Chapter 30

SEEA-2003 and the Economic Relevance of Physical Flow Accounting at Industry and National Economy Level

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This year the international handbook on integrated Environmental and Economic Accounting (SEEA-2003) will be published. This handbook provides a detailed overview of environmental accounting approaches that have been developed in parallel with the System of National (economic) Accounts. In addition to natural resource stock accounts, and environmental protection expenditure accounts, SEEA-2003 pays considerable attention to physical flow accounting. Expanding the national economic accounts with physical data sets facilitates the joint analysis of environmental and economic policy issues. This article discusses the main characteristics of national accounts-oriented physical flow accounting approaches and provides an overview of the kind of indicators they may put forward. Also the analytical advantages of national accounts oriented physical flow accounts are illustrated. The article is not an attempt to provide a comprehensive review of macro-oriented physical flow accounting approaches. For such reviews in this Journal we would like to refer to Daniels (2002) and Daniels and Moore (2002).

National Accounts and SEEA-2003

The System of National Accounts (SNA 1993) provides the world-wide internationally standardized macroeconomic accounting standards. The national accounts provide coherent and consistent data sets and indicators for economic policy analysis. However, the standard SNA-1993 is too restricted with respect to environmental research questions. Since environmental functions are in many cases available

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without direct monetary costs incurred to their users, monetary accounting will usually not reflect the social costs of depleting or deteriorating natural resources.

As a solution to this problem the international Handbook on Integrated Environmental and Economic Accounting 2003, commonly referred to as SEEA-2003, is developed as a coherent and comprehensive accounting framework for measuring objectively and consistently how environmental functions contribute to the economy and, subsequently, how the economy exert pressures on the environment. As a satellite accounting system, the SEEA-2003 extends the coverage of the SNA by way of several supplementary environmental accounting modules. Satellite accounting systems have also been developed in other fields of interest such as public health, transportation and tourism, but the SEEA-2003 represents probably one of the most well-developed satellite systems to SNA.

SEEA-2003 is jointly published by the EC/Eurostat, IMF, OECD, UN and World Bank and can be regarded as an international environmental accounting reference book for statistical offices, national governments and international organizations.

SEEA-2003 expands the system of national accounts (SNA 1993). This means that national accounts concepts and definitions are used as the basis for the environmental accounting in SEEA-2003. One big advantage of linking environmental statistics to the national accounts is the consistency and direct comparability of (physical-oriented) environmental indicators and mainstream (monetary-oriented) national accounts indicators. This is for example shown in the National Accounting Matrix including Environmental Accounts (NAMEA), one of the main building blocks of the SEEA-2003.

Although focus in this article is on the physical flow accounts it should be mentioned that SEEA-2003 includes, in addition to physical flow accounts, also accounts (in money terms) for environmental protection activities such as waste and waste water treatment, accounts for environmental taxes and subsidies and natural resource stock accounts. The system also presents valuation techniques for measuring in money terms environmental depletion of natural resources as well as degradation of nature assets and ways to adjust the national income figures of SNA for depletion and degradation (i.e. “green GDP”-type figures). Finally, SEEA-2003 describes various applications and uses of the environmental accounts and related modeling approaches.

The physical accounts of the SEEA-2003 specifically focus on the material, energy and spatial requirements and flows of production and consumption processes rather than on the consequences on the availability of natural resources and the services provided by the natural environment. There are at least two reasons for this. Firstly, policy decisions often primarily focus on changing the environmental consequences of human behavior by addressing the causes. This requires information on ‘who is doing what?’ Secondly, an accounting-wise description of changes in environmental assets, such as ecosystems or species, face limitations due to the multidimensional and non-linear nature of cause-effect interactions within the environmental sphere. If at all possible, changes in the state of such environmental assets can only be described by combining accounts with ecological models.

