility in production, increased the role of multi-national enterprises, and led to an overall increase in international flows in raw materials and manufactured goods (OECD, 2007a). In consequence, the scale of many policy issues has widened from the local and national to the global. In recent years, prices for energy and other material resources have risen significantly amid growing demands from OECD and other countries, notably from fast-growing economies. Rising prices affect the manner in which natural resources are supplied to and used in the economy. They also influence decisions about technological development and innovation. Hence, natural resource consumption and the economic efficiency of materials use have become important issues, adding to long-standing concerns about natural resource management and the environmental effectiveness of materials use.

In the next 50 years, the world population will continue to grow. So will the world economy, thus placing increasing strains on a variety of material and energy resources and the global environment. This creates formidable economic and environmental challenges for policy- and decision-makers. The question arises as to how to sustain economic growth and welfare in the longer term whilst keeping negative environmental impacts in check and preserving natural resources.

Policies and actions

Responding to these issues, the Heads of State and Government of G8 countries paid specific attention to the resource basis of economies at their summits in 2003, 2004, 2006, and 2007. In 2004, the Council of the OECD adopted a Recommendation on material flows and resource productivity asking OECD countries to improve information and knowledge on material flows and resource productivity and to develop common methodologies and measurement systems, with emphasis on areas in which comparable and practicable indicators can be defined. In 2007, an International Panel on Sustainable Resource Management has been set up by UNEP with the support of the European Commission to address resource efficiency issues from a life-cycle perspective, and to provide scientific assessment on the associated environmental impacts. Sustainable resource use is further supported by international efforts to promote good governance in the raw materials sector and to make the management of natural resource rents more transparent.

Most OECD countries have already addressed the issue of efficient management and sustainable use of natural resources in their national sustainable development strategies or environmental plans. They have launched initiatives to promote waste prevention, sustainable materials management, and integrated product policies, 3R (Reduce, Re-use, Recycle) related policies, sustainable materials management, and circular economy approaches[4]. Some countries work in partnership with industry to move towards sustainable use of natural resources and materials.

Many business sectors address these issues by establishing stewardship programmes for materials and products, investing in R&D and using advanced technologies to increase materials and energy efficiency, enhancing environmental management, promoting eco-design and coherent materials supply and use systems.

4 3R and circular economy initiatives aim at closing materials loops and extending the lifespan of materials through longer use and the increased use of secondary raw materials. These initiatives also aim at material substitution: the use of materials with smaller environmental impact, and replacing the environmentally most damaging materials.

Information needs and knowledge gaps

Implementing effective natural resource and materials management policies requires good knowledge of: (i) the use, depletion and discovery of resources; (ii) the stocks and flows of resources; and (iii) technologies, recycling and substitution. Gathering such information is not easy. It is complicated by factors such as uncertainties about future demand and supply, and the environmental impact of their exploitation and use. Other factors include inter-temporal trade-offs, spatial and distributive aspects, and interactions between different resources.

Although the magnitude and flows of capital and human resources are tracked in great detail in economic accounts and in social and labour statistics, natural resources are not yet traced to allow a systematic evaluation. Of the information that is currently available, most shows natural resources flowing into the economy, i.e. the magnitude of the use of raw materials over time, both absolutely and in relation to other commodities. However, this information does not provide much insight into what happens to materials as they move inside and out of the economy, and how this relates to environmental risks and impacts, to resource productivity, and to developments in commodity prices. Neither do currently available data provide information about "unused" flows associated with the extraction of commodities, i.e. about materials that do not enter the economy as products, but whose displacement can have adverse environmental effects. Gaps also remain as regards (i) some kinds of material resources; (ii) flows of secondary raw materials (recycled and recyclable materials), and (iii) the coverage of international resource flows, including indirect effects in terms of natural resource use, pollution and waste induced by countries' demand for traded raw materials and products.

Filling knowledge gaps with Material Flow Analysis

Material Flow Analysis (MFA) is among the most useful tools to help fill these knowledge gaps and guide decision making. In recent years, good progress has been made in developing and harmonising methodologies for MFA. Also, the number of practical applications is growing[5].

Work carried out so far has covered various resource flows at different levels of detail. Among these are complete material flow accounts and indicators at the economy-wide level. Special mention should be made of the joint research carried out by Austria, Germany, Japan, the Netherlands and the United States in the late 1990s, involving governmental and non-governmental institutions, and the collaborative work in Europe by Eurostat (on methodological guidelines) and the European Environment Agency (EEA). This research is further supported by international work on Integrated Environmental and Economic Accounting (commonly referred to as SEEA; United Nations, *et al.,* 2003) led by a UN Committee of Experts, and by OECD work on environmental indicators (OECD, 2003a), on environmental accounting, and on material flows and resource productivity (OECD, 2003b).

Material Flow Analysis (MFA) is the study of physical flows of materials into, through and out of a given system (usually the economy). It is generally based on methodically organised **accounts** in physical units. It uses the principle of **mass balancing** to analyse the relationships between material flows (including energy), human activities (including economic and trade developments) and environmental changes.

Material flows can be analysed at various scales and with different instruments, depending on the issue of concern and the purpose of the study. The term MFA therefore designates a **family of tools** encompassing a variety of analytical approaches and measurement tools, including **accounts and indicators**.

5 OECD (2008), *Measuring material flows and resource productivity – Volume III. Inventory of country activities*, OECD, Paris.

2. WHAT IS MATERIAL FLOW ANALYSIS?[6]

Terminology and concepts

The term MFA designates a family of tools based on the materials balance principle, encompassing a variety of analytical approaches and measurement tools at different levels of detail and completeness. These tools range in scope from economy-wide to substance or product-specific analysis, and input-output analysis. Each type of analysis is associated with MF accounts or other measurement tools, and can be used to derive various types of indicators.

A material flow study can cover any set of materials at various levels of detail, from the complete collection of all resources and products flowing through a system, to groups of materials at various levels of detail, or to specific products. MFA can also be applied to specific materials or even single chemical elements of particular concern (e.g. in terms of the environmental implications of their use, or economic or trade implications).

The most complete applications take a holistic approach and encompass so-called unused or indirect flows of materials that do not enter the economy as priced goods. The underlying rationale is that every movement or transfer of materials or energy from one place to another potentially affects the environment in some way, e.g. by adding to the pollution burden, disrupting habitats, or altering landscapes. Even though the magnitude of such flows is not necessarily the most appropriate proxy for environmental impact, showing unused flows at least raises awareness of a potential problem. A good example is mining overburden, which can be much larger than the actual amounts of the desired mineral ore extracted. Further examples are the pollutants and wastes generated upstream in a production process and that occur outside the system being considered. Most of these flows are hidden and never seen in economic accounts or in trade and production statistics (Box 1).

Material flow accounts (MFAcc) are MFA's basic measurement tool because they provide the structure to the information needed to carry out material flow analysis. They form the basis for many types of analysis, including the calculation of various types of indicators. MFAcc are a special application of physical flow accounts as described in the System of integrated Environmental Economic Accounting (SEEA).

Material flow indicators are important for measuring progress with resource productivity and materials use, and for communicating the results of MF studies to a non-expert audience (general public, high-level decision makers, policy analysts, etc.).

> MFA uses the **principle of mass balancing** to study how materials and energy flow through the economy and the environment within countries and among countries.
>
> The principle of mass balancing is founded on the first law of **thermodynamics** (called the law of conservation of matter), which states that matter (mass, energy) is neither created nor destroyed by any physical process.
>
> This leads to the following **accounting identity**: natural resource extraction + imports = residual output + exports + net addition to man-made stocks

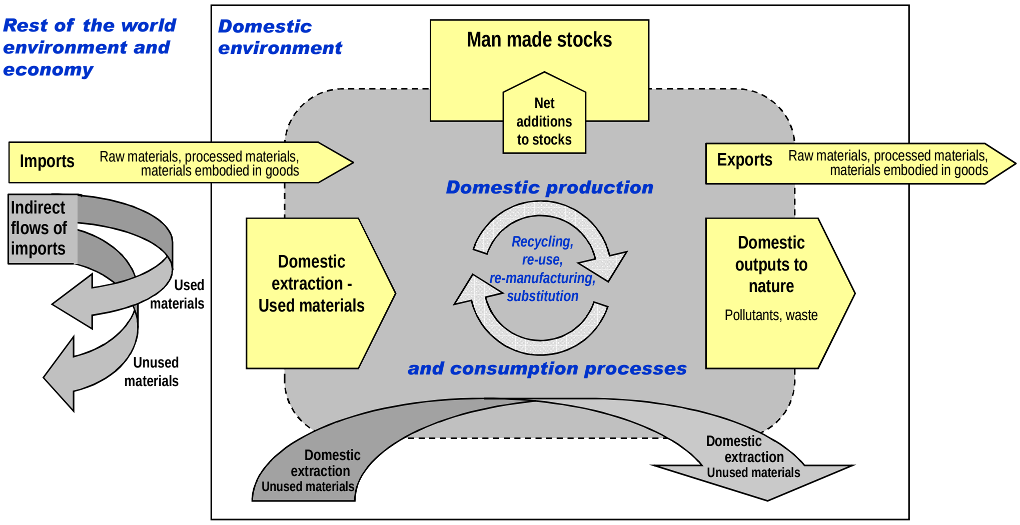
> In the language of MFA, **the word 'material'** denotes the actually observed flows of raw materials, underlying natural resources, products and residuals, which are often a mix of various substances (e.g. fuels, water, timber, plastics, non-ferrous metals, total material throughput), whereas the word 'substance' tends to mean 'pure' chemical elements or compounds (e.g. heavy metals, chlorinated chemicals).

> **Material flow accounts** (MFAcc) are methodically organised accounts in physical units (usually tonnes) that quantify the flows of different types of materials into, out of and possibly within a given system at different levels of detail and completeness.
>
> They record material flows from extraction and harvesting through product manufacture, product use, reuse/recycling and disposal, including discharges to the environment that are associated with each stage of these flows.

[6] Based on OECD (2008), *Measuring material flows and resource productivity – Volume I. The OECD Guide*, *Chapter 3*, OECD, Paris.

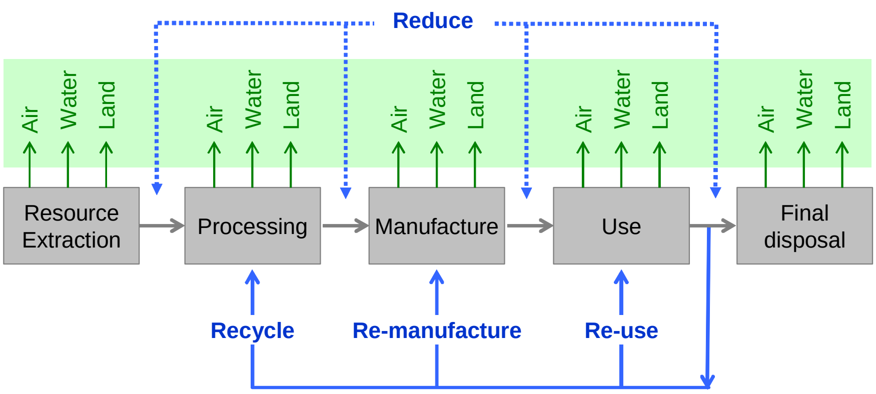
Box 1 Material balance and flow schemes

Economy-wide material balance scheme



- Material resources used in an economy stem from raw materials extracted from natural resource stocks in the country (domestic material extraction) or extracted from natural resource stocks abroad and imported in the form of raw materials, semi-finished materials and materials embodied in manufactured goods.
- Material resources are extracted from the sub-soil and water bodies, or harvested from forests and farm land. The usable parts of these resources enter the economy as material inputs where they become priced goods that are traded, processed and used. Other parts remain unused in the environment. These materials are called "unused materials" or "unused extraction". Examples include mining overburden, soil and rock excavated during construction and not used elsewhere, dredged sediments from harbours, harvest residues.
- Some materials accumulate in the economy where they are stored in the form of buildings, transport infrastructure or durable and semi-durable goods, such as cars, industrial machinery or household appliances. These materials are sooner or later released back to the environment in the form of demolition waste, end-of-life vehicles, e-waste, bulky household waste, etc.
- After use in production and consumption activities, the materials leave the economy as an output either to the environment in the form of residuals (pollution, waste), or to the rest of the world as exports in the form of raw materials, semi-finished materials and materials embodied in manufactured goods.
- When materials are imported for use in an economy, their upstream production is associated with unused materials that remain abroad, and with the generation of residuals (pollution, waste). These "indirect flows" of materials take into account the life-cycle dimension of the production chain, but are not physically imported. Their environmental consequences occur in countries from which the imports originate.

Flows of materials through the commercial life-cycle



Source: OECD.

Six ways to analyse material flows

The type of MF analysis best suited for any particular case depends on the issues of concern and the questions being addressed. One can distinguish two broad groups comprising three types of analysis each. Starting from particular economic activities, businesses, countries, or world regions, the first group of analyses (Type I) focuses on the environmental and economic concerns associated with substances, materials and manufactured goods. The second group (Type II), starting from particular substances, materials, or manufactured goods, examines economic and environmental concerns related to the flows of materials through a given system (called throughputs) at the level of specific businesses, economic activity sectors, countries or world regions (Box 2).

Box 2 Types of MF analysis and associated issues of concern

Issue of concern	Specific concerns related to environmental impacts, supply security, technology development			General environmental and economic concerns related to the throughput		
	within certain businesses, economic activities, countries, regions			of substances, materials, manufactured goods		
	associated with			*at the level of*		
Object of interest	**Substances** chemical elements or compounds	**Materials** raw materials, semi-finished goods	**Products** (manufactured goods) batteries, cars, computers, textiles	**Businesses** establishments, enterprises	**Economic activities** mining, construction, chemical industry, iron& steel industry	**Countries, regions** total materials groups of materials, particular materials
Type of analysis	**Substance Flow Analysis**	**Material System Analysis**	**Life Cycle Assessment**	**Business level MF Analysis**	**Input-Output Analysis**	**Economy-wide MF Analysis**
	⇳	⇳	⇳	⇳	⇳	⇳
Type of measurement tool	**Substance Flow Accounts**	**Individual Material Flow Accounts**	**Life Cycle Inventories**	**Business Material flow accounts**	**Physical Input-Output Tables, NAMEA-type approaches**	**Economy-wide Material Flow Accounts**

Substance flow analysis — Substance flow analysis and accounts (SFA) monitor flows of specific substances (e.g. Cd, Pb, Zn, Hg, N, P, CO_2, CFC) that are known for raising particular concerns as regards the environmental and health risks associated with their production and consumption.

Material system analysis — Material system analysis (MSA) is based on material specific flow accounts. It focuses on selected raw materials or semi-finished products at various levels of detail and application (e.g. cement, paper, iron and steel, copper, plastics, timber, water) and considers life-cycle-wide inputs and outputs. It applies to materials that raise particular concerns as to the sustainability of their use, the security of their supply to the economy, and/or the environmental consequences of their production and consumption.

Life cycle assessments — Life cycle assessments (LCA) are based on life cycle inventories. They focus on materials connected to the production and use of specific products (e.g. batteries, cars, computers, textiles), and analyse the material requirements and potential environmental pressures along the full life cycle of the products. LCA can equally be applied to services, and are standardised in ISO 14010.

Business level MFA — Business level material flow analysis and accounts monitor material flows at various levels of detail for a company, a firm or a plant.

Input-Output analysis — Input-Output analysis (IOA) is based on physical input-output tables (PIOTs) that record material flows at various levels of detail to, from and through the economy, and by economic activity and final demand category. It can also make use of NAMEA-type tables or of hybrid flow accounts.

Economy-wide material flow analysis — Economy-wide material flow analysis (EW-MFA) is based on national economy-wide material flow accounts (EW-MFAcc) that record all materials entering or leaving the boundary of the national economy. Data from these accounts can easily be aggregated for communication purposes and serve as a basis for deriving aggregated MF and RP indicators. EW-MFAcc build on a fairly detailed data basis that, if well structured, can be used for many other purposes (e.g. in-depth analysis; material specific indicators).

Source: OECD, based on Bringezu and Moriguchi (2002).

Analysing material flows at macro-, meso- and micro- levels

MFA can be applied to a wide range of economic, administrative or natural entities, studying the flows of materials within the global economy or the economy of a region or country (macro level), within an economic activity (meso level), within a city, river basin or ecosystem, a firm or a plant (micro level).

Macro-level

Macro-level MFA is particularly useful to support decisions in areas such as economic, trade and environment policy integration, sustainable development strategies and action plans, and national waste management and resource conservation policies.

The main measurement tools to support macro-level MFA are economy-wide MFAcc (EW-MFAcc), which in their simplest form, consider the economic system itself as a black box. These accounts are compiled in a physical accounting framework as described in the SEEA handbook. The emphasis is on material exchanges between the economy and the environment, and on material accumulations in national economies, rather than on flows within the economy (Box 1).

Economy-wide MFAcc are relatively easy to compile for direct national input flows of used material (i.e. flows entering the economy) as data are abundant. This is not the case, however, in terms of indirect flows and unused extraction. Indirect flows need to be estimated by the use of modelling and inclusion of additional data.

Meso-level

Meso-level MFA enables a more differentiated tracking of information and analyses material flows at finer levels of detail within the economy, distinguishing not only categories of materials or individual materials, but also industries or branches of production. Meso-level MF information is particularly useful to track structural changes at macro- and global level, to monitor developments in resource productivity (RP) and environmental performance at the meso level. It helps detect waste of materials, pollution sources and opportunities for efficiency gains in specific sectors, and serves as a basis for deriving related indicators.

At industry level, the main measurement tools to support MFA are physical input-output tables (PIOTs) and NAMEA-type tables[7]. Accounts following these approaches are compiled in a physical accounting framework in the form of physical supply and use tables (PSUs) as described in the SEEA handbook. For particular materials, the main measurement tools to support meso-level MFA are individual national MFAcc and natural resource accounts based on the materials balance principle. Data from such

Questions that can be addressed at the macro-level:

- What is the material basis of an economy? What is the level and composition of the domestic demand for materials?
- What is the material productivity of an economy and how does it relate to labour and capital productivity?
- To what extent are material inputs into the economy coupled with economic output? with pollutant and waste generation?
- How much of the materials required to sustain the economy can be supplied from domestic sources? What is their composition?
- How dependent is the national economy on external markets? On imported materials? On demands from external markets?
- What are the underlying material intensities of imported goods?
- Which materials leave the economy as exports, and as releases to the environment (pollutants, waste)?
- How much material accumulates in the economy in the form of stocks (buildings, infrastructure, durable goods, etc.)?
- How much material is removed from nature to sustain the economy without being used? At home, abroad, worldwide?