SEEA-2003's Basic Building Blocks

Physical Supply-Use Tables

SEEA-2003 distinguishes four main types of physical matter: natural resources, ecosystem inputs, products (e.g. classified by HS, SITC or CPC) and residuals.[1] *Ecosystem inputs* are substances withdrawn from ecosystems for purposes of production and consumption such as gases needed for combustion and production processes as well as air and water for living things. *Residuals* are the unintended and undesired outputs from production and consumption processes. They include the usual types of solid waste and emissions to land, air and water, but also all other materials left behind from production and consumption processes. Thus, surplus N and P from using fertilizers, road salt and grit are ultimately included in the residuals concept just as so-called dissipative flows from car brakes, erosion and corrosion of infrastructures. An important residual in terms of volume is water evaporation. Thus, the residual concept includes in principle all material outputs whether regarded harmful or not.

In order to categorize the origin and destination of flows, the SEEA-2003 distinguishes between the economy and the environment. The economy is divided into three main entities: *Producers* (e.g. classified by ISIC, NACE), *Households* (e.g. the Classification of Individual Consumption According to Purpose, COICOP) and *Capital*. The latter covers traditional economic assets (e.g. building and machines) but also other physical stocks like controlled landfills, which are still under the control of human beings. Capital related flows of residuals include for instance the disposal of capital equipment (scrap), leakages from landfills and infrastructure and waste stocked in landfills. A *Rest of the World* (ROW) entry is added to describe the physical interactions with foreign economies. These include airborne pollution transfers such as acid rain and pollution transferred via river systems, the cross-border transportation of (solid) waste and residuals transferred via internationally operating activities such as transport and tourism.

SEEA-2003 structures the presentation of physical flows in so-called supply (origin) and use (destination) tables. The structure of supply–use tables is shown by Tables 30.1 and 30.2. Ton is often used as the unit for the physical supply–use tables, but also alternative units (e.g. Joule for energy) can be applied.

The supply table shows the origin of flows while the use table shows their destination. At later stages in the process of accounting and analysis, the origin and destination of physical flows can be interconnected in so-called physical input-output tables described below.

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[1] HS Harmonized Commodity Description and Coding Systems – SITC Standard International Trade Classification – CPC Central Product Classification. SEEA-2003 contains a classification of assets and subsequently asset inputs (cf. SEEA-2003: Annex 2), material throughputs (Annex 3) and residual outputs (Annex 4). A detailed classification of material flows is an important precondition for indicating the wide variety of environmental impacts associated with different material flows.

Table 30.1 Schematic Outline of Supply Tables

		Industries 1 2 3 … n	Capital	Consumption 1 2 3 … c	Rest of the world imports	National environment	Total supply
Products	1	Output by product and by industry			Imports by products		Total supply of products
	2						
	3						
	.						
	.						
	.						
	p						
	Total						
Residuals	1	Residuals generated by type and by industry	Scrap of capital goods Leakages from landfills etc. by residual type	Residuals generated by type and by household consumption groups	Residuals from non-residents on national territory and cross-boundary inflows		Total supply of residuals by type
	2						
	3						
	.						
	.						
	.						
	r						
	Total						

Supply tables for products can be presented in physical (tons) or monetary units. Supply tables for residuals can be presented in physical units (tons, cubic meters, energy units, etc.

Table 30.2 Schematic Outline of Use Tables

		Industries 1 2 3 . . . n	Capital	Consumption 1 2 3 . . . c	Rest of the world exports	National environment	Total use
Natural resources	1 2 3 . . . n Total	Use of natural resources by type and by industry		Use of natural resources by type and by household consumption groups	Use of natural resources by type and by non-residents on national territory		Total use of resources by type
Ecosystem inputs	1 2 3 . . . e Total	Use of ecosystem inputs by type and by industry		Use of ecosystem inputs by type and by household consumption groups	Use of ecosystem inputs by type and by non-residents on national territory		Total use of ecosystem inputs by type

(continued)

Table 30.2 (continued)

		Industries 1 2 3 . . . n	Capital	Consumption 1 2 3 . . . c	Rest of the world exports	National environment	Total use
Products	1	Use of products as intermediate inputs by products and by industry	Use of products for capital formation by products	Use of products for private consumption by household consumption groups	Exports by products		Total use of products (= total supply of products)
	2						
	3						
	.						
	.						
	.						
	p						
	Total						
Residuals	1	Absorption (reuse and treatment) of residuals by type and by industry	Accumulati-on of residuals in economy (e.g. controlled landfills)		Residuals generated by residents in the rest of the world and cross-boundary outflows	Residuals ending up in the national environment by type	Total use ("dis-appearance" of residuals) by type (=total supply of residuals)
	2						
	3						
	.						
	.						
	.						
	r						
	Total						

Use tables for products can be presented in physical (tons) or monetary units. Supply tables for natural resources, ecosystem inputs and residuals can be presented in physical units (tons, cubic meters, energy units etc.)

For products the supply table shows the amounts of various products (e.g. animal and vegetable products, stone, gravel, energy, metals) supplied by domestic industries or imported from abroad. The use tables for products show how products are used by industries for intermediate consumption or, alternatively, for final consumption by government or households, as fixed capital formation or for foreign use (exports).

For each residual type (emissions to air and water and solid wastes) the supply table records how much each industry or household emits. In addition, the supply table records residuals originating from the capital stock (e.g. scrapping and leakages). The use table of residuals shows what happens to all residuals generated: whether these residuals have been re-absorbed and converted to other materials and substances, for example, in connection with waste treatment, whether they are accumulated within the economy, e.g. in controlled landfills or whether they have been disposed of in the environment. The system boundary between the economy and the environment refers to the extent to which materials can be regarded as being under the control or not of economic entities.

For each category, e.g. subsoil assets, non-cultivated biological assets, water, air, oxygen, the use tables for natural resources and ecosystem inputs show the extraction by industries, households and the rest of the world. Extractions by non-residents may occur, for example, when foreigners fish on national territorial waters. The supply of natural resources and ecosystem inputs are not shown explicitly.

Material Balances and Bookkeeping Identities

The accounting identities that structure the physical flow accounts in the SEEA-2003 are based on the material balance principle. This law on the conservation of mass states that ‘what goes in must come out’. In the SEEA-2003 the material balance principle is applied to the various categories of flows as well as to the various entities.

For a physical *flow* of a given type or group of materials the material balance principle can be expressed as:

$$\textbf{Supply} \equiv \textbf{use}\ (\text{or } \textbf{origin} \equiv \textbf{destination})$$

So, the accounts reflect that total supply in mass terms must by definition correspond to the total use. An example from the Netherlands may illustrate this accounting principle for residuals. Table 30.3 shows the supply and use of acidifying and eutrophicating substances. These substances may first of all be emitted by Dutch residents (from industries, households and leakages from capital), however, they may also originate from the rest of the world, via both non-residents operating in the Netherlands, as well as by transfers into domestic territory via water and air. On the use side, part of the substances is reabsorbed by producers, or transferred to the rest of the world, while the remaining part accumulates on Dutch territory.

Table 30.3 Acid and Nutrient Pollution in the Dutch Physical Flow Accounts, 1997 (de Haan 2004: Table 3.1)

		NO_x	SO_2	NH_3	P	N
				1,000 t		
Supply	Emission by residents	701	236	188	100	1,034
	From the rest of the world					
	Non-residents in The Netherlands	41	12	–	–	11
	Transfer by surface water or air	60	70	22	15	313
	Total supply (origin)	**801**	**319**	**210**	**115**	**1,359**
Use	Absorption by producers (waste water treatment)				21	118
	To the rest of the world					
	Residents in the rest of the world	282	131	–	–	79
	Transfer by surface water or air	414	92	34	16	425
	Accumulation in the Netherlands					
	Acidification	108	96	176		
	Eutrophication				77	736
	Total use (destination)	**801**	**319**	**210**	**115**	**1,359**

For a given entity, e.g. a producer, a household or a capital stock, the material balance principle leads to the following identity:

$$\textbf{Total inputs} \equiv \textbf{total outputs} + \textbf{net accumulation}$$

In other words, what goes into a system is either accumulated in the system or leaves the system again as an output. In this case, the balance is based on an aggregation of different types of materials. Table 30.4 illustrates the application of this identity in the SEEA-2003.