Questions that can be addressed at the meso-level:

- How resource- and residual-intensive are industries and product groups? What is their share in the generation of residuals?
- Which demands for final products influence the generation of residuals most?
- How resource- and residual- intensive are domestic consumption, investments, exports?
- What is the level of the demand for a given material?
- What is the origin of a material? How much is produced domestically or imported? How do flows of a given material shift among countries or world regions? Are there risks of supply disruptions?
- What are the raw material requirements for the full cycle of materials use?
- How efficiently is the material used within the system? How much is used or stocked and where? How much becomes waste, how much is recycled, how much goes to final disposal?

[7] National Accounting Matrices including Environmental Accounts (NAMEA).

accounts are useful for analysing the magnitude of given material flows, their economic and environmental consequences, detecting supply problems, and pointing at unnecessary waste and emissions of the material in the economy and at the related environmental burden and risks.

Micro-level

Micro-level MFA provides detailed information for specific decision processes at business (company, firm, plant) or local level (city, municipality, ecosystem, habitat, river basin) or concerning specific substances or individual products. MF information from business-level MFAcc or mass balances is useful to monitor developments in resource productivity and environmental performance at the company or plant level (Figure 1). Micro-level MFA supports the implementation of policies and decision in areas such as product policies, energy efficiency, integrated waste management, sustainable materials management, IPPC. It helps set corporate strategies on investments and emissions, and monitor the availability of critical resources and the vulnerability of a company or a plant to disruptions in the supply chain.

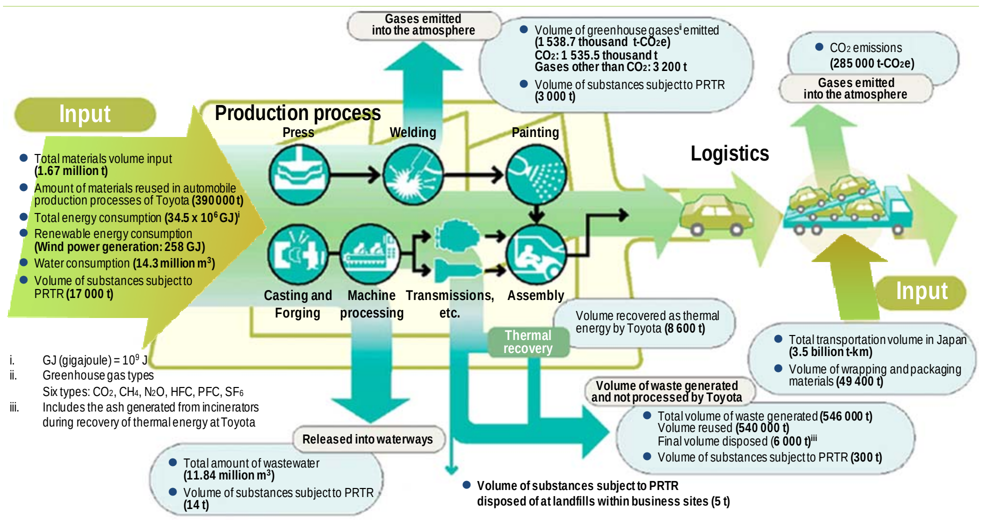
Questions that can be addressed at the micro-level:

- Where and how much of substance X is flowing through a given system? Where do flows of a substance X end up? How much of substance X is stored in durable goods? is flowing to wastes?
- Where are potentials to use substance X more efficiently in technical processes?
- Where are options for substituting the harmful substance?
- Where do substances end up once they are released into the natural environment?
- Which environmental pressures occur along the life cycle (extraction, processing, use, disposal) of individual products?
- Where can environmental pressures along a product's life cycle be managed and controlled best?
- What are the life-cycle-wide environmental pressures of product A as compared to those of product B?
- What is the resource intensity of a product?

Particularly useful at micro-level are substance flow accounts and analyses (SFA) that quantify the pathways of specific chemical substances or compounds (e.g. chlorine, mercury, nitrates) within a given system. SFA provides information that supports the management and control of hazardous substances that threaten human health or ecosystems.

Another micro-level application is a Life Cycle Inventory (LCI) as a standard step in Life Cycle Assessment (LCA), which is a widespread tool in product-related environmental policies. LCA allows the analysis of the problems related to a particular product, comparing improvement variants of a given product, designing new products, and choosing between several comparable products. In the LCI phase all material and energy flows related to the life cycle of a product are systematically taken into account. LCA can also be applied to the macro-level by using a bottom-up approach.

Figure 1. Analysing material flows at business level: the example of the automobile industry



Source: Toyota Motor Corporation (2005).

How does MFA relate to other information tools?

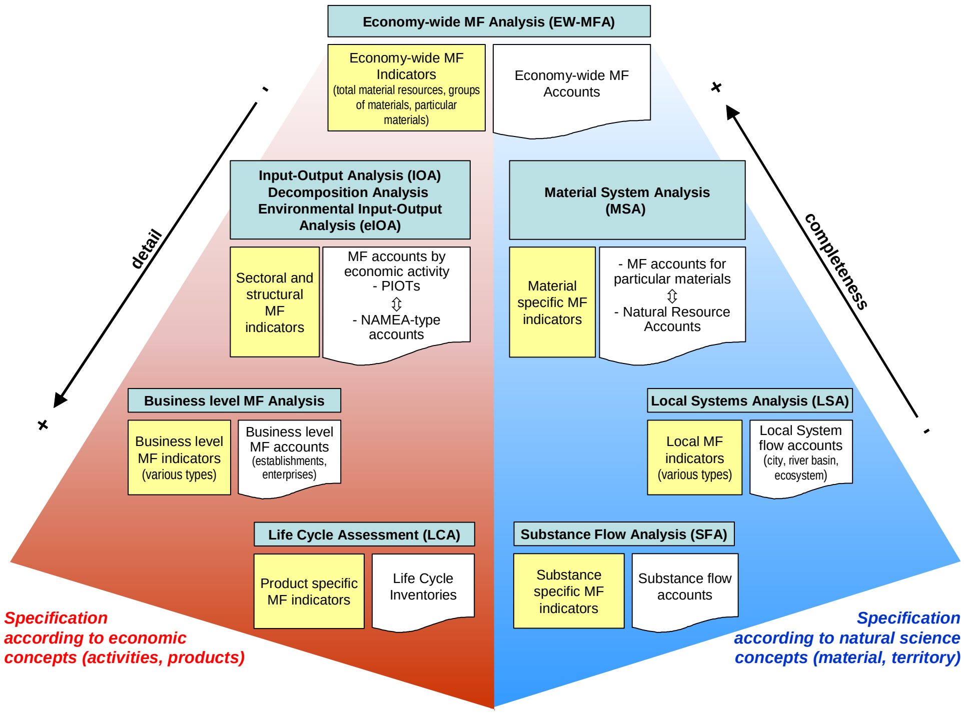
To give the insights needed, the various MFA tools should be positioned within a broader architecture of accounts, indicators and analytical tools, including economic modelling and qualitative assessments. This helps see the interrelationships between different types of information tools, and identify the most appropriate level of detail for a given purpose, taking into account the resources and expertise available (Table 1, Figure 2).

Table 1 Links between MFA and other information tools

Economic information and analysis	
Monetary input-output tables	National MFAcc in which inputs and/or outputs of the system are disaggregated by industry can be connected to monetary input-output tables to establish so called hybrid flow accounts in the context of integrated environmental and economic accounting. This helps attribute the use of materials and the associated generation of residuals to their ultimate economic purpose, i.e. the delivery of final products and services to consumers and investors, disaggregated by product groups or industries and by kind of final demand.
National economic accounts	Data from national MFAcc can be linked with data from national economic accounts and their aggregates without changing either type of account, assuming that both accounts are constructed using the same concepts and classifications. This helps calculate various types of resource efficiency indicators (intensity and productivity ratios, decoupling indicators).
Value chain analysis	Material flow analysis of particular industrial materials, such as metals, can be combined with value chain analysis(b) (VCA) to shed further light on concepts such as resource productivity and their relation to labour productivity, raw material prices and competitiveness. This is a potentially very powerful way of analysing issues related to sustainable resource management, in particular at business level, but also at global level.
Market prices, resource rents, etc.	Among other links that merit attention are those between trends in material flows (domestic, international) and trends in market prices of certain materials or groups of materials and trends in resource rents.
Environmental information and analysis	
Environmental accounts	Linking MF information with information derived from natural resource accounts (e.g. water, forest, land, energy) and from specific environmental accounts such as waste accounts is important to relate natural resource use and material flows to the stocks of natural resources available for use, and to give a comprehensive picture of the physical flows of materials.
Environmental information	Linking MF information with information describing specific environmental issues or derived from tools such as Pollutant Release and Transfer Registers (PRTR), air emission inventories, and waste statistics are important to enhance the policy-relevance and interpretability of MF indicators, to relate MF indicators to environmental pressures and impacts, and detect shifts in environmental pressures from materials use between environmental media (air, land, water), economic activity sectors or countries and world regions. Links with environmental information are also important to populate national MFAcc.
Environmental input-output analysis	Environmental input-output analysis (or extended IOA) refers to the application of input-output techniques to the study of the relationships between the functioning of the socio-economic system and environmentally relevant variables, especially expressing the pressures exerted by production and consumption on the natural environment (material flows to and from the natural environment).
Forecasting tools	
Outlook studies and scenario development	MF information can be applied in outlook studies and scenario development to study future demands for materials and natural resources and related use and trade patterns. This provides a basis for informed policy development and implementation, including ex-ante and ex-post evaluation of policy performance. Life cycle inventory modelling and LCA can be combined with technology forecasting scenarios (e.g. higher efficiency) to estimate the to-be expected environmental impacts of future technologies. Sectoral MF indicators can be coupled with economic models distinguishing between different economic activity sectors in order to simulate business-as-usual or alternative developments.
Econometric modelling	Aggregates from MFAcc and derived indicators can be used in econometric modelling, for example as elements of cost functions, or as endogenous variables in order e.g. to forecast future demand for strategic materials.
World economy models	Aggregates from MFAcc can be included in world economy models where they have a great potential for integrated analysis of the economic and environmental aspects of world-wide economic development and globalisation, of environmental burden-shifting phenomena or price implications of growing world demand.

Source: OECD.

Figure 2 Architecture and levels of application of MFA tools



When analysing material flows, emphasis can be put on:

❶ all materials entering and leaving the national economy (top of the Figure);

❷ the industry level, enterprise level, and product level, from product groups down to specific products (left hand side of Figure);

❸ certain material and substance flow systems, from the national down to the local level (right hand side of Figure); or

❹ a combination of the different types of specifications.

Source: OECD.

3. WHICH POLICY AREAS WOULD BENEFIT MOST FROM MFA? [8]

As will be made clear throughout this document, MFA more generally enhances the understanding of the material basis of the economy and affords insights into the interaction between economic policy and natural resource and material flows. MFA achieves this by using already available production, consumption and trade data in combination with environment statistics (on waste, emissions, etc.), and by improving modelling capacities. MFA also helps identify inefficient use of natural resources, energy and materials in process chains or the economy at large that would go undetected in conventional economic or environmental monitoring systems.

MFA does not lead to any particular policy. Its characteristics make it rather a useful tool for examining trade-offs between policies and for understanding the implications of decisions that depend on interrelationships in the economy and the environment. It can be used to analyse issues that cut across different media and policy areas and support decisions that have economic, environmental and social implications.

Experience suggests MFA is particularly useful in three broad policy areas: (i) economic, trade and technology development policies; (ii) natural resource management policies; and (iii) environmental

[8] Based on OECD (2008), *Measuring material flows and resource productivity – Volume I. The OECD Guide*, *Chapter 2*, OECD, Paris.

policies. The three policy areas overlap because they are all concerned with particular aspects of resource use and management. Potentially, a wide range of government agencies, ministries and departments will find use for these types of analysis.

MFA is only one approach amongst others, but it is the only tool that can:

- provide an integrated view of resource flows through the economy;
- capture flows that do not enter the economy as transactions, but that are relevant from an environmental point of view;
- reveal how flows of materials shift within countries and among countries and regions, and how this affects the economy and the environment within and beyond national borders.

The different MFA tools can be combined to gain additional insights and can easily be adapted to suit countries' specific circumstances.

Value of MFA for economic, trade and technology development policies

The supply of materials for use in economic activity depends on a country's endowment in natural resources as well as on its access to external sources of material through imports. The more efficiently a country can use natural resources and materials, and the better it is able to innovate and develop new technologies, the less any bottlenecks in the supply of resources will constrain its economy. At international level, the supply of materials is influenced by their geographical distribution[9], by worldwide demand for, and market prices of materials, as well as by political, institutional and regulatory factors.

At the national level, material flow accounts provide information expressed in physical units (usually tonnes) paralleling the information presented in national economic accounts. Such accounts can show how economic performance can be improved by reducing inefficiencies in the use of energy and materials (Table 2).

In the trade area, MFA can show the materials relationships between a country and international markets. It will bring to the fore the role of the rest of the world (i) as a user of a country's raw materials, goods and services, and (ii) as a provider to fulfil a country's demand for them (Figure 5). Such information can reveal opportunities for national economies in a global market to avoid supply disruptions. It will also help in analysing the effect of changes in worldwide demand and supply for various materials on the global economy and environment (Table 2).

MFA can further be used to help understand the economic, material, energy, health and environmental implications of new technologies and identify areas for further research. This usually requires quite detailed MFA analysis (even at the product level) combined with an analysis of the relevant value chain. Practical applications are not yet well developed (Table 2).

Value of MFA for natural resource management policies

Natural resource stocks, both renewable and non-renewable, are a major foundation of economic development and when these stocks are depleted or degraded, they cannot easily be restored or replaced.

Information systems based on MFA complement and enrich conventional natural resource and energy accounts by providing system-wide lifecycle information on the status and trends of natural resources. Such information can be used to encourage more sustainable use of resources and to integrate the work of different agencies and sectors managing the same natural resource (Table 2).

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9 When development relies heavily on a particular resource that is geographically concentrated (such as certain minerals or oil) this can put the supply of that resource to economic activities at risk (e.g. in case of political instability or weak governance, in case of natural disasters).

Value of MFA for environmental policies

After focussing initially on individual media (air, water, land) and pollution sources, and adopting an end-of-pipe approach, environmental policy gradually evolved towards a more result-oriented approach, with greater emphasis on preventive and integrated approaches, increased use of cleaner technologies and of mixes of policy instruments. Examples of preventive and integrated policies include: integrated pollution prevention and control (IPPC), ecosystem-based water management, integrated product policy (IPP), green purchasing policies, sustainable building, and sustainable materials and waste management as reflected in 3R "reduce, reuse, recycle" programmes and in "circular economy" initiatives.

MFA complements and enriches conventional media-based environmental information systems. By adopting a systems perspective, MFA makes it possible to, for instance, identify environmental releases associated with i) different stages of a particular material flow (e.g. releases from extraction or production versus use or disposal) or ii) the flows of different materials. These types of analysis will improve understanding of the driving forces behind the environmental burden. Greater insight will then help decision makers to prevent environmental problems, reduce inefficiencies in materials use, and improve resource productivity (Table 2).

Table 2. Applicability of MFA to policy making

Policy areas		**Relevant MFA functions**	**Appropriate MFA tools**	**Examples of applications**
Economic, trade and technology development policies	Economic policies	♦ Measure aspects of the physical performance of the economy and relate it to its economic performance. ♦ Analyse the materials requirements for activities that involve construction, reconstruction, maintenance and disposal of infrastructure. ♦ Measure the degree of "decoupling" between direct and indirect environmental pressures (pollution, waste, primary resource inputs) and economic growth	♦ Economy-wide MFA ♦ Physical I-O analysis *In conjunction with*: ♦ Productivity measures ♦ Economic modelling ♦ Analysis of energy requirements	*United Kingdom*: business sector study on iron, steel and aluminium flows (Biffaward Mass Balance programme); *USA*: WRI study; *Austria*: study on the economic and employment effects of resource savings *Germany*: raw material productivity; PIOTs *European Union*: Mosus project; *Japan*: national resource productivity indicators in support of the Government's Fundamental Plan for establishing a sound material cycle society
	Trade aspects & supply patterns	♦ Support structural analysis of the global economy in physical terms: effects of globalisation on international material flows; substitution of domestic raw materials with imported ones; interaction with production & consumption patterns. ♦ Monitor the structural effects of trade and environment measures on international materials markets and on flows of environmentally significant materials (e.g. hazardous materials; secondary raw materials, recyclable materials). ♦ Monitor the environmental implications of changes in international material flows, including (i) environmental pressures from indirect flows abroad associated with trade; (ii) environmentally significant materials embedded in imported goods; (iii) environmental risks related to international transport of materials, etc.	♦ Economy-wide MFA covering trade flows by origin/destination; ♦ Physical I-O analysis; ♦ Environmental I-O analysis; *In conjunction with:* ♦ Monetary I-O tables; ♦ International trade statistics; ♦ International transport statistics.	*Japan*: study on world resource flows around Japan (e.g. aluminium flows and associated CO2 emissions); *Italy*: research study on indirect material flows associated with imports *European Union*: research study on environmental impacts of natural resource trade flows into the EU
	Technology development	♦ Guide the development of new technologies and identify those that would severely strain material availability or generate excessive additional environmental pressures. ♦ Identify potential areas for research on substitutions of materials and on the availability of materials for the development of new technologies. ♦ Detect opportunities for new technologies that help reduce inefficiencies in energy and materials use, increase domestic reuse or recycling and the use of alternative materials.	♦ Material system analysis and material specific accounts; ♦ Life cycle analysis of products *In conjunction with:* ♦ Value chain analysis	*Japan*: use of MFA in the automobile industry and in other industries (iron&steel, cement, chemicals, paper, construction, home appliances); *United Kingdom*: studies by the business sector on various material flows (Biffaward, Mass Balance programme).