Total material input of the *production* system equals 831 million tons. This breaks down to 442 million tons of products supplied and used for the production processes, 261 million tons of natural resources and 121 million tons of ecosystem inputs extracted by the industries from nature, and finally 7 million tons of residuals released but, subsequently, reabsorbed by the industries (for recycling and reuse after cleaning or processing). These 831 million tons of materials are transformed by the production system into 551 millon tons of products and 280 million tons of residuals. No accumulation enters the balance for production. This is due to the fact that accumulation is explicitly accounted for via the capital account. Similar balances are presented in the table for the other entities. In the case of households, the accounts include accumulation entries for consumer durables.

The presented identities can only be applied in the accounts when the underlying statistics are well developed and sufficiently cover both the input and the output side. In practice, data are often missing. This does not mean, however, that the balancing principle and the bookkeeping identities are without relevance. The identities can often be used to compare existing, and in some cases, contradictory pieces of

Table 30.4 Physical Input-Output Relationships for Economic Activities (SEEA-2003: Table 3.18)

	Inputs		Outputs
	(Million tones)		(Million tones)
Production			
Intermediate consumption of products	442	Output of products	551
Extraction of natural resources	261	Generation of residuals	280
Ecosystem inputs	121		
Re-absorption of residuals	7		
Total material inputs	*831*	*Total material outputs*	*831*
Capital formation			
Capital formation and changes in inventories	119	Generation of residuals	73
Waste to landfill sites (absorption of residuals)	26	Net material accumulation in the economy	72
Total material inputs	*145*	*Total material outputs*	*145*
Consumption			
Household consumption of products	39	Generation of residuals	48
Extraction of natural resources	2	Net material accumulation of products (consumer durables)	17
Ecosystem inputs	24		
Total material inputs	*65*	*Total material outputs*	65
Rest of the world			
Exports	101	Imports	150
		Net material accumulation of products in the rest of the world	−49
Total inputs of products to ROW	*101*	*Total outputs of products from ROW*	*101*
Residuals generated by residents in ROW	5	Residuals by non residents in national territory	6
Cross boundary flows to ROW	4	Cross boundary flows from ROW	8
Natural resources and ecosystem inputs to ROW	3	Natural resources and ecosystem inputs from the rest of the world	10
		Net accumulation of natural resources, ecosystem inputs and residuals in ROW	−12
Total inputs of natural resources, ecosystem inputs and residuals to ROW	*12*	*Total outputs of natural resources, ecosystem inputs and residuals from ROW*	*12*

The figures are fictitious and do not relate to any specific country.

information. Thus, the accounting principles are instrumental in checking data, to find erroneous data, to fill gaps in data and ensure a better quality of the information provided. In relation to this it should be observed that the accounting identities must hold at all levels, i.e. for the total economy level, for industry groups, for specific industries, for all materials and for specific products, natural resources and residuals.

Physical Input-Output Tables

While the two dimensional rectangular (product × industry) supply and use tables show separately the origin and destination of the flows, symmetric physical input-output tables (PIOTs) merge this information into one single square matrix (with either the dimensions product × product or industry × industry). Additional assumptions and techniques are required to convert physical supply–use tables into physical input-output tables. These assumptions are in fact the same as those underlying monetary input-output tables (cf. Commission of the European Communities 1993: Chapter XV; United Nations 1999). This conversion leads to an information loss since either the industry or product dimension disappears. However, it also adds information since an input-output table directly connects supply to use. This interconnected quantification of production chains presented in input-output tables serves various analytical purposes.

Table 30.5 shows an example of an industry-by-industry physical input-output table. A cell in the table shows the amount of material flowing from an activity/category, identified in the row headings of the matrix, to an activity/category identified by the column headings. For example, it shows that 121 million tons of products are transferred from agriculture, fishing and mining to manufacturing, electricity and construction.