Policy areas		Relevant MFA functions	Appropriate MFA tools	Examples of applications
Natural resource management policies		♦ Assess the status and trends of a country's natural resources. Monitor sustainable production levels (e.g. forest resources) and support related management plans. ♦ Examine the demand, scarcity and raw material requirements, based on the full material cycle and understand what is behind price and production trends in commodities over extended periods of time. ♦ Assess mineral systems by tracking (i) raw materials used in the economy, (ii) the flow of a specific material in the economy as a commodity (iii) the flow of different materials as a product, (iv) material stocks in use, reuse and disposal in a country. ♦ Assess energy systems by tracking energy carriers used in the economy, by giving insights into multiple uses, including non-fuel uses (e.g. plastics, synthetic fibres).	♦ Material system analysis and resource specific accounts; *In conjunction with:* ♦ Natural resource accounts ♦ Information on proven reserves and rates of discovery. ♦ Energy accounts and statistics ♦ Modelling	*Australia*: Accounting for water resources to support negotiations on water allocation. *USA*: studies of world metal flows (copper, zinc, silver, nickel, etc.) by the Yale University, Stock and Flows project. *Japan*: Material and carbon flows of harvested wood. *Canada*: Material and Energy flow accounts
Environmental policies	Pollution prevention & control	♦ Map the flows of nutrients or contaminants in a region, country or river basin and identify whether, where and to what extent these flows contribute to environmental degradation "downstream". ♦ Estimate environmental pressures from metal ore extraction and metal production, the part due to inefficiencies in production technologies and the benefits that could be gained from new technologies and from improved recovery and recycling. ♦ Monitor and help understand indirect and unused materials flows and their effects on the environment, at home and abroad.	♦ Economy-wide MFA with detailed breakdown of materials. ♦ Substance flow analysis. ♦ Material system analysis and material specific accounts. *In conjunction with:* ♦ Waste statistics & accounts	*Sweden*: study of mercury, lead and copper flows in the Stockholm area. *Sweden*: study on chemical products in industry. *Denmark*: mass flow analyses of mercury (project financed by the Danish EPA). *USA*: study of heavy metals and other hazardous substances in the New York/New Jersey harbour. *USA*: mapping of nitrogen flows in the Mississippi Basin (USGS). *USA*: study on chlorine flows (research project, Yale University).
	Waste and materials management	♦ Analyse trends in waste generation, and how they affect opportunities for (i) resource conservation, (ii) resource productivity, and (iii) material recovery and recycling. ♦ Assess the economic benefits and costs to keeping materials in the active materials stream and to minimising the amounts going to final disposal. ♦ Assess developments in markets for reused and recyclable materials. ♦ Identify areas for research on (i) energy conservation and recovery, (ii) materials recycling, (iii) alternative materials and (iv) new technologies.	♦ Various MFA tools distinguishing between primary and secondary raw materials, and recyclable materials. *In conjunction with:* ♦ Waste statistics & accounts ♦ Cost benefit analysis ♦ Modelling	*Japan*: waste and recycling indicators in support of the Government's Fundamental Plan for establishing a sound material cycle society. *Austria*: use of material balances and life-cycle analysis to determine the effects of product re-use on resource conservation (applied to electrical and electronic household appliances). *Norway*: waste accounts. *United Kingdom*: business sector studies, (Biffaward, mass balance programme).
	Product related policies	♦ Examine source reduction, substitution, and recyclability of the materials composing a product and help understand the synergistic nature of the flows of these materials. ♦ Examine environmental impacts of products, in particular products with toxic ingredients (e.g. lead paint, asphalt roofing, batteries with cadmium). ♦ Explore design issues that affect the environment at end of product life, and identifying leverage points for green design and pollution prevention, and implications of a policy shift (e.g. ban on use of certain materials in particular products).	♦ Life cycle assessments	*Many applications (business sector, research institutes, government departments)*
	Other	♦ Analyse the effects of environmental policy instruments on material flows and on the material supply mix. ♦ Analyse the benefits of government purchasing policies (e.g. for the availability of recycled or redesigned products to the market), and how they affect material flows ♦ Monitor environmental performance targets with industry and government.	♦ Various MFA tools *In conjunction with:* ♦ Cost benefit analysis ♦ Modelling ♦ EMS	

Source: OECD.

4. MEASURING PROGRESS WITH MATERIAL FLOW INDICATORS[10]

Function, audience and types of indicators

Material flow (MF) indicators provide insight into the economic efficiency and environmental effectiveness of materials use in the production and consumption chain, up to final disposal. Such indicators are derived from any of the MFA tools described earlier, as well as from other statistics. They can cover any set of materials at various levels of detail and application[11]. They report on:

- The level and characteristics of physical resource use by an economy or activity.
- The environmental aspects of material resource use at national and international level.
- The effects of environmental and economic policies on materials use, and the implications of trade and globalisation for national and international material flows.

> **Material flow indicators** are quantitative measures, which point to, inform about, describe, the characteristics of material flows and material resource use and which have a meaning or a significance that goes beyond that directly associated with the underlying statistics.
>
> The term "material flow indicators" designates all indicators that report on material flows and material resource use, ranging from aggregated measures to measures of individual material flows, including substance flows.

A key function of MF indicators is to communicate the results of MF analysis and accounting in a way adapted to users' needs. Often, some degree of simplification is necessary, involving a trade-off between an indicator's relevance for users and policies and its statistical quality, analytical soundness and scientific coherence. Indicators should therefore be regarded as reflecting the "best knowledge available" and need to be embedded in larger information systems (e.g. databases, accounts, monitoring systems, models).

MF indicators are particularly useful for non-expert audiences: the general public, journalists, managers and decision makers in the business and government sectors, policy-makers, including parliamentarians, and stakeholders from NGOs. They should therefore convey messages in a meaningful way that reduces the complexity and level of detail of the original data and address concrete questions (Box 3).

Box 3 Questions addressed by material flow indicators

❶ What are the material requirements of an activity or an economy?
Which and how much material resources are used for what purposes? How much is non-renewable vs. renewable, primary raw material vs. secondary raw material? How does this change over time? How does this relate to available stocks of natural resources?

❷ How dependent is an activity or an economy on external material inputs or external material markets?
How much stems from own vs. foreign territory (resilience, dependence, supply security)? How does this change over time? To what extent do international material flows shift between countries and world regions? How does this relate to foreign outsourcing, international trade and market prices for materials?

❸ How efficiently are material resources being used?
Are valuable resources wasted unnecessarily? What is the level of coupling or decoupling of economic growth, resource use and environmental pressures? How does this relate to the productivity of the economy, of industrial sectors?

❹ What is the potential for improving resource productivity?
What opportunities arise from improved materials management and resource policy? How does this relate to labour and capital productivity?

❺ What are the main environmental risks and pressures associated with material resource use?
Where in the material cycle (extraction, processing, consumption, disposal) are these risks located and how do they change over time?

❻ What are the main environmental consequences of international material flows?
How do these consequences change over time and shift between countries and world regions?

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10 Based on OECD (2008), *Measuring material flows and resource productivity – Volume I. The OECD Guide*, *Chapter 4*, OECD, Paris.

11 In this report, emphasis is put on indicators that can be used to support the development and implementation of national policies and international work.

Most MF indicators correspond to the main variables of MF accounts in accordance with the materials balance scheme and describe the use of materials in the economy at the different stages of the flow chain. The main types of indicators are: input indicators, consumption and balance indicators, and output indicators. These indicators can be combined with each other to give a balanced picture of the issue described. They can also be combined with economic indicators to construct efficiency ratios (Table 3).

Table 3 Main types of material flow indicators

Input indicators describe the materials mobilised or used for sustaining economic activities, including the production of export goods and services. They are closely related to the mode of production of a particular country or region. They are sensitive to changes in the level and patterns of foreign trade and to other factors such as a country's endowment in natural resources, and its level of technology development and uptake.	
Domestic extraction used (DEU)	DEU measures the flows of materials that originate from the environment and that physically enter the economic system for further processing or direct consumption (they are "used" by the economy). They are converted into or incorporated in products in one way or the other, and are usually of economic value.
Direct Material Input (DMI)	DMI represents materials supply. DMI measures the direct input of materials for use into the economy, i.e. all materials that are of economic value and are used in production and consumption activities; DMI equals domestic (used) extraction plus imports.
Total Material Requirement (TMR)	TMR includes, in addition to TMI, the (indirect) material flows that are associated to imports but that take place in other countries. It measures the total 'material base' of an economy. Adding indirect flows converts imports into their 'primary resource extraction equivalent'.
Consumption indicators describe the materials consumed by economic activities. They are closely related to the mode of consumption and are fairly stable over time. The difference between consumption and input indicators is an indication of the degree of integration of an economy with the global economy, which also depends on the size of the economy.	
Domestic Material Consumption (DMC)	DMC represents materials use. DMC measures the total amount of material directly used in an economy (i.e. the direct apparent consumption of materials, excluding indirect flows). DMC is defined in the same way as other key physical indictors such as gross inland energy consumption. DMC equals DMI minus exports.
Total Material Consumption (TMC)	TMC measures the total material use associated with domestic production and consumption activities, including indirect flows imported (see TMR) but less exports and associated indirect flows of exports. TMC equals TMR minus exports and their indirect flows.
Balance indicators describe the physical growth of materials within the economy. They show net flows of materials added to the economy's stock each year taking into account gross flows added and removed from the stocks, or taking into account just materials coming from the international trade (physical trade flows). Balance indicators supplement consumption indicators.	
Net Additions to Stock (NAS)	NAS reflect the physical growth of the economy, i.e. the net expansion of the stock of materials in buildings, infrastructures and durable goods. NAS may be calculated indirectly as the balancing item between the flow of materials entering the economy minus those leaving it, taking into account the appropriate items for balancing. NAS may also be calculated directly as gross additions to material stocks, minus removals (such as construction and demolition wastes and disposed durable goods, excluding materials recycled).
Physical Trade Balance (PTB)	The PTB reflects the physical trade surplus or deficit of an economy. It is defined as imports minus exports (excluding or including their hidden flows).
Output indicators describe the material outflows related to production and consumption activities of a given country. They account for those materials that have been used in the economy and are subsequently leaving it either in the form of emissions and waste, or in the form of exports.	
Domestic Processed Output (DPO)	DPO represents the waste and pollution from materials use. DPO measures the total weight of materials extracted from the domestic environment or imported, which after use in the economy flow back to the environment. These flows occur at the processing, manufacturing, use, and final disposal stages of the production-consumption chain. Included are emissions to air, industrial and household wastes deposited in landfills, material loads in wastewater and materials dispersed into the environment as a result of product use (dissipative flows).
Total Domestic Output (TDO)	TDO represents the environmental burden of materials use, i.e. the total quantity of material outputs to the environment caused by economic activity. TDO equals DPO plus unused domestic extraction.
Efficiency indicators relate economic output indicators (such as GDP or value added) to economy-wide or sectoral MF indicators, thus providing information about the material productivity or intensity of the economy or economic activity sectors.	
GDP per DMI	GDP per DMI indicates the direct materials productivity
GDP per DMC	GDP per DMC indicates the domestic materials productivity
GDP per TMR	GDP per TMR indicates the total material productivity.

Source: OECD.

Input and consumption indicators are sometimes used as proxies for the generic environmental pressure on the assumption that sooner or later every material input becomes an output in the form of waste or emissions, and that measuring the inputs therefore gives a first approximation of the overall environmental burden. This should however not be interpreted as reflecting actual environmental impacts.

Reservations about the use of MF indicators often concern highly aggregated indicators and the fact that they can hide important variations in their constituent variables. For example, quantities of particular materials flows can vary considerably from year to year, as can monetary values, while the aggregated figure may remain constant. Also, the value of highly aggregated indicators can be dominated by one single material group that masks developments in other material groups. Proper interpretation of such an indicator therefore requires documentation or breakdown of the indicators. Furthermore, problems arise when aggregated input or consumption indicators are mistakenly assumed to reflect the environmental impacts of material resource use. Aggregate weight measures do not consider any characteristic of materials other than weight. The actual environmental pressure of material flows and the subsequent impacts on environmental conditions however depend on many factors, such as the chemical and physical properties of the materials, the locality at which ores are mined or pollutants released, or the way the materials are managed across their life-cycle.

Using material flow indicators

The appropriate use and interpretation of MF indicators in policy analysis is subject to the same caveats normally applied to other types of indicators (e.g. the need to always consider context). Most indicators need qualification, due to methodological and empirical shortcomings, and careful interpretation, due to differences among economies related to factors such as resource endowment, geography, demography and technology.

Among other factors that play a role, are the level of aggregation of the indicators, and the way they can be related to environmental issues, to economic demand and supply issues, and to globalisation and trade issues.

One should therefore not forget the efforts that need to be made to inform the users, the interested public and the press about the value, objectives and limits of the indicators derived from MFA. This turns out to be a key element to ensure proper use and interpretation of MFA results.

Adding reference values such as benchmarks, thresholds, baselines, goals or targets will help users better understand the significance of the indicator values, and enables comparisons between data that are otherwise not easy to compare. A reference value might be a:

- qualitative objective (aim, goal), e.g. "reduced consumption of non-renewable natural resources with focus on minerals, metals and fossil fuels" (EC, 2003);
- a target (distance to target), e.g. "resource productivity will improve by 40% by 2010 compared to the baseline year 2000" (Government of Japan, 2003);
- a baseline (distance to a certain state);
- a threshold value (distance to a collapse);
- a reference year (change in time); or
- a benchmark (difference with another country or entity).

Answering questions with the help of MF indicators

What are the material requirements of an economy or an activity?

Questions about the material requirements and the material basis of an economy or an industry should be answered with the help of input or consumption indicators. They can be expressed in absolute values or be normalised by relating them to population data. These indicators group materials in mass units (usually tonnes). Examples are: direct material inputs (DMI), total material requirements (TMR), domestic material consumption (DMC) or total material consumption (TMC).

Such indicators are particularly useful to give an overview of opportunities and problems in material and energy flows, attract attention to key trends and changes, and support broader policy goals. Their information value is greatly enhanced when they are associated to objectives or targets such as those included in national sustainable development strategies or circular economy programmes, and when they are broken down into their constituent variables.

- Indicators broken down by type of material (grouped on the basis of some common characteristic) should answer questions about the materials mix flowing into an economy. This helps see the weights of different types of materials in the overall material basis of the economy, including how these weights change over time. The most common way to reveal the materials mix is to use basic material groups as they appear in MF accounts. This results in the presentation of between five and up to 12 major material groups: metals (metallic ores and metal-based products), non-metallic industrial minerals, construction minerals, fossil energy carriers (oil, coal, gas, others such as peat), biomass (food crops, fodder crops, timber, wild animals, other).

- Other ways of grouping materials provides answers to different questions. For instance, grouping according to the type of natural resource from which they are extracted, such as materials from renewable natural resource stocks versus materials from non-renewable natural resource stocks, or abiotic materials versus biotic materials provides a picture of the share of materials from renewable natural resource stocks in direct material inputs or in total material requirements.

- Indicators broken down by major economic activity answer questions about the overall consumption of materials and the generation of emissions and wastes by a specific sector. The weight of various sectors and industries will differ significantly and also change over time. A decrease in material consumption in one industry can be offset by an increase in another, which would result in a shift of problems rather than in alleviation. MF indicators in this category should be aligned with the International Standard Industrial Classification of All Economic Activities (ISIC).

How efficiently are materials resources being used and what is the potential for improving resource productivity?

Improving the productivity of member countries' economies has been a key interest of the OECD for many years. Capital productivity and labour productivity have been, and remain, central concepts in the measurement of productivity. Extending productivity measurement and analysis to material resources to complement existing productivity measures like labour and capital productivity is one of the purposes of MF indicators. Used in parallel, the three indicators afford a much deeper understanding of total factor productivity than is possible with only one or two indicators.

Material productivity[12] indicators can be applied at the national level, at sectoral level or to particular industries.

[12] Material productivity is defined as the quantity of output produced per unit of materials inputs used in the production of the output. Material intensity indicators are the inverse of productivity indicators. Decoupling indicators describe the relationship between the use of natural resources and materials and economic growth or industrial activity.

At the national level, they are particularly useful to:

- Monitor the decoupling of material resource use from economic growth;
- Compare different levels of material resource use and productivity among countries and serve as a basis for further research to reveal the factors responsible for the differences;
- Identify resource – and hence also emission – intensive sectors also facing particular challenges with respect to resource productivity and sustainable resource use.

At the sectoral or industry level, these indicators are useful to show structural changes in material productivity at national level, and differentiate among industrial sectors that may exhibit differences in material and resource productivity. The material use productivity of particular economic activity sectors or industries can be revealed by MF indicators broken down by these sectors and linked to the appropriate economic variables, i.e. the gross value added of the same sectors (Figure 3).

Some examples of material productivity indicators are:

- Domestic material productivity represents the amount of materials used to generate one unit of gross domestic product (GDP/DMC).
- Total material productivity represents the total amount of materials extracted, moved or used to generate one unit of gross domestic product (GDP/TMR). Total material productivity is the most complete indicator from an environmental point of view, but is difficult to measure due to the inclusion of unused and indirect flows.
- Direct material productivity represents the amount of materials used as inputs in the economy to generate one unit of gross domestic product (GDP/DMI).
- Raw material productivity represents the raw material inputs, i.e. sum of raw materials extracted in the country (considering the portion actually used) and imported materials in the form of raw materials, used to generate one unit of gross domestic product or value added (at constant prices) (GDP/RMI). It describes the efficiency with which raw materials are used in the national economy.

The term **material productivity** refers to the effectiveness of an economy or a production process in using materials extracted from natural resources. Material productivity can be defined with respect to:

- **Economic-physical efficiency**, i.e. the money value added of outputs per mass unit of material inputs used. The focus is to decouple value added and material consumption.
- **Physical or technical efficiency**, i.e. the amount of material input required to produce a unit of output, both expressed in physical terms (e.g. iron ore inputs for crude steel production or raw material inputs for the production of a computer, a car, batteries). The focus is on maximising the output with a given set of inputs and a given technology, or on minimising the inputs for a given output
- **Economic efficiency**, i.e. the money value of outputs relative to the money value of inputs. The focus is on minimising material input costs and/or maximising the value of outputs.

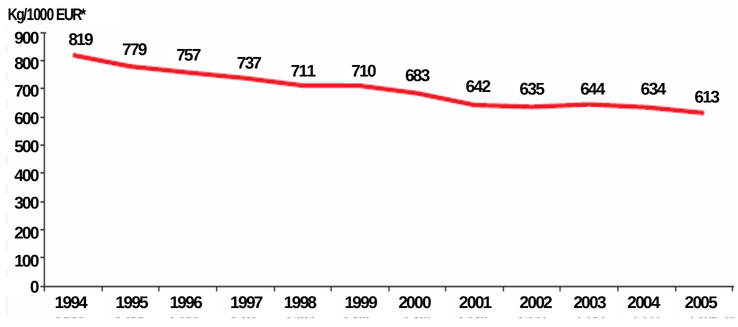
The choice of the appropriate input and output measure needs to take into account the statistical coherence between the two. Adjustments to the economic variable may be required depending on the MF variable used.

What are the implications of trade and globalisation for material flows?

Economies fulfil their material demands partly from their own territory and partly by importing materials from other countries. The higher the import share in domestic material input and domestic material consumption, the more the economy is sensitive to incidental shortage of particular commodities abroad, increases in their market price, or upheaval of other barriers to foreign trade. The higher the export share, the more the economy is sensitive to changes in demands from external markets and changes in international market prices. Monitoring these characteristics is particularly important for strategic or rare material resources, such as metals and metal ores, other industrial minerals, fossil fuel carriers, and certain agricultural commodities (Figure 4).

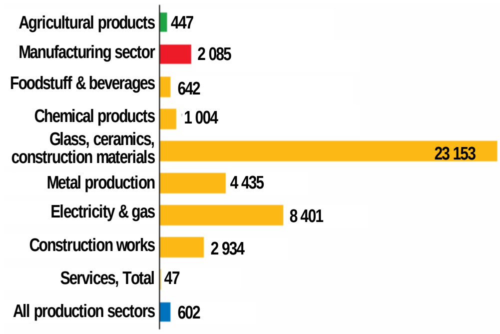
Figure 3. Monitoring resource productivity: Indicator examples

Raw material intensity, 1994-2005, Germany



* price adjusted, interlinked volume

Material intensity by sector, 2004, Germany

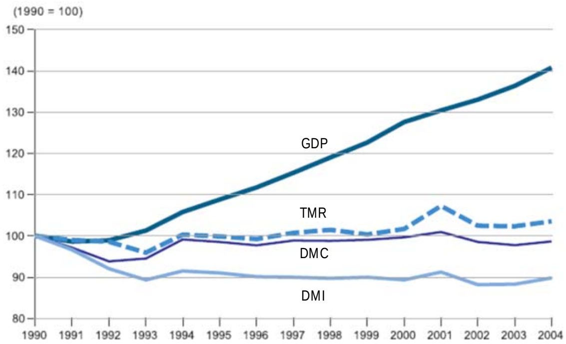


* kg material input/1000 EUR gross value added (at respective prices)

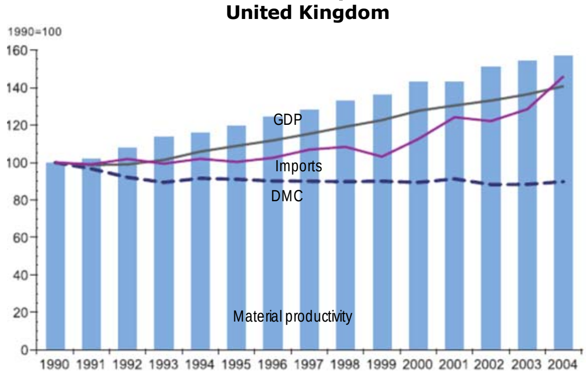
In this example, the direct material inputs from domestic primary sectors and from imports were attributed to the receiving branches representing the second stage of use in the production and consumption chain. The amounts of abiotic materials used were then related to the gross value added of the branch to benchmark material intensity, i.e. the inverse of (direct) material productivity. A comparison over time allows to record those branches, which reduced or increased their material intensity.

Source: UBA, Destatis, and BGR (2007).

Resource use in relation to GDP, 1990-2004, United Kingdom



Material Productivity, 1990-2004, United Kingdom



In this example, three different indicators (DMI, DMC, TMR) are used to compare trends in the material basis of the economy with GDP growth. The first figure shows a decoupling between trends in material resource use and trends in GDP. The second figure shows gains in material productivity over time. It also shows that in recent years imports of materials (in weight) increased faster than GDP. As "hidden flows" associated to imports are relatively important, this can explain the weaker decoupling in TMR over the period, whereas DMC experienced an absolute decoupling from the economy (left figure). This also suggests that some of the environmental impacts associated to consumption in the UK are progressively transferred abroad.

Source: Office for National Statistics (2005).

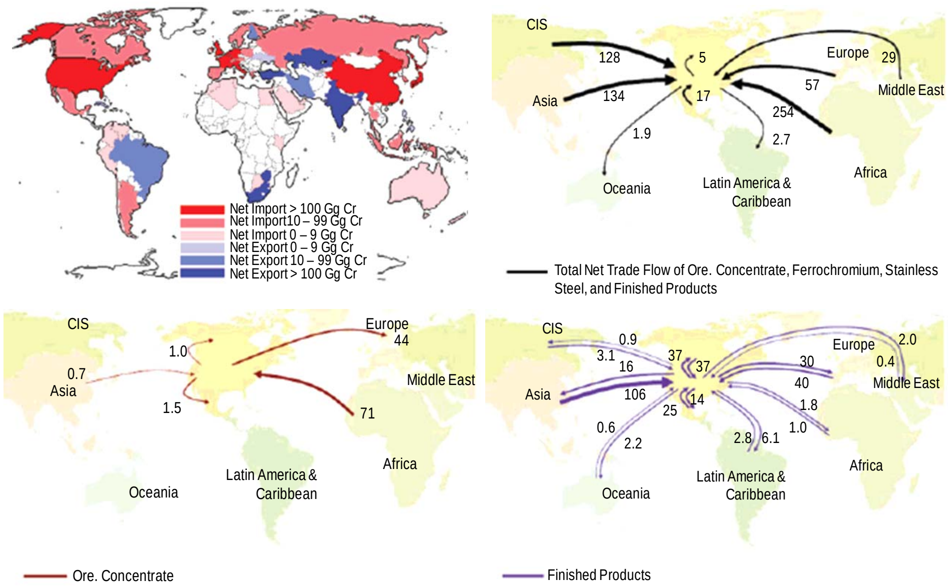
MF indicators that capture international flows help monitor the interactions and interdependencies among countries and world regions by measuring the weight of a group of countries in global resource flows, the material security of countries, and the level of foreign resource use by domestic economic activities. They can be linked to foreign outsourcing and competitiveness, to demand and supply issues, to international market prices of raw materials, and to trade in recyclable materials and remanufactured goods. They also help identify to what extent the environmental consequences of the production and consumption of natural resources and materials of a country or a group of countries extend beyond their borders, and where the associated environmental burden is located.

- The share of imported materials in domestic material inputs or consumption (IMP/DMI; IMP/DMC) are examples of indicators showing the dependency of an economy on foreign material inputs. The share of domestic material extraction in domestic material inputs or consumption (DEU/DMI; DEU/DMC) are examples of indicators that show the dependency of an economy on domestic material inputs.

- The material intensity of trade flows is an indication of the extent to which trade consists of processed and technologically sophisticated products (the lower the ratio, the more trade is in high-end products). Indicator examples are the material intensity ratios that measure the material weight of imports and exports, in physical terms, compared to the value of imports (M) and exports (X), in monetary terms (IMP/M and EXP/X).

Figure 4. Monitoring the implications of trade and globalisation

International trade of chromium, focus on the United States and its major trade partners, 2000



This example stems from the Stock and Flows (STAF) project of the Yale University (USA). It shows the regional disparities in demand and supply of chromium resources. Then it shows, as an example, the level of dependence of the United States on chromium supply in the following forms: ore and concentrate from Africa, and finished products from Asia.

Note: (a) Net trade of chromium in ore, concentrate, ferrochromium, semi-finished products, finished products, and scrap; United States' trade of chromium in (b) ore and concentrate; (c) ferrochromium; (d) stainless steel (semi-finished); (e) finished products; (f) the total of these four groups. All values are given in Gg Cr/yr.

Source: Johnson, Schewel and Graedel (2006).

How well are specific resources and materials managed?

When, for a specific natural resource, the intensity of use with respect to available natural stocks grows to be of concern, and when the efficiency with which certain materials or waste flows are managed becomes an issue, better monitoring will assist the management of those resources and materials. The choice of what particular resources and materials should be monitored depends on the specific circumstances of each country, including:

- the contribution of certain flows to specific environmental impacts,
- the scarcity at national level and/or high foreign trade dependency for particular materials,
- raw material prices,
- the importance of particular materials for country specific industrial branches,
- the recycling potential of particular materials, etc.

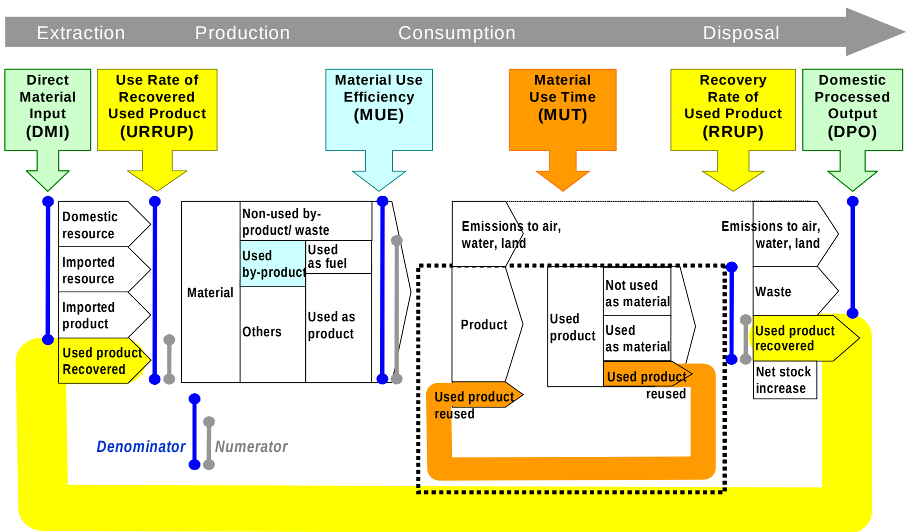
In their simplest form, indicators that monitor the intensity of use of natural resources generally represent the ratio of natural resource extraction compared to the amount of resources available for use. When applied to resources from renewable natural stocks (biotic resources such as forests, agricultural resources, fisheries, wildlife, freshwater), such indicators help establish a link between resource extraction and concerns related to the reproduction capacity and primary productivity of the resources, and to the provision of environmental services. When applied to resources from non-renewable natural stocks, such indicators help establish a link between resource extraction and existing or known reserves that are exploitable under current technological conditions. They can be linked to economic concerns related to changes in market prices, to supply security and to trade flow patterns.

The growing use of raw materials over the past decades has been accompanied everywhere by an increased production of waste, representing a potential loss to the economy of valuable material and energy resources. Increasing the efficiency with which materials are managed over their entire life cycle therefore is a vital element of improving resource productivity and safeguarding environmental quality. In line with the principle of the 3Rs (reduce, reuse, recycle), consistent recycling of used materials helps prevent waste of materials, including energy, and reduce releases to nature (Figure 5).

These questions can be addressed with the help of MF indicators that show: (i) the level of actual recycling and reuse, and (ii) the potential of current material flows for being recycled in future. The former type of indicators can be derived from material system analysis and from waste statistics to reveal potentials for recycling; the latter type would require a grouping of materials by their degree of "recyclability," which would then suggest which parts of a MF can, in theory, be recycled. Examples of these types of indicators include:

- Indicators reflecting the (potential) share of reused goods in material consumption.
- Indicators such as the (potential) use rate of recovered used products, the (potential) material use efficiency, the (potential) material use time, the (potential) recovery rate of used products.

Figure 5. Waste and recycling indicators derived from MFA



Three material cycles are distinguished, each of them contributing to the objectives of a sound material cycle (i.e. preserving natural resources and minimising the environmental burden):

1-reuse of used products ,

2-recovery of by-products (as material and heat) , and

3-recovery of used products (as material and heat) .

Source: Hashimoto and Moriguchi (2004).

What are the main environmental consequences of material resource use?

Two types of pressure are exerted on the environment by the use of material resources. First, there are pressures associated with the quantity and quality of the natural resource stocks from which the materials are extracted. Second, there are pressures associated with the environmental burden (pollution, waste, habitat disruption) generated during the extraction, processing, consumption, recovery and end-of-life disposal of the materials. For both types, the main concerns relate to the rate of depletion and the reproduction capacity of natural resources, to changes in environmental services provided by natural resources, and to the impact on environmental quality (e.g. air, climate, water, soil, biodiversity, landscape, human health).

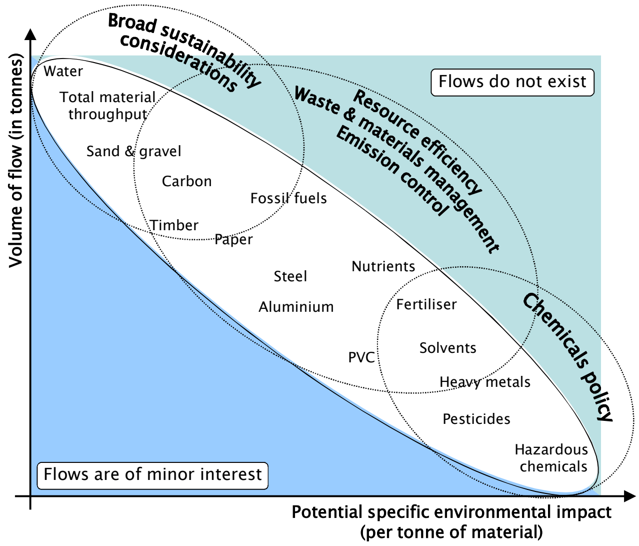
Resource use and material flows can be characterised in different ways in order to evaluate the associated potential environmental pressures. First, one can distinguish between different types of materials; commonly a distinction is made between two broad types: toxic flows and bulk flows (Figure 6). Secondly, one can distinguish the pressures associated with the different stages of the material flow cycle or the supply chain. A third way is to distinguish between internal and external pressures, i.e. between those occurring within the borders of a country at the place of extraction, processing, use and disposal of materials, and those that occur outside the borders of a country, upstream in the production process and that are indirectly associated with imported materials and products.

Characterisation by material type

- Toxic flows comprise industrial raw materials such as industrial minerals (e.g. fertilisers, pesticides), metals (e.g. copper, mercury, aluminium, lead) and fossil fuels used for non-energy purposes (e.g. for the production of plastics, cosmetics). The overall magnitude of use of this group of materials is comparatively low in terms of weight, but their impact per mass unit can be very high. Furthermore, many toxic substances accumulate in environmental media and living species, and present a danger to human and ecosystem health (Figure 7).

  Since there are so many toxic substances, a choice needs to be made as to which substances to monitor, e.g. heavy metals and organic compounds. Such a choice must be based on risk assessment (taking account of e.g. toxicity, dose-response assessment, persistence and mobility) and the quantities of individual substances being released to the environment. Among heavy metals, flows of lead, cadmium, mercury and nickel could be traced. Among organic substances, the flows of certain pesticides could be traced as a first step. Also, the question arises whether indicators based on mass units only will be adequate, or if it is feasible to calculate indicators that are weighted by impact. Currently, no internationally agreed list of substances with appropriate weighting factors exists.

Figure 6. Schematic representation of material flows, environmental impact and policy uses



Source: OECD, based on Steurer (1996) as developed with Radermacher in 1995.

- Bulk flows comprise non-toxic bulk materials including biomass, construction minerals and fossil fuels. Agricultural biomass provides food and fibres and is gaining importance as an energy source (bio-fuels); biomass from pastures is a major input for livestock; wood is used as a structural material and as an energy source (fuel wood, charcoal, wood pellets). Construction minerals (sand, gravel, stone) supply housing, transport and other infrastructure. Fossil fuels provide energy. The overall magnitude of use of this group of materials is high in terms of weight, but their impact per mass unit is relatively low compared to that of toxic flows. Since materials exert environmental pressures at all stages of their lifecycle, the cumulative environmental impact of this group can be high.

  A breakdown of bulk material flows into food crops, feed crops, wild animals, timber (for biomass) and oil, gas, coal and others (for fossil fuel carriers), for example, is a useful starting point for analysing the underlying drivers and associated pressures, and for identifying the potential for reducing negative environmental effects.

Characterisation by the stage of the material flow cycle

- During the extraction stage (upstream), due to movements of used and unused materials, including water, and to pollution and waste generated.
- During the processing and consumption stages (downstream), due to pollution and waste generated (process related, accidental). The type and intensity of these pressures mainly depend on current management practices and technologies, the level of compliance and enforcement with government policies, and consumer behaviour.
- During the waste treatment and recycling stages (post-consumption stages) where the type and intensity of the pressures again depend on the management practices and the technologies applied, and on the level of compliance and enforcement with government policies.
- During the transportation stages, directly via transport accidents or leakages, such as oil spills, and indirectly via energy consumption and related air emissions. The type and intensity of these pressures mainly depend on (i) the mode of transport and the distance travelled, (ii) the safety rules applied, and (iii) the level of compliance and enforcement with international agreements, such as those on the transport of hazardous goods, the prevention of marine pollution or the transboundary movements of hazardous waste.

Characterisation by location

In terms of the third type of characterisation, distinguishing environmental pressures by location helps monitor shifts in the location of potential impacts due to changes in domestic material demands and consumption, to changes in related trade patterns and to foreign outsourcing. Examples of generic indicators that reflect internal versus external impacts include output indicators such as: domestic processed outputs (DPO), total domestic output (TDO), and indirect flows associated with imports (IFimp). To give insights into shifts in the location of potential environmental impacts abroad, the indicators need to be complemented with information on import flows by country or region of origin.

Environmentally weighted material consumption

There have been a few attempts to weight material flows according to their environmental impacts. An example is environmentally weighted material consumption (EMC) that combines data from material flow analysis (MFA) and impact coefficients from life cycle assessment (LCA). Work in this area is still in the early stages and there are still problems of data availability and weighing methods that constrain a systematic development of such indicators at the international level.

5. ESTABLISHING MATERIAL FLOW ACCOUNTS[13]

Before undertaking a national effort to develop and implement material flow accounting, countries should carefully consider i) the purposes and uses for which the accounts are to be established; ii) the institutional arrangements and partnerships required to ensure continuity of effort; iii) the costs/benefits of creating and maintaining the accounts; and iv) the statistical basis available for populating the accounts. Countries should avoid building overly ambitious theoretical systems and resist the temptation to engage in a large, indiscriminate data compilation exercise that risks becoming an end-to-itself, rather than being concrete, user-oriented and pragmatic.

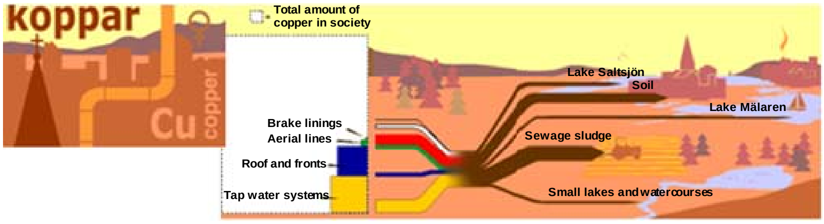
[13] Based on OECD (2008), *Measuring material flows and resource productivity – Volume I. The OECD Guide*, *Chapter 5*, OECD, Paris.

Figure 7. Monitoring the environmental impacts of materials

Heavy metal flows in Stockholm, Sweden

This example builds on results from a series of substance flow analysis (SFA) used to support the environmental programme of Stockholm city and the related public communication.

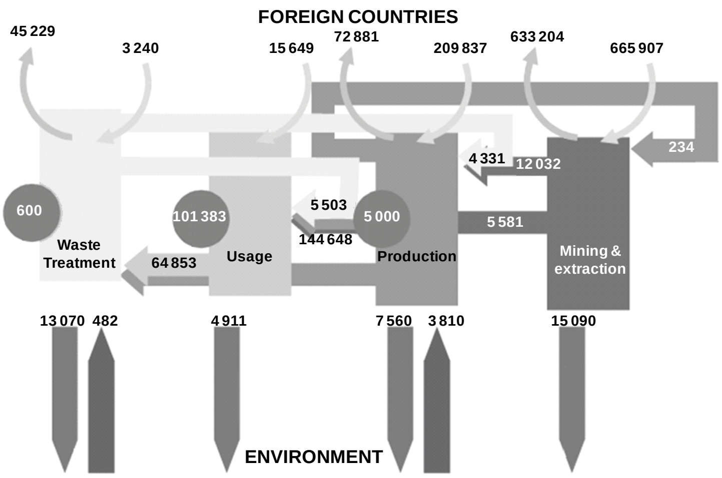
It focuses on toxic substances and is part of a web presentation that, for each substance, informs about its characteristics, the products in which it is contained, the way it disperses and impacts on the environment, and the measures that can be taken and by whom to reduce negative environmental impacts.



Source: Stockholm city, www.stockholm.se/miljogift.

The information is presented at different levels of detail to suit different users. Main target groups are students (from about age 13 and elder), politicians, and civil servants

Data from substance flow analysis, Cadmium, the Netherlands



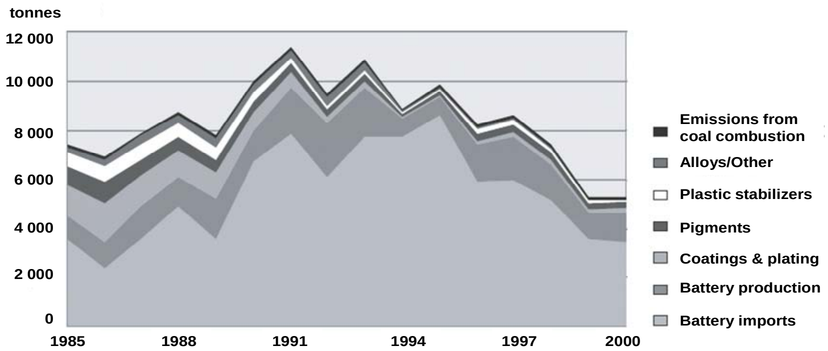
This example builds on results from a substance flow analysis (SFA) carried out to detect those processes that are most involved in the release of harmful substances to the environment.

The study showed that releases of cadmium stem from diffuse applications that may lead to an exceedance of critical levels in the environment. Here, the flow of the critical substance, i.e. cadmium, becomes the indicator itself.

The analysis led to the insight that emission control and even product bans will not solve the problem. Since inflow always equals outflow the authors conclude that the only way to reduce the outflow to the environment is to reduce the inflow to society. Cadmium, however, is produced not on demand but as a by-product of the zinc industry. The study suggested that the real solution to this problem would thus be to either reduce the amount of zinc being produced or to immobilise the cadmium directly after production.

Source: Kleijn and Voet, in OECD (2003).

Estimated Cadmium releases by end-use products, United States, 1975–2000



Note: Cadmium contained in batteries in imported finished goods is not included.

Source: Wernick and Irwin (2005).

A step-wise approach

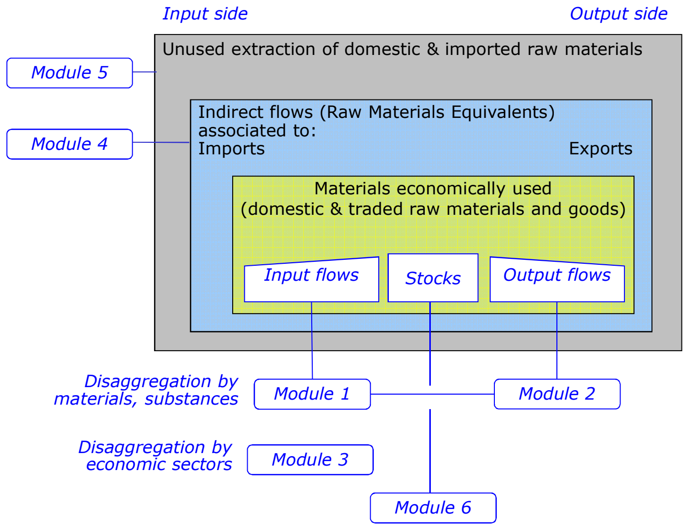
A step-wise approach may be the most practical tactic to establishing the information base required for MFA. The OECD has developed a menu of options to help establish national MF accounts in practice. The menu comprises a set of modules to reflect several levels of ambition and completeness of accounts, and is so designed that it can be implemented equally well in part as in whole (Figure 8).

Depending on the availability and quality of underlying data series, base tables can be compiled following a series of modules starting with the input side of the flow accounts and then be progressively expanded to cover other flow aspects up to a full materials balance. Advancing through the sequence of accounts and tables, progressively more primary data and compilation work is required. Disaggregation by materials or material categories, which is relatively easy to implement, is part of the first modules; the more difficult disaggregration by economic activities is part of subsequent modules.

Figure 8. Hierarchy and sequence of steps for a system of national MF accounts

To assist countries in setting up national MFAcc, practical guidance is being developed jointly with Eurostat.

Emphasis is first be put on the establishment of simple MFAcc to allow newcomers to join in and to demonstrate what can be achieved with modest resources.



Each of these modules provides a basis for deriving material flow indicators.

Implementation modules

Six modules have been identified:

- Module 1 focuses on the compilation of simple MFAcc at national level that trace input flows into the economic system, disaggregated by materials and material categories. The economic system itself still is treated as a black box. Module 1 can be used to establish accounts that measure the flows of particular materials into the economy and emissions from it.
- Module 2 expands Module 1 by adding base tables and core variables on output flows to establish simple material flow balances. The economic system is still treated as a black box in this module. Module 2 can be used to establish accounts that measure the flows of particular materials or residuals from the economy (exports, pollutants, waste).
- Module 3 disaggregates MF data by economic activities, thereby opening up the black box. It benefits from Input-Output work and the existence of monetary and physical input-output tables. It can be used to measure the contribution of economic activity sectors to the flows of materials in the economy and to monitor structural changes.
- Module 4 addresses up-stream flows related to imports (as well as to exports) according to the concept of raw-material equivalents for assessing the material advances for imports (exports).
- Module 5 addresses the side effects of the extraction of materials in a national economy, i.e. unused extraction not entering the economic process but having an environmental significance.
- Module 6 suggests an approach for directly assessing the changes in material stocks in a national economy.

6. SELECTED MFA APPLICATIONS[14]

The following sections are based on selected material flow data from various national and international sources, on research projects, and on related policy work by the OECD. They show examples at different levels of application, and illustrate how such data could be used to describe and analyse material flows within and among countries.

The material basis of OECD and other economies

Since 1980, global resource extraction (by mass) has increased by 36%, and is expected to grow to 80 billion tonnes in 2020.[15] Growth rates and extraction intensities vary by material categories and among world regions, reflecting different levels of economic development and endowment in natural resources, varying trade patterns and industrial structures, and different socio-demographic patterns. OECD countries as a group figure substantially in both global resource use and raw materials supply, although non-OECD economies, especially the BRIICS countries (Brazil, Russia, India, Indonesia, China and South Africa) are catching up to OECD levels (Figure 9).

Anticipated growth in primary resource extraction is also unevenly distributed among the main material categories. Metal ores exhibit the highest rates, and these are expected to almost double — from 5.8 billion tonnes in 2000 to more than 11 billion tonnes in 2020. With expected growth of 31%, extraction of biomass (agriculture, forestry, fishery, grazing) is expected to expand less than all the non-renewable resource categories combined, indicating a decreasing share of renewable resources in the production and use of materials at the global level (Figure 9).

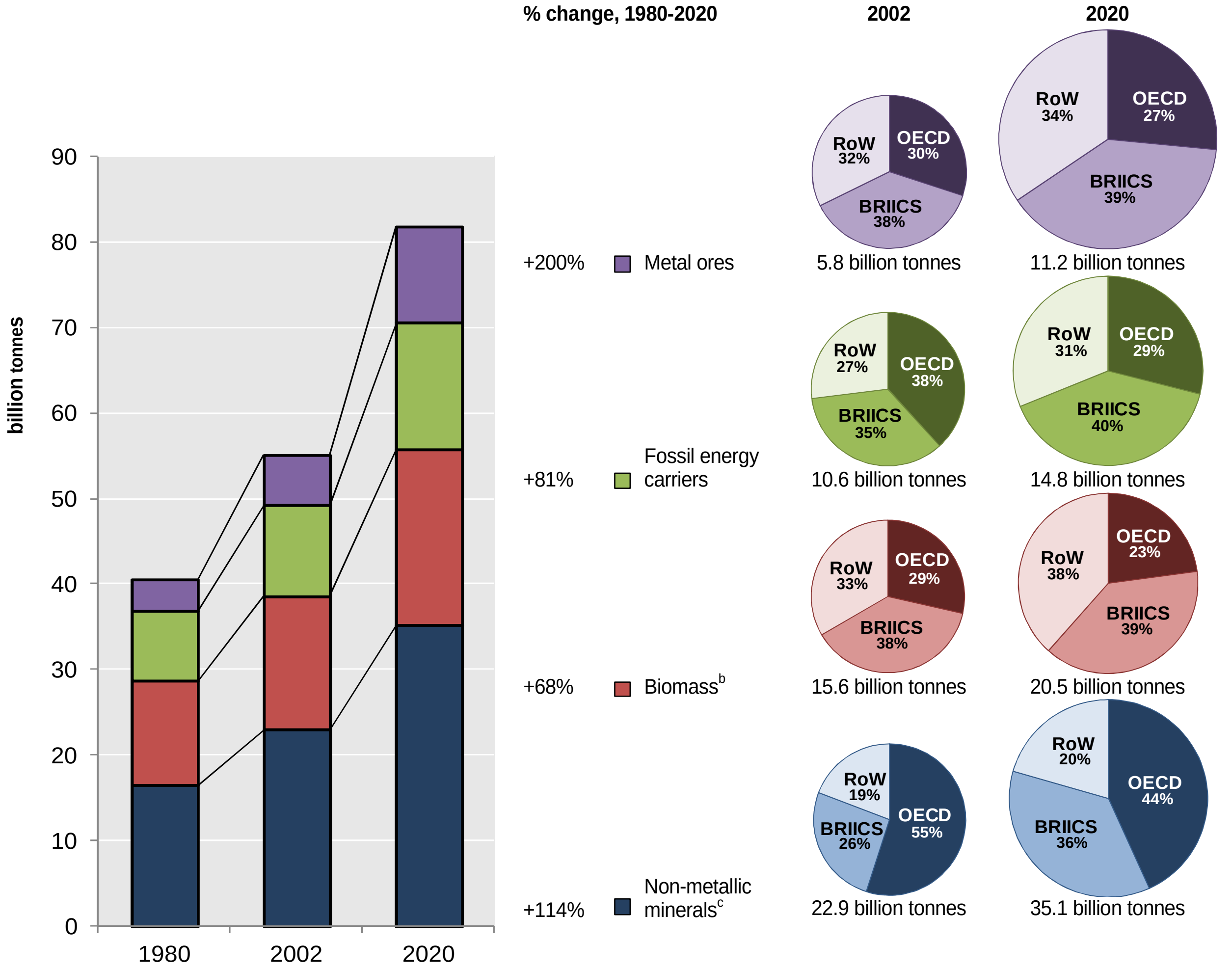
On a per capita basis, resource extraction levels are highest in the OECD area, in particular in North America and the Asia-Pacific region, and are expected to grow further to reach about 22 tonnes per capita in 2020, mainly because of growing demands for coal, metals and construction minerals. Extraction levels in the BRIICS countries are expected to grow much more rapidly over this period, to 9 tonnes per person in 2020, a growth of 50% (Giljum *et al*., 2007).

On a per unit of GDP basis, OECD countries have decreased their extraction intensity in recent decades, reflecting some decoupling of primary resource extraction from economic growth. This trend is expected to continue until 2020. The main drivers are increased applications of more material efficient technologies (technology effect[16]), structural changes away from the primary and secondary sectors towards the service sector (structural effect), and associated increases in material intensive imports (trade effect[17]), due to outsourcing of material intensive production stages to other world regions.

Although not visible in production statistics, displacements of unused materials, unwanted but unavoidable, will add to the environmental burden from resource extraction, disrupt habitats or ecosystems, and alter landscapes in the region where the extraction takes place. The amounts of unused material resources are particularly high for energy carriers (some 3.5 tonnes per tonne of fossil fuel extracted[18]) and metals (some 2 tonnes per tonne of metal ore extracted).

14 Based on original drafts prepared by Aldo Femia and Eric Turcotte.
15 *Outlook* data on global resource extraction and materials use up to 2020 are based on the BASE scenario of the GINFORS model (Giljum *et al*., 2007).
16 This can be achieved through innovation (e.g. eco-design, cleaner technologies, managerial approaches) and encouraged by integrated products policy, including stricter efficiency standards, green public procurement and better environmental monitoring and control.
17 This could add to the environmental burden in the exporting countries when environmental regulations are less restrictive. Resource extraction displaces wide amounts of unused materials (e.g. mining overburden, agricultural and forestry harvest losses, by-catch from fishing), and extraction and processing activities are generally intensive in material, water, energy and land use, as well as in emission and waste generation, often including hazardous substances.
18 The average factors of overburden per tonne vary widely according to the type of fossil fuels extracted: for example, this factor is 16 times higher for coal than for crude oil (for more details, see Bringezu and Schütz (2001) quoted on www.materialflows.net/).

Figure 9. Global resource extraction, by major groups of resources and regions



	WORLD			OECD			BRIICS*			ROW*		
		Rate of change			Rate of change			Rate of change			Rate of change	
	2002	1980 -2002	2002 -2020	2002	1980 -2002	2002 -2020	2002	1980 -2002	2002 -2020	2002	1980 -2002	2002 -2020
Amounts extracted (billion tonnes)												
Total	55.0	36%	48%	22.9	19%	19%	17.7	67%	74%	14.4	35%	63%
Metal ores	5.8	56%	92%	1.8	41%	70%	2.2	110%	100%	1.9	30%	104%
Fossil energy carriers [a]	10.6	30%	39%	4.1	12%	6%	3.7	58%	59%	2.9	31%	60%
Biomass [b]	15.6	28%	31%	4.5	11%	6%	5.9	49%	33%	5.2	25%	50%
Other minerals [c]	22.9	40%	54%	12.6	21%	21%	5.9	81%	115%	4.4	58%	63%
Per capita (tonne/capita)												
Total	8.8	-4%	22%	20.0	0%	8%	6.0	19%	51%	6.7	-16%	20%
Metal ores	0.9	11%	58%	1.5	19%	54%	0.7	51%	73%	0.9	-19%	51%
Fossil energy carriers [a]	1.7	-8%	14%	3.6	-6%	-4%	1.3	13%	38%	1.3	-18%	18%
Biomass [b]	2.5	-9%	8%	3.9	-6%	-4%	2.0	7%	15%	2.4	-22%	11%
Other minerals [c]	3.7	-1%	27%	11.0	2%	10%	2.0	30%	86%	2.0	-2%	21%
Per unit of GDP (tonne/1000 USD[d])												
Total	1.6	-26%	-14%	0.8	-33%	-24%	4.6	-35%	-32%	4.5	-21%	-26%
Metal ores	0.2	-15%	11%	0.1	-20%	9%	0.6	-18%	-23%	0.6	-24%	-8%
Fossil energy carriers [a]	0.3	-29%	-19%	0.1	-37%	-32%	1.0	-38%	-38%	0.9	-24%	-28%
Biomass [b]	0.4	-30%	-24%	0.2	-37%	-32%	1.5	-42%	-48%	1.6	-27%	-32%
Other minerals [c]	0.6	-24%	-11%	0.4	-32%	-22%	1.5	-29%	-17%	1.4	-8%	-26%

Notes: (a) Crude oil, coal, natural gas, peat; (b) Harvests from agriculture and forestry, marine catches, grazing; (c) Industrial minerals, construction minerals; (d) Constant 1995 USD. * BRIICS = Brazil, Russia, India, Indonesia, China and South Africa; RoW = Rest of the world.

Source: OECD, based on SERI (2006), MOSUS MFA database, Sustainable Europe Research Institute, Vienna, http://www.materialflows.net; Giljum, *et al.* (2007).

Trends in the relative magnitude of used/unused flows of materials reveal a certain long-run stability, at least as far as the global picture is concerned. For metal ores and biomass, the downward trends in the used portion of material extracted suggest a change in the international composition of each of the groups in favour of higher unused-intensity materials. The used portion of each type of material is generally of a similar magnitude in the different world regions considered, except for fossil fuels. Compared to other types of material, the used portion of fossil fuels extraction is (i) considerably higher and has (ii) been growing noticeably in the rest of the world (RoW), since the mid 1980s, while this portion remained quite stable in OECD and BRIICS countries.

The weight of a product from the consumer end is normally just a small fraction of what it is actually from the resource end. Indeed, most of the material flows needed in the production process of products is not physically embodied in the product itself. The magnitude of this ecological rucksack greatly depends on the types of materials used in a product, being for instance very high for rare metals. According to Halada (2007), total material inputs are about 15 times the weight of a car, 300 times that of LCD panel, 500 times that of a cell phone, and 1000 times that of a computer.

Globalisation and material trade flows

The weight of worldwide trade in primary commodities[19] amounted to 5.6 billion tonnes in 2003, more than double of what it had been 20 years earlier (Figure 10). Trade increased significantly for all broad material categories, but the highest growth was observed for natural gas (3.3 times up), coal (x 3.2), wood-related goods (x2.7), iron and steel (x2.5), other base metals (x2.1), food (x2), and petroleum products (x1.9). Fossil fuels –petroleum products in particular – still represent the bulk of worldwide commodity trade, with roughly two-thirds of the total weight. Iron and steel products, and biomass goods follow with, respectively, a little more than one-sixth and one-tenth of the total each.

OECD net imports of materials have been increasing (+80%) more than three times as fast as domestic extraction used (DEU) (+23%) since 1980. The rise in demand for materials, which more recently has been intensified by the strong growth of emerging economies, also affects commodity prices. Price rises impinge differently on individual countries (depending on whether a country is an importer or exporter of particular commodities), but the supply-dependency of the OECD area as a whole on the rest of the world appears to be rising for all commodities and groups of materials. Fossil fuels (especially crude oil[20]) continue to dominate the OECD's physical trade balance (Figure 11).

Flows of waste and recyclable materials

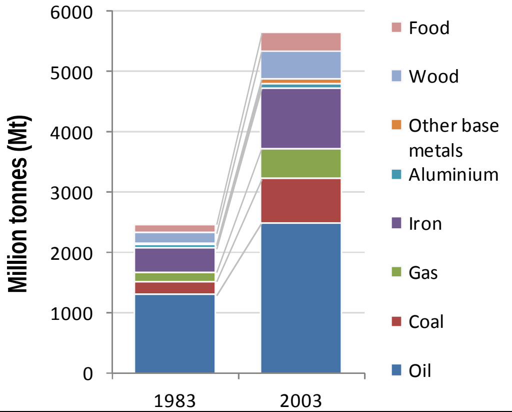
In line with growing demands for raw materials, the amount of waste generated by economic activity has been rising worldwide. In the absence of appropriate material recovery and recycling, many valuable materials contained in waste are thus lost for the economy. The secondary use of materials – through material and energy recovery – reduces the demand for primary materials, and environmental pressures related to their extraction (e.g. land and ecosystem disruption). In many cases, the processing of secondary materials also represents substantial savings in energy use (e.g. aluminium, steel) and lower levels of emissions to nature, compared to the processing of primary raw materials. Recycling can provide considerable economic and social (e.g. increased employment) benefits, and might as well mitigate risks related to security of supply for some countries. However, these "positive externalities" of secondary materials are often forgotten by markets.

19 Excluding precious metals and "highly processed commodities" such as machinery and chemicals. All non-metallic minerals such as lime and gravel – in particular – were also excluded in the study. Save for industrial minerals (ex. fertilisers), non-metallic minerals are rarely traded between countries, so that even by excluding non-metallic minerals, the coverage of trade flows for primary commodities remains quite complete.

20 In 2005, crude oil accounted for 77% of total fossil fuel net imports in the OECD area, and two thirds of the region's crude oil consumption relied on net imports from non-OECD countries.

The size of world secondary material markets have been estimated around 600 million tonnes (Mt) in 2004 (Lacoste and Chalmin, 2007). This includes recovered scrap metals (405 Mt), recovered fibers (papers) (170 Mt), recovered non-ferrous metals (24 Mt) and recovered plastics (5 Mt). Global trade in secondary materials was estimated around 135 Mt in 2004. Also, the globalisation of trade has made transboundary movements of waste an attractive and cost-efficient option for the recovery and disposal of problematic end-of-life materials and products, such as electric and electronic equipments (e-waste) and ships. Globally, some 20-50 Mt of e-waste are estimated to be generated every year (UNEP 2006). The magnitude of all these flows toward Asian countries (e.g. Bangladesh, China, India, Pakistan, Turkey) is so important that it raises concerns about (i) environmental impacts in these countries and (ii) harms that this may cause to some national recycling industries (e.g. plastic recycling in Japan, cellulose fiber in European countries).

Figure 10. Trade in primary commodities, world, 1983-2003

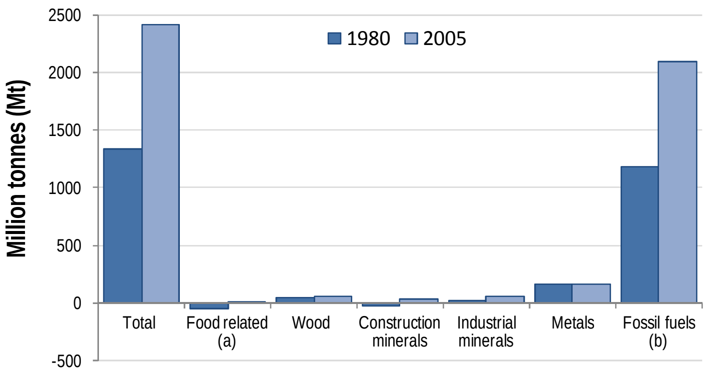


		Weight (Mt), 2003	Change, since 1983
Total		**5 643**	**128%**
Food		**293**	**101%**
	Meat	24	204%
	Fish & shellfish	20	212%
	Cereals	248	89%
Wood		**464**	**169%**
Metals		**1 149**	**142%**
	Iron	991	148%
	Aluminium	87	110%
	Other base metals	71	113%
Fossil Fuels		**3 737**	**122%**
	Oil	2 502	92%
	Coal	733	224%
	Gas	503	228%

Source: OECD, based on the *Material Flow Data book* (Moriguchi and Hashimoto, 2006).

Figure 11. Trade Balance and material dependency, OECD, 1980-2005

Physical trade balance (PTB)



Domestic material dependency (DEU/DMC)

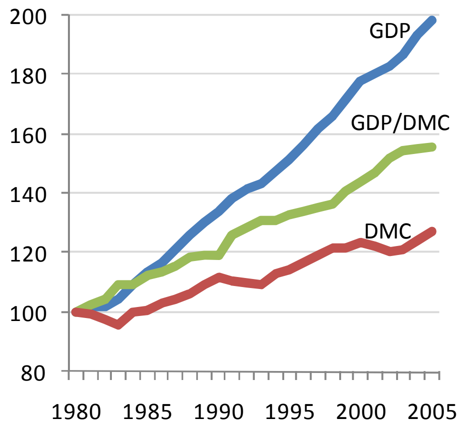
DEU/DMC ratio	2005	Rate of change* 1980-2005
Total	**0.88**	**-4%**
Food related (a)	1.00	-2%
Wood	0.94	0%
Construction minerals	1.00	-1%
Industrial minerals	0.90	-6%
Metals	0.87	+3%
Fossil fuels (b)	0.66	-13%

Notes: A decrease in the DEU/DMC ratio indicates an increase of the dependency on net imports.
All categories include used raw materials, semi-finished and finished goods.
a) Include used food crops, fodder crops, animals and small amounts of non edible biomass
b) Include used coal, crude oil, natural gas and other fossil fuels (such peat).

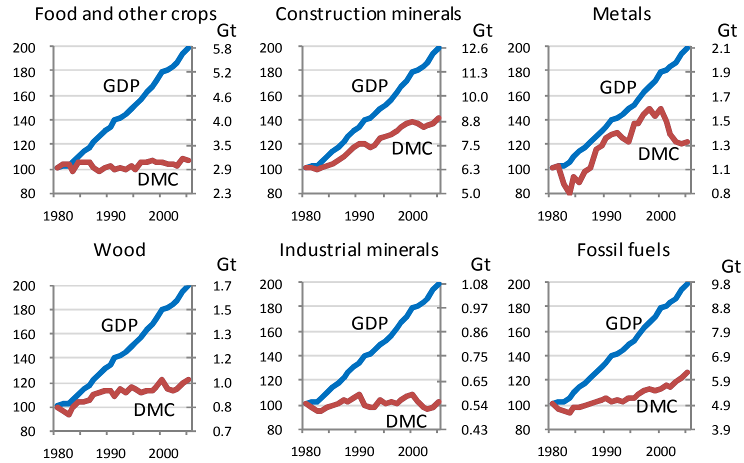
Source: OECD MF pilot database (provisional data for 2005).

Figure 12. Trends in domestic material consumption (DMC), OECD, 1980-2005

Trends, all materials and GDP*, OECD
(1980=100)



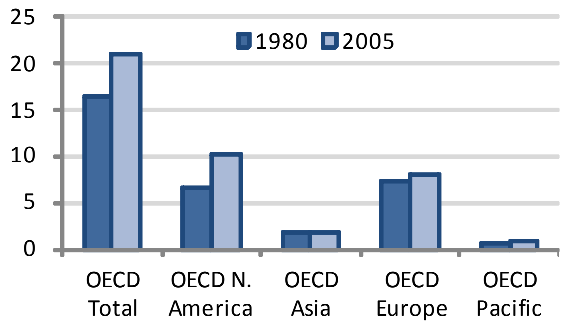
Trends by material category and GDP*, OECD
Left axis: 1980 = 100; right axis: Billion tonnes (Gt)**



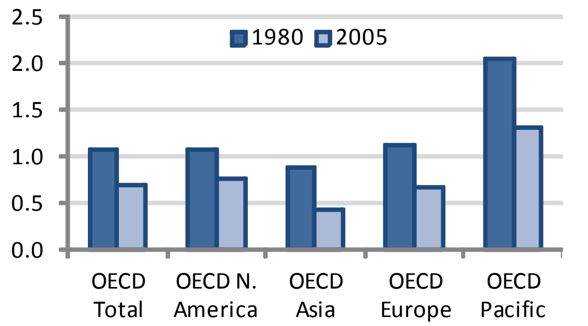
* GDP at 2000 prices and PPPs.

** DMC fits to both axes; GDP fits to left axis only.

Material consumption, by OECD region
(billion tonnes)



Consumption intensity per unit of GDP, by OECD region
(tonne DMC/1000 USD*)



Materials mix, by OECD region

	Total OECD			OECD-North America			OECD-Asia			OECD-Europe			OECD-Pacific		
DMC (million tonnes)	1980	2005	% change	1980	2005	% change	1980	2005	% change	1980	2005	% change	1980	2005	% change
Total	16 486	20 984	27%	6 565	10 120	54%	1 911	1 943	2%	7 387	8 048	9%	622	873	40%
of which															
Food related (a)	2 881	3 078	7%	937	1 152	23%	153	175	14%	1 542	1 484	-4%	248	267	8%
Wood	826	998	21%	433	564	30%	75	64	-15%	301	341	13%	16	28	78%
Construction minerals	6 281	8 887	41%	2 128	4 090	92%	952	740	-22%	3 017	3 799	26%	184	257	40%
Industrial minerals	538	544	1%	118	193	64%	218	150	-31%	182	181	0%	20	19	-7%
Metals	1 053	1 273	21%	636	807	27%	126	138	10%	248	259	4%	44	70	60%
Fossil fuels (b)	4 907	6 204	26%	2 314	3 313	43%	386	675	75%	2 097	1 984	-5%	110	232	110%
GDP (billion USD)	15 218	30 229	99%	6 191	13 220	114%	2 141	4 462	108%	6 584	11 880	80%	303	668	121%
Population (million)	966	1 169	21%	321	434	35%	155	176	14%	472	534	13%	18	24	37%

Notes: (a) Food and other crops include used food crops, fodder crops, animals and small amounts of non edible biomass.
(b) Fossil fuels include used coal, crude oil, natural gas and other fossil fuel carriers (e.g. peat).

Source: OECD MF pilot database (provisional data for 2005).

Decoupling material consumption from economic growth in OECD countries

During 1980-2005, overall domestic material consumption (DMC[21]) in the OECD area increased by 27% and GDP grew by 99%, signifying a relative decoupling of DMC from economic growth over the period (Figure 12). Decoupling took place for each broad class of materials and in each OECD region. The decoupling was absolute (i.e. DMC remained constant while GDP rose) for industrial minerals and derived products. For the consumption of food-related materials, decoupling was absolute in OECD Europe, and this was almost the case for the whole of the OECD (i.e. DMC increased by just 7%). On the other hand, a significantly lower degree of decoupling occurred for goods and products made from construction minerals, metals, wood or fossil fuels. Decoupling trends may reflect efficiency gains, but also simply changes in the materials mix, and in some cases, substitution of domestic production with imports of semi-finished or finished goods.

Metal ores, metals and metal products

The worldwide annual extraction of run-of-mine metal ores has shown a steady, unbroken rise since the early 1980s, reaching about 5.8 billion tonnes in 2002. Between 1980 and 2002, a total of about 100 billion tonnes of metal ores were extracted from natural stocks. Over the same period, the share of OECD countries in metal ore extraction fell from 33 to 30%, that of BRIICS countries grew from 28 to 38%, and that of the rest of the world fell from 39 to 32% of total worldwide extraction.

Metal ores stem from non-renewable resource stocks. Predictions as to how long world reserves of the different metals will last depend on a host of different assumptions, notably about the pace of economic growth and decoupling scenarios (e.g. resource efficiency gains, 3Rs, circular economy). Nevertheless, for most metals and most scenarios, and in the absence of new discoveries and new technologies, natural reserves will run out some time this century (Table 6).

The steady increase in metal ore extraction since the 1960s has been accompanied by fluctuating, but generally decreasing real prices. Since 2002, however, the price indices of the broad commodity groups, including metals, have been rising, reflecting continued strong growth in global output. Over the last four years, the prices of metals have increased more than energy and agricultural prices; this was due to strong demand especially from China, but also to underinvestment brought by low prices in the 1990s, numerous supply problems and delays in bringing new capacity for metals, and rising development costs coming from ore grades deterioration and higher oil prices. Hence, the price index for metals and minerals reached historical highs in 2007, but is generally expected to decline in the coming years with rising capacity. Even so, in the view of many the emerging economies of populous countries such as China and India have only just begun making an impact on commodity markets. Their use of raw materials is still modest, but this will change as their populations grow richer, substantially increasing the demand for commodities, particularly for metals and energy. (Figure 13, Figure 14).

Within the OECD area, four countries dominate the extraction of metal ores (Australia, Canada, Mexico and the United States); in 1980 these countries accounted for 82% of all OECD metal ore extraction, a figure that had reached 93% by 2005. In particular, Australia’s share grew appreciably, and to a lesser extent also Mexico’s; the share of the USA, which had reached 55% in 1992, had returned to its 1980 level by 2005, while Canada’s share decreased throughout the period. European countries tend to disappear from this scene as their extraction of ores was halved over the period. Australia tripled its net metal exports over the period, and by far is the major exporter of metal ore, followed by Canada and Sweden, whereas Japan, USA, Mexico, Korea, Germany, and Italy in that order, were the main importers in 2005.

[21] Readers are reminded that DMC should not be taken as a proxy for environmental pressures associated with materials use. DMC does not include hidden flows, nor the emissions or waste flowing to the environment. Other measures discussed earlier in this document, such as TMR, DPO or TMC, are better suited for such a purpose.

Table 6 – Life expectancies of selected world reserves of metal ores

Metal ores [a]	1999 Reserves (tonnes)	1997-99 average annual primary production (tonnes)	Life expectancy in years[b], at three growth rates in primary production [b]			Average annual growth in production 1975-99 (%)
			0%	2%	5%	
Aluminium	25×10^{9}	123.7×10^{6}	202	81	48	2.9
Copper	340×10^{6}	12.1×10^{6}	28	22	18	3.4
Iron	74×10^{12}	559.5×10^{6}	132	65	41	0.5
Lead	64×10^{6}	$3\,070.0 \times 10^{3}$	21	17	14	-0.5
Nickel	46×10^{6}	$1\,133.3 \times 10^{3}$	41	30	22	1.6
Silver	280×10^{3}	16.1×10^{3}	17	15	13	3
Tin	8×10^{6}	207.7×10^{3}	37	28	21	-0.5
Zinc	190×10^{6}	$7\,753.3 \times 10^{3}$	25	20	16	1.9

Notes: (a) For metals other than aluminium, reserves are measured in terms of metal content. For aluminium, reserves are measured in terms of bauxite ore;
(b) With current production and consumption patterns, technologies and known reserves.
(c) Life expectancy figures were calculated before reserve and average production data were rounded. As a result, the life expectancies in years (columns 4, 5, 6) may deviate slightly from those derived from reserves and average production (columns 2 and 3).

Source: OECD, based on Tilton (2002), US Bureau of Mines (1977), US Geological Survey (2007).

Figure 13. Metals price index, 1960-2010

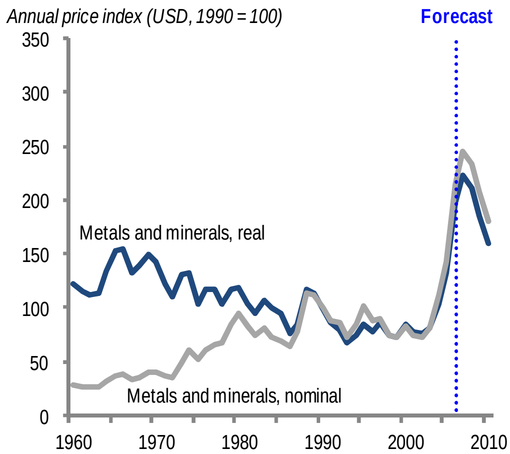
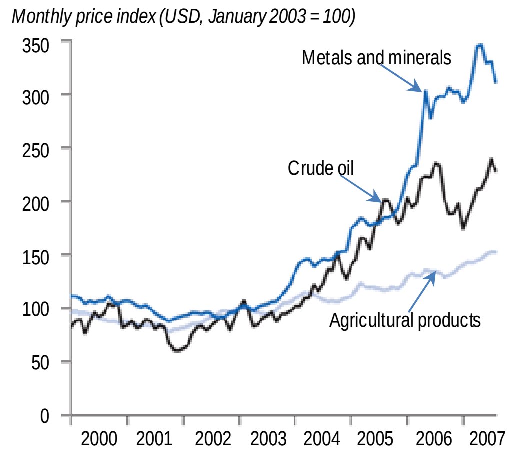


Figure 14. Commodity price index, 2001-2007



Source: OECD, based on World Bank (2008), *World Bank Commodity Price Data* (projections as of December 20, 2007) and Global Economic Prospect 2008.

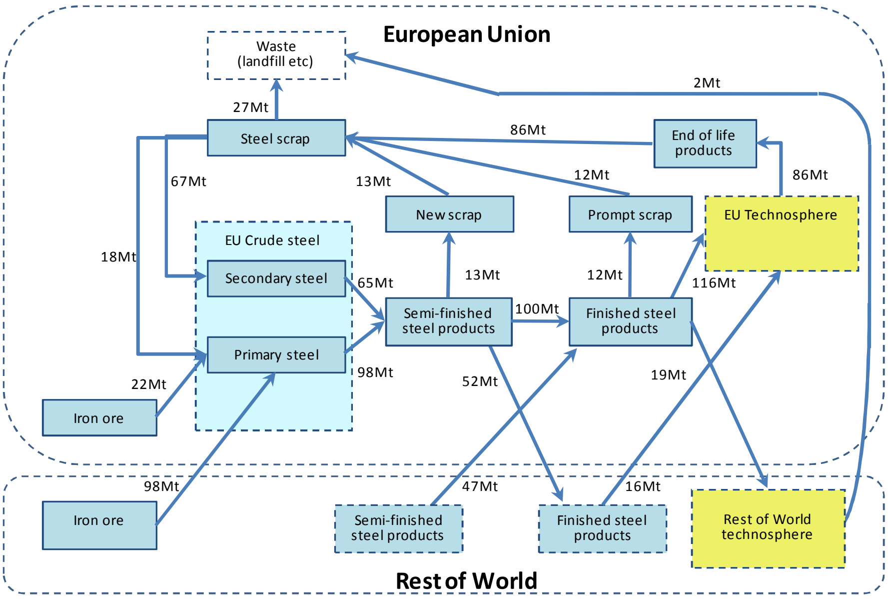
Iron and steel

By sheer volume, steel is by far the most important industrial metal. Steel consumption in the early 2000s was well over 30 times the consumption of aluminium, the second most widely used metal. World crude steel production grew about fivefold since 1960 to more than 1.2 billion tonnes in 2006; OECD countries account for around 40% of global production.

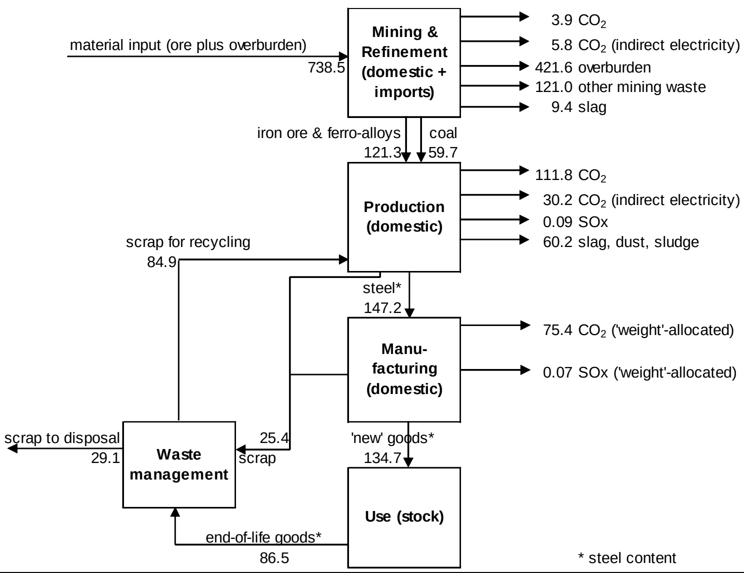
The iron and steel transformation chain is highly material and energy intensive, and is associated with several environmental concerns. In mining, main challenges include alteration of landscapes and water regimes, high consumption of energy and water, and generation of waste and wastewater. In the iron- and steel-making processes, they include releases of harmful air emissions, particularly in the earlier production stages. Important efforts are being made to improve industry's environmental performance (e.g. development of new production techniques to eliminate energy-intensive steps of the steel-making process or reduce emissions of air pollutants, use of waste-heat, development of new products, such as high-strength and corrosion-resistant steels, increased recycling of by-products).

Figure 15. Iron and steel flows, European Union, 2000

Overview of iron & steel flows, European Union, 2000 (Mt=million tonnes)



Overview of the "environmental hot-spots" of the iron & steel system, European Union, 2000 (million tonnes)



In this example, the iron and steel system of the EU was analysed on a life-cycle wide basis to address the "environmental hot-spots" along the production-consumption chains.

The figure presents the resulting indicators reflecting major resource inflows, critical emissions and recycling of the extended process network.

The study showed that the environmental pressures of primary steel exceed those of secondary steel significantly (ore vs. scrap based supply). The analysis, however, revealed that, even complete recycling (i.e. 100% of the currently generated scrap) would not fulfil current demand for steel and that scrap levels will not meet the level of iron & steel demand before 25 years in the future (an insight that would not have been reached without a MFA model). The results suggested technology improvements and indicated the need for higher materials efficiency in the sectors that use iron & steel as a base material (e.g. construction and automotive sectors).

Source: Moll, Acosta and Schütz (2005).

A study of iron and steel flows in 2000 in the European Union showed that an input of about 120 Mt of iron ore (of which 98 Mt was imported) yielded 98 Mt of *primary* crude steel (i.e. produced directly from iron ore and coke). A further 65 Mt, representing 40% of total crude steel production, were produced as *secondary* crude steel, produced from scrap steel. The output of about 135 Mt of steel in finished steel products in EU15 countries is based on a gross total of direct and indirect solid material flows of about 739 Mt, including about 422 Mt overburden and 121 Mt of other mining waste from the extraction and refinement of iron ore, ferroalloys (chromium, manganese and nickel), and hard coal. Only about 18% of the solid materials moved for the manufacture of the iron and steel cycle end up in the finished product (Figure 15).

The physical/technical efficiency of material use can be improved in two ways. First by increasing the share of secondary steel, which depends on the availability of scrap. Improved product development and design – facilitating the dismantling of goods that contain steel – and improved management schemes may help to increase the recycling rate. The EU15 study suggests that only limited increases can be expected in this respect given the already high recycling rate (70%) of end-of-life steel goods in the EU15. Second by acting upon the main applications of steel, especially in vehicles, machinery and construction work. Here, improving material efficiency can substantially reduce the environmental pressures associated with the use of steel. This can be done through wider uptake of new technologies, innovation, increased recycling of by-products (e.g. use of slag in cement production, transport infrastructure, fertiliser production) and product development (e.g. ultra-light steel for automobiles).

Aluminium

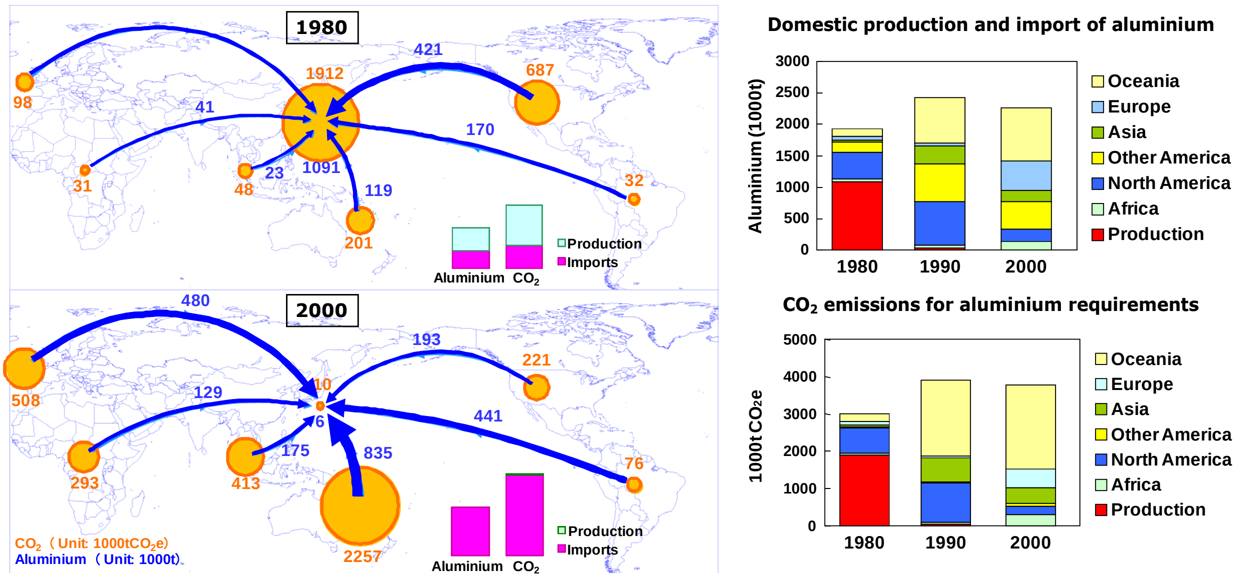
Aluminium is the most used nonferrous metal and is easily recyclable. Aluminium production and consumption worldwide have increased by a factor of 21 since the 1950s, especially in the past few years. Between 1980 and 2005, both bauxite ore extraction and alumina production grew by 78% (2.4% per year), whereas world primary production and consumption of aluminium increased by 107% (3.1% per year). In 2005, worldwide bauxite extraction reached 176.0 Mt, and resulted in the production of 65.8 Mt of alumina, and 31.9 Mt of primary aluminium. Adding to this 7.6 Mt of recycled aluminium, world global aluminium production reached a record level of 39.5 Mt in 2005 (Natural Resources Canada, 2005). Recycled aluminium thus accounted for almost 20% of world global aluminium production in 2005, but it had a lower annual growth (+2.7%) than that of primary production (+7.0%) in 2005. International trade in aluminium resources (including bauxite, alumina, aluminium goods and scraps) is significant, amounting to 87 Mt in 2003 (34% of world production).

The transformation of bauxite ore, first to alumina, then to primary aluminium, is highly intensive in terms of both energy and greenhouse gas emissions, though important progress has been made in this respect in the past decades. The industry is also making progress in reducing other environmental pressures (e.g. emissions of fluoride, PFCs, PAH) associated with the production of aluminium. Emissions of CO_2 are unavoidable in the aluminium smelting process, but over the last ten years the industry has reduced its CO_2output by around 10% through better production techniques. By 1998, on average each tonne of aluminium produced generated 12.7 tonnes of CO_{2e} (carbon dioxide equivalents), from alumina refining to primary casting. Emission intensities however vary notably among world regions. As shown by a Japanese study, the relocation of the primary aluminium production not only leads to the redistribution of CO_2 emissions, but can lead to an increase in the global CO_2 emission intensity (Figure 16).

However, consideration of the environmental aspects of aluminium use should not be limited to the production process. For example, in the car industry, aluminium can replace heavier steel and thus reduce the fuel requirements of vehicles. According to the International Aluminium Institute, over a vehicle's lifetime there is a potential to save 13.9 to 26.7 tonnes of CO_{2e} for each tonne of additional automotive aluminium products used, depending on whether the aluminium used is derived from primary or recycled material. This would compensate the 12.7 tonnes emitted during the production phase, and would result in a net reduction of greenhouse gas emissions over the full life-cycle of aluminium.

Figure 16. Aluminium flows and CO_2 emissions

Domestic production and import of primary aluminium and related CO_2 emissions, 1980-2000, Japan



This example shows the growing dependence of the Japanese economy on imported primary aluminium from 1980 to 2000, and the developments in flows of CO_2 associated with the extraction and processing of aluminium ores at home and abroad by region of origin.

Source: NIES

Copper

Copper is, after iron and aluminium, the most used metallic mineral in the world. It is essential for electrical equipment (electric wires and other electrical parts) and finds many uses in buildings (in plumbing, wiring, and air conditioning units) and the built infrastructure (e.g. in power and telecommunications applications). The price of copper was at record highs as of mid-2007. Current estimates of the life expectancy of world reserves of copper ores range between 18 to 28 years[22]. The mining of copper is dominated by South America (Chile, Peru), whereas the remainder of mining occurs in about eight further countries. The processing (refining) of the copper ore is predominantly carried out in about ten countries, with Asia (mainly China and Japan) being a major player. As for the consumption of copper, Asia including China, Japan, Korea, again features prominently (Figure 17).

About 15.0 Mt of copper ores were mined in 2006, and this figure is projected to grow substantially over the next five years, owing to increased capacity utilisation and new mine developments. Not all mined copper, however, will become "in-use stock", since a significant proportion will end up as waste or scrap. The Stock and Flows Project of the Yale University showed that of the 10.7 Mt of copper extracted annually in the mid-1990s, 7.8 Mt became "in-use stock". Of the remaining 2.9 Mt, unrecovered copper was estimated to account for about 1.8 Mt. The copper lost at the first stage, as tailings of slag, amounted to 1.6 Mt, of which just 250 Kt was recovered. An estimated 0.6 Mt of new scrap and 2.0 Mt of old scrap were recovered (Graedel, *et al.* 2004a; 2004b; Figure 18).

The twentieth century accounted for about 90% of all copper mined throughout five millennia of human history. As a result, two significant anthropogenic stocks of copper now exist, i.e. "in-use

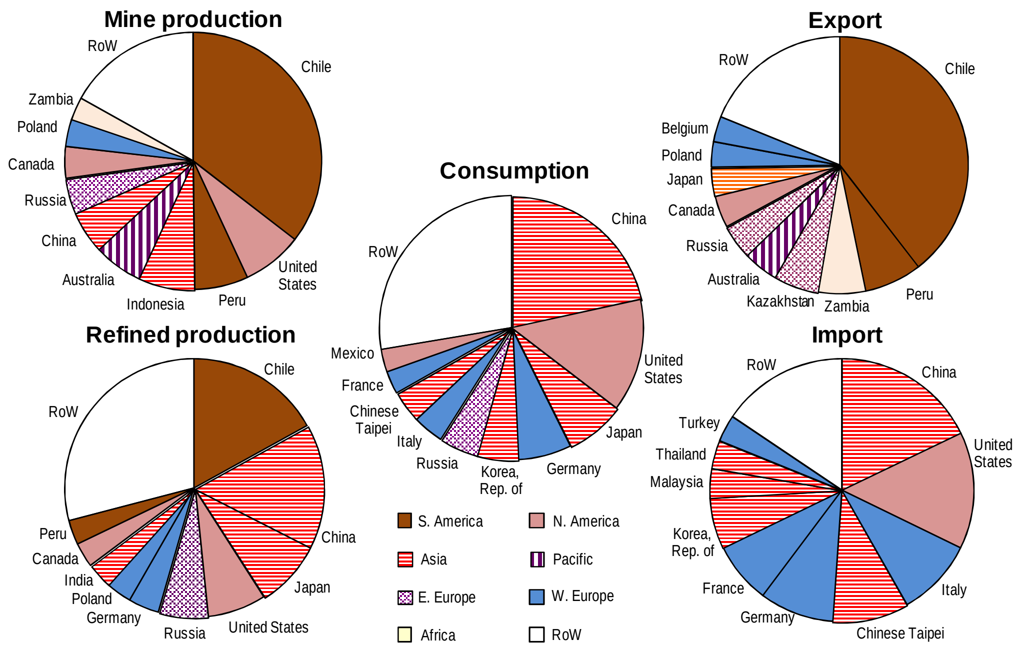
22 Based on USGS (2007) and Geoscience Australia (2006) data, Chile (29%) has the largest economic demonstrated resources of copper, followed by Australia (9%), the United States and Indonesia (7% each) and Peru, Poland and Mexico (6% each).

stocks[23]" and "landfills, tailings and slag reservoirs" (Spatari, *et al.* 2005). Worldwide, the ratio of the stock of un-mined copper to the anthropogenic stock was estimated to be around 1.3 in 2000[24]. This ratio can be expected to decline rapidly with the growth of the world economy, with the result that anthropogenic stocks will come to exceed un-mined ones by a factor of two or three in a near future (Kapur and Graedel, 2006; Kapur, 2006).

The recycling rate of copper is significant: 57% in Europe and 60% in North America. Recycled copper by far consists of production waste (prompt scrap) rather than post-consumer waste (old scrap). The recycling rate of copper old scrap amounts to about 36% in North America. Old scrap is a large and growing part of the technological copper cycle, but unless the copper stored in waste repositories can be economically extracted, that resource should be considered as lost to society (Spatari *et al.,* 2005).

Improving the infrastructure for secondary material recovery can contribute significantly to supplying society's copper needs, especially for electrical and electronic equipment (EEE) and End-of-life vehicles (ELV) which together contain some 70% of all discarded copper (Reck *et al.*, 2006). The judicious design, use, recycling, and disposal of copper (and other) products should be an integral part of a sustainable society. Furthermore, the collection and storage of waste materials so that they may be located and recovered at minimal cost are an important part of ensuring the feasibility of secondary (post-consumer) recovery and reuse of copper resource (Spatari *et al*., 2005).

Figure 17. World-wide production, consumption and trade of copper, by country, 2005

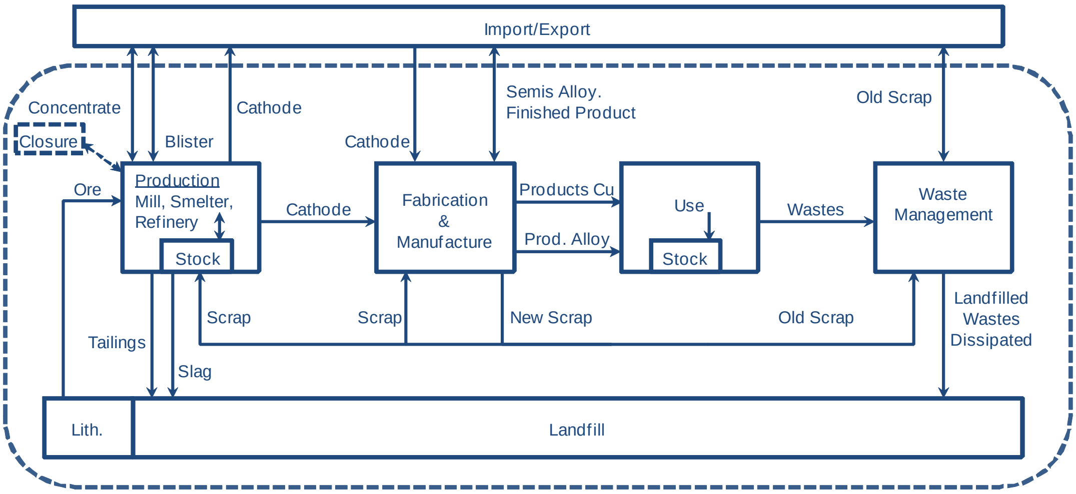


Source: OECD, based on World Metal Statistics – quoted by World Bank (2007) – and British Geological Survey (2007).

23 In this publication, the term "in-use stocks" includes "hibernating stocks" (i.e. copper that is no longer being used, but has not yet been discarded: such as copper in obsolete computers stored on closet shelves).

24 Earth stocks of copper in 2000: lithospheric stocks 940 Tg; anthropogenic stock 747 Tg of which 330 Tg are "in-use" and 24 Tg are hibernating, while 393 Tg are deposited (landfilled) and 1 Tg is dissipated in the environment.

Figure 18. Simplified copper flow diagram[a]



Note : (a) Diagram used in the analysis of the Stocks and Flows (STAF) project of the Yale University.
Source: Spatari *et al.*, (2005).

Biomass and related products

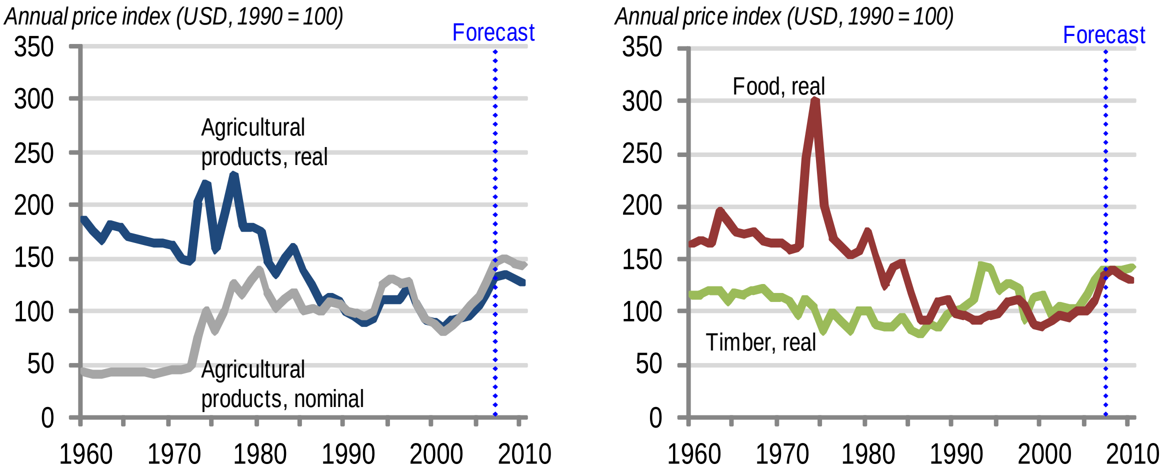
Biomass[25] can be regarded as one of the most fundamental of all material flows because it provides food, medicines, wood, fibre and fuel to sustain human populations. The consumption of biomass has a direct impact on ecosystems, biodiversity, and ecological services such as carbon sequestration and water purification. About 38% of the OECD territory is used for agriculture and a large share of its forest land (34% of the territory) consists of production forests. The use of land for biomass extraction therefore competes directly with other land uses, including land use by nature (i.e. encroachment on natural habitat). Agriculture, forestry and fisheries, in a sense, represent humanity's appropriation of biomass, which must be confined within the biosphere's productive capacity. Indeed, in the view of some, the world in recent years reached an ecological deficit, meaning that the risk of local exhaustion of ecological assets (e.g. water scarcity, deforestation, loss of biodiversity and overfishing) and ecosystem collapse is increasingly likely to grow.

At world level, biomass extraction has been relatively decoupled from both GDP and population growth during the last two decades, the extraction having grown at a slower pace between 1990 and the early years of this decade. Still, biomass extraction reached a record 15.6 billion tonnes worldwide in 2002, a figure that has not changed greatly since then. The share of OECD countries of total biomass extraction fell from 33 to 29% during 1980-2002, while that of BRIICS countries rose from 33 to 38% and that of the rest of the world remained constant (Figure 9).

The decelerating growth of extracted quantities of biomass has been accompanied by a strong fall in the real price of agricultural products since the mid-seventies. Even though prices have risen again from a cyclical low in 2001, the scale of this rise is much smaller than has been the case for oil and metal prices. According to the World Bank, this is partly due to agricultural demand being less sensitive to economic growth than industrial demand, and because agricultural supply responds more quickly to increased demand and prices. Compared to prices of agricultural products and, particularly, food, prices of timber have long been quite stable. In 2005, the real price of timber was about the same as in 1960. But since then, timber prices have grown similarly to food prices, amid rising demands for biofuels, rapid income growth in developing countries, high fertilizer prices, low stocks and droughts (Figure 19).

25 Biomass includes food crops, feed crops, animals, wood and non-edible biomass such as fibres and rubber.

Figure 19. Selected agricultural products price index and projections, 1960-2010



Source: OECD, based on *World Bank Commodity Price Data* (projections as of December 20, 2007).

Despite its diminishing share of world biomass extraction, OECD countries increased their extraction by about 10% over 1980-2005. The composition remained stable during this period, with food crops, fodder crops, and timber accounting for 41%, 34% and 24% respectively in 2005. Wild animal catch (essentially fish) and non-edible biomass together accounted for little more than 1%. OECD countries (as a whole) switched from being a net supplier of biomass goods in the 1980s to becoming a net user from 1991. This switch can be mainly attributed to a doubling of net imports of wood products during the period, and a progressive decrease in net exports of food crops.

Industrial and construction minerals

Industrial and construction minerals, among the four broad categories of material considered in this chapter, represent the bulk, about 40%, of world-wide total materials extraction over the period 1980-2002[26] (Figure 9). This category of materials comprises low-value minerals (e.g. sand, gravel and stone) that are mainly used locally, as well as high-value minerals (e.g. diamonds, phosphate rock, asbestos) that are traded internationally. Construction minerals, by weight, account for the lion's share (95% in the OECD countries) of this class of materials.

Around 22.9 billion tonnes of industrial and construction minerals were extracted worldwide in 2002, representing a rise of 40% since 1980. The share of OECD countries of total extraction fell from 63 to 55% during 1980-2002, while that of the BRIICS rose from 20 to 26%, and that of the rest of the world increased from 17 to 19%. The extraction of industrial and construction minerals in the OECD as a whole was relatively decoupled from GDP growth over the period. Within the OECD area, trends vary among countries and regions, reflecting among others differences among countries in the building and maintenance of infrastructure.

Even though construction minerals have a low environmental impact per tonne (compared to metals, fossil fuels or certain industrial minerals), the large volumes involved make them environmentally significant. Thus, the mining and processing of industrial and construction minerals engenders a host of environmental issues, such as destruction of habitat at the mine site, alteration of landscape and loss of land-use, mine waste/tailings disposal, dust, noise, energy use, siltation and changes in river regimes. Also, the manufacture of derived products like cement, glass, ceramics, bricks and tiles have considerable environmental impact. Cement production accounts for instance for about 5% of anthropogenic CO_2 emissions worldwide.

[26] Readers are reminded there is considerable uncertainty regarding the quality of data for industrial and construction minerals.

Fossil fuels

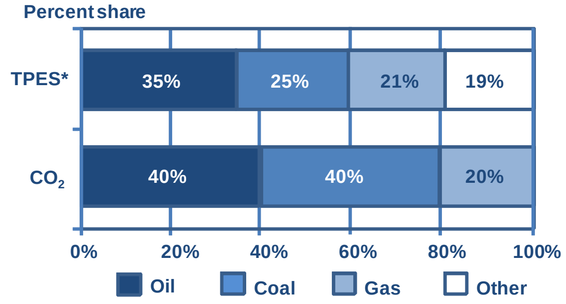
From 1980 to 2002 the cumulative worldwide extraction of fossil fuels – coal, crude oil, natural gas, and peat – amounted to some of 216 billion tonnes. Around 10.6 billion tonnes were extracted in 2002, representing a 30% increase compared to the amount extracted in 1980. It is likely that fossil fuels will continue to supply the bulk of the world's energy needs during the next few decades, accounting for four-fifth of the increase in energy supply. The growing share of emerging economies in energy demand is expected to further boost this growth over the next decades. The share of the OECD countries of total fossil fuel use (in mass) fell from 44 to 38% during 1980-2002, while that of the BRIICS countries rose from 29 to 35%, and that of the rest of the world accounted for 27% in 2002, the same figure as in 1980 (Figure 9).

Despite the growth of non-fossil energy (e.g. nuclear, hydropower and wind), fossil fuels have maintained their overall share of the world energy supply over the course of the past 35 years, accounting for 81% of the total primary energy supply (TPES) in 2004, and almost all CO_2 emissions of the energy sector at this time. Oil still dominates TPES, with a share of 35% in 2004. However, the share of oil in TPES has decreased by about 10% since 1971, largely counterbalanced by the penetration of gas whose supply in 2004 was more than 2.5 times as high as in 1971.

The various types of fossil fuels have different carbon "footprints" because each type has a different carbon content (tonnes of carbon per 1000 tonnes) and a different net calorific value (TJ per 1000 tonnes), and thus emits different amounts of carbon per unit of energy (tonnes of carbon per TJ). For example, though representing only one-quarter of world TPES in 2004, coal accounted for 40% of global CO_2 emissions (Figure 20). Coal is on average up to twice as emission intensive as gas (IPCC).

World market prices of fossil fuels have fluctuated tremendously since the 1970s. The real price of crude oil has in recent times exceeded that during the 1981 "oil shock." These fluctuations have been influenced by the limited responsiveness of worldwide supply, and by different political and climatic events. It is expected that oil prices will remain quite high (far above 1980s level) and volatile, at least until 2010 (Figure 21).

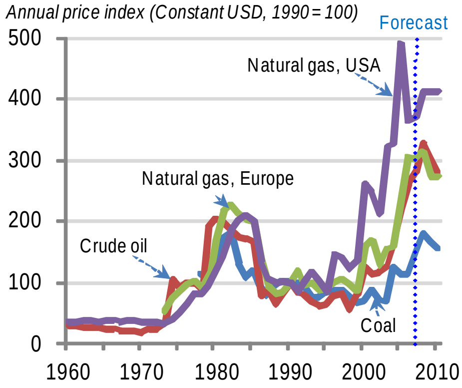
Figure 20. World primary energy supply and CO_2 emissions, shares by fuel, 2004, in %



Note: * TPES includes international bunkers; ** Other: nuclear, hydro, geothermal, solar, tide, wind, combustible renewables and waste.

Source: OECD/IEA (2006).

Figure 21. Selected energy price index and projections, 1960-2010



Source: Based on *World Bank Commodity Price Data* (projections as of 20/12/ 2007).

Fossil fuel carriers are extracted from non-renewable resource stock, and it is difficult to predict when world reserves of the different fossil fuels will be exhausted. Estimates of world reserves life expectancies – at growth rate in primary production varying between 0% and 5% – are roughly of 216 to 49 years for coal, 44 to 23 years for crude oil and 64 to 29 years for natural gas. Thus scarcity is an emerging issue. Since fossil fuel reserves are concentrated in few non-OECD countries, OECD's security of supply could be affected by political and economic instability in the producing regions. The recent record-high oil prices, and their damping on economic growth, may have given a foretaste of the possible consequences of the eventual shortages of oil.

7. UPTAKE OF MFA BY OECD COUNTRIES[27]

OECD countries have to varying degrees seized the opportunities for improving economic and environmental decision-making opened up by the progress made in Material Flow Analysis. The pioneering work of research institutions (e.g. World Resources Institute, Wuppertal Institute, IFF-Vienna) and national statistical offices, as well as the catalytic role played by international organisations (e.g. OECD, Eurostat) in developing methodological guidance have enabled individual countries to explore the usefulness of the approach.

Two-thirds of OECD member countries have developed or are developing economy-wide MF accounts. Other countries have focussed on individual flow accounts in areas of particular relevance to the countries concerned. Some countries are developing specific flow accounts distinguishing not only categories of materials but also branches of production.

Institutions and partnerships

Traditionally, MFA has mainly been carried out by academics or as part of research projects steered by national statistical offices, and in a few cases environment ministries and agencies. In some countries, responsibilities have progressively moved from the academic and research side to the policy side, with environment ministries being increasingly interested in indicators derived from MFA.

The production of MF accounts is generally in the hands of national statistical offices (NSOs). In a few countries, research institutes are conducting MF research on behalf of their government sometimes with government funding or in co-operation with government agencies.

The development of MF indicators, and their use in environmental reporting is shared among NSOs and environment agencies and ministries, and sometimes research institutes. In countries where MF work is well advanced, partnerships are commonly established among various partners within the country as well as with international networks and with partners in other countries. Some countries provide assistance to non member countries via their research activities.

Applications and types of uses

According to a survey among OECD member countries, material flow accounts and the information they provide are commonly used for:

- linking environmental and economic information (19 countries)
- supporting modelling and outlook activities (11 countries)
- informing decision making (10 countries) and as a basis for policy analysis (6 countries)
- informing the public and policy makers about key issues and trends (12 countries).
- monitoring the efficiency of materials use (19 countries) and its sustainability (14 countries) at various levels, often with a link to waste management or to other aspects such as: the effects of globalisation and trade; the environmental impacts of material flows, the economic impact of material flows; and the security of materials supply.

Information from economy-wide MF accounts is commonly used for monitoring the material basis of the economy and illustrating productivity or decoupling trends in areas linked to natural resource use and waste generation. Information derived from other flow accounts and analysis (material specific accounts, PIOTs, SFA) is often used as a tool for materials management. It supports for example the implementation of policies related to integrated product management, the control of chemicals or the control of air and GHG emissions.

[27] Based on OECD (2008), *Measuring material flows and resource productivity – Volume III. Inventory of country activities,* OECD, Paris.

MFA tools are also increasingly used by business and promoted by industry associations.

Indicators and policy goals

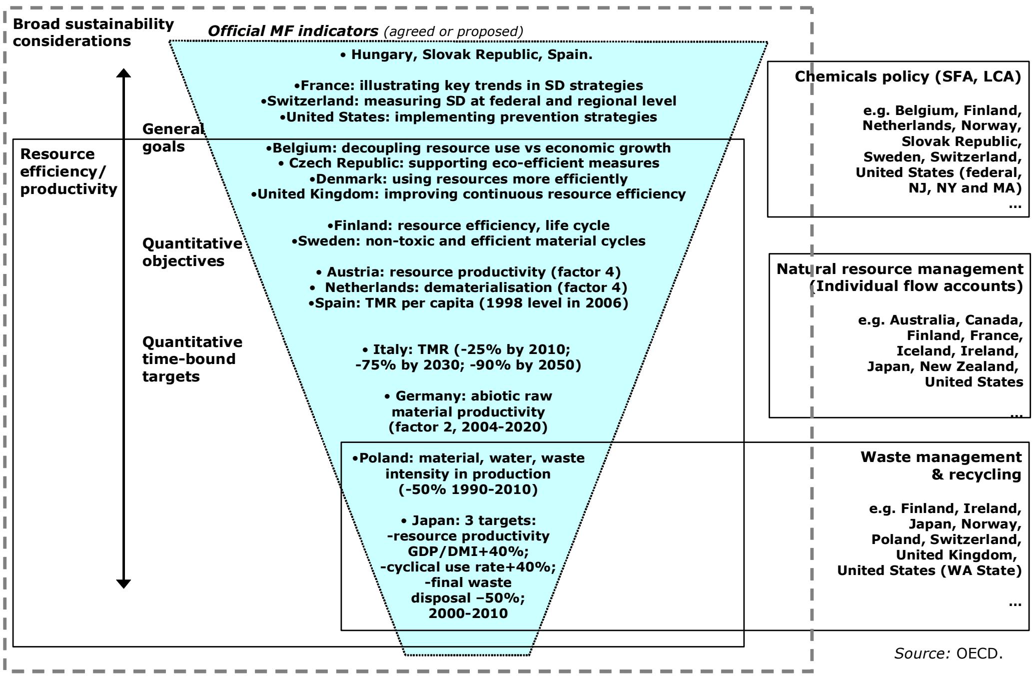
An increasing number of countries are incorporating MF indicators into national environmental or sustainable development indicator sets, while some are also formulating broad national goals, quantitative objectives, and even time-bound numerical targets in terms of MF indicators.

Twenty-one OECD countries have calculated and/or use one or several economy-wide MF indicators. These indicators generally describe economy-wide material use, as well as related intensities and decoupling trends when linked to the relevant economic variables. Most of them are used to monitor the overall trends and to draw attention to key developments that will require further analysis. In 14 OECD countries, MF indicators are part of proposed or agreed sets of environmental or sustainable development indicators. Among the most common indicators feature i) Direct material input DMI (19 countries); ii) Domestic material consumption DMC (19); and iii) Total material requirement TMR (14).

In several OECD countries, goals and objectives concerning the efficient management and sustainable use of natural resources and materials have been embodied in national sustainable development strategies, environmental action plans or waste management plans (Figure 22):

- In nine countries, MF indicators are linked to broad policy goals (e.g. to reduce TMR/capita).
- In three countries MF indicators are linked to quantitative objectives of a general nature (e.g. increasing resource productivity by a factor of 4 in the longer term).
- In four countries, MF indicators are linked to quantitative time-bound targets on resource productivity or material resource use intensity (e.g. achieve a reduction of TMR of 25% by 2010, 75% by 2030 and 90% by 2050 compared to 2000).

Figure 22. Examples of uses of MF information and links to policy goals



Source: OECD.

8. LOOKING AHEAD

A considerable amount of work on MFA has been carried out in the past decade, much of it in developing methodologies and doing the necessary "spade work" (i.e. setting up databases and populating accounts) required before the more visible MF indicators can be calculated. Many countries have been carrying out research on material flows, and MF information is increasingly used to monitor progress towards improved resource productivity and as part of national indicators sets.

Despite these advances, MFA remains a "young" tool, and systematic use in national policy debates and policy making has remained limited. Countries are at a variety of stages in developing and using MFA. The status of their work, its characteristics and scope, purpose and policy use vary. This reflects the varying economic and environmental importance of a given resource or material flow for different countries, as well as remaining differences concerning the concepts and methodologies applied. More is needed to achieve greater convergence of already existing initiatives and to facilitate wider dissemination and uptake of existing experience and guidance. More is also needed to explain the added value of MFA compared to other monitoring and measurement tools and to promote the use of MF analysis and indicators.

The work carried out since 2005 by the OECD and its member countries to establish a common knowledge base on material flows and resource productivity and to develop guidance on how to construct material flow accounts and indicators in a coherent framework, is a first step in this direction.

Improving knowledge on the environmental impacts and costs of resource use

In order to address the widely held environmental concerns associated with resource use, the priority for further improving the MFA knowledge base is for a better understanding of environmental impacts and costs of resource use throughout the entire life cycle of materials and the products that embody them (i.e. from natural resource extraction, manufacturing, use/consumption to end of life management). This includes:

- Scientific knowledge about environmental impacts, and methodologies for assessing environmental impacts and costs considering both downstream effects (e.g. toxicity by pollution), and upstream effects (e.g. on biodiversity by resource extraction/harvest) with links to (i) the quality/deterioration of natural resource stocks, (ii) critical environmental cycles, and (iii) the effects of trade and globalisation on the geographical distribution of environmental burdens.
- Methodologies for calculating indicators that reflect environmental impacts. In the case of aggregated indicators, further exchange of experience among countries active in this area of work would help develop a consensus about the validity of the methodologies and conversion factors to be used and a broader acceptance of the weighing methods to be used (to assess the toxicity or potential environmental pressures associated to each materials).
- Methodologies for estimating indirect and unused flows of materials that are of environmental importance. Further exchange of experience among countries and research institutes and joint international work would help develop a consensus on the conversion factors to be used to measure such "hidden" flows.

Implementing compatible measurement systems and upgrading data quality

Required also is the actual implementation of compatible measurement systems and associated databases for material flows and resource productivity, giving particular attention to:

- The availability and international comparability of data on physical trade flows, including flows of recyclable materials and waste, and data on particular flows that are of economic and environmental importance, including flows of metals, plastics, paper, 3R "Reduce, Reuse, and Recycle" related flows.
- Internationally compatible MF accounts and databases, which provide a factual basis for international and global material flow studies and that countries can further adapt to their own needs and circumstances.
- Disaggregated accounts and databases, which provide industry-level and material specific information that can serve as an early warning tool, and indicate opportunities for improved performance and efficiency gains.

Promoting the use of material flow and resource productivity indicators

Though many countries have incorporated material flow and resource productivity indicators in their national sets, feedback on the policy relevance of the indicators in use is still seen by some as insufficient and further insights are needed to guide their refinement and to promote their systematic use. Required is:

- A policy dialogue on the benefits and implications of pursuing various methods for developing and adopting a balanced set of common MF and RP indicators. Such a set would include, beside material specific indicators, a few comprehensive and easily understandable indicators for policy makers and other stakeholders, which could complement key macro-economic indicators such as GDP.
- A review of applications for indicators that assess the efficiency of material resource use at various scales and for various materials (e.g. wastes, reusables, recyclables), including applications in planning or target setting.

Fostering co-operation and sharing of good practices

As to the provision and uptake of guidance, OECD governments should co-operate with industry and non-member economies to strengthen their capacity on measurement and analysis of material flows and the associated environmental impacts. OECD countries should also encourage co-operation and sharing of good practices among enterprises in order to promote the development and use of MF accounts and analysis at business level. They should encourage co-operation among all institutions involved, including research institutes, policy departments and statistical offices, in order to promote the use of MFA in national policy debates and policy making.

Inter-governmental organisations play an important role in addressing the international aspects of material flows and resource productivity, raising awareness about the importance of resource efficiency, sharing information on research and development concerning MFA, and fostering the convergence of the methodologies used. They also play an important role in sharing good practices and in elaborating common principles and guidelines concerning resource productivity.

In this context, it is important that the synergies between OECD work on material flows and resource productivity and other relevant international activities, such as the 3R initiative (Reduce, Reuse and Recycle) endorsed by the Heads of State and Government of G8 countries, the International Panel on Sustainable Resource Management established by UNEP and initiatives by the European Commission, are used.

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