Table 30.5 Physical Input-Output Table, Million Tons (SEEA-2003: Table 3.25)

			Industries				*Capital*	*Households*	*Row exports*	*Residuals*	*Accumulation*	*Total*
			I1	I2	I3	I Total	CF	C	X	R		
Industries	I1	Agriculture, fishing and mining	26	121	11	158	46	14	32	35	0	285
	I2	Manufact., electricity and construction	26	146	10	183	67	13	36	187	0	486
	I3	Services	0	1	0	1	0	0	0	58	0	60
	I	Total industries	53	268	21	342	112	28	69	280	0	831
	CF	Capital								73	72	145
	C	Households								48	17	65
	M	ROW imports	21	69	10	100	7	11	32	6	−52	104
	N	Natural resources	196	65	0	261	0	2	1			525
	E	Ecosystem inputs	15	81	25	121	0	24	2			268
		Absorption of residuals	0	3	4	7	26				0	40
		Total	285	486	60	831	145	65	104	406	37	

The figures are fictitious and do not relate to any specific country.

Physical input-output tables are equally established on the basis of material balance identities which means that total input (a column total) is by definition equal to total output (the corresponding row total). This input-output identity holds for each industry, household category, capital category or the rest of the world. For example, Table 30.5 shows that input of agriculture, fishing and mining equals 285 million tons. Subsequently, this industry delivers 158 million tons of products to (other) industries, and 46, 14 and 32 million tons to capital formation, households and exports correspondingly. Furthermore, this industry generates 35 million tons of residuals. In total, this amounts to 285 million tons of outputs which correspond to the total sum of inputs.

Complete physical input-output tables for national economies have, for example, been constructed by Stahmer et al. (1998) and Gravgård (1999).

PIOTs provide an interconnected picture of inter-industry flows. The physical input-output tables enable – based entirely on a physical representation – modeling and analysis of the physical flows and the economic activities lying behind these. Based on empirical results, Weisz et al. (2004: 53) concludes that monetary input-output tables cannot adequately approximate the physical interrelations of an economy and that PIOTs are to be preferred, for example, for the calculation of raw material equivalents of imports and exports. Furthermore, as shown by Gravgård (2004), physical input-output tables can be used to construct industry specific waste accounts based on the material balance principle. Experiences with the analytical use of physical input-output tables are still very limited. Alternatively, so-called hybrid input-output tables are often used. Examples of such applications are given below.

Comparison of SEEA-2003 and Economy-Wide MFA

Economy-wide material flow accounting (MFA) as defined in Commission of the European Communities (2001) and compiled by e.g. Steurer (1992), Adriaanse et al. (1997), Matthews et al. (2000) and Bringezu and Schütz (2001), are examples of accounting frameworks that are totally restricted to (1) the material exchanges across the boundary between the environment and the economy and (2) to the material inputs and outputs connected to international trade. In the latter system, the economic system itself remains basically a black box. Contrary to this, the physical supply–use tables and input-output tables of SEEA-2003 are used to address the physical flows *within the economy* (products) as well as the material flows *exchanges* of the economy with the environment. However, the SEEA physical accounts can be aggregated into an economy-wide MFA type of account for direct flows. This is illustrated in Table 30.6.

The SEEA-2003-based economy-wide MFA account is established on the basis of the following accounting identity:

$$\begin{gathered}\textbf{Natural resource extraction} + \textbf{imports}\\ \equiv \textbf{residual output} + \textbf{exports} + \textbf{net addition to stock (NAS)}\end{gathered}$$

Table 30.6 Economy Wide Material Flow Account[a] Based on SEEA-2003 (Table 3.24)

	Inputs	Outputs
	Million tons	
Economic sphere		
Imports of products	150	
Exports of products		101
Environmental sphere		
Subsoil deposits	238	
Non-cultivated biological assets	16	
Water	12	
Air (O_2, N_2)	142	
Residuals		
To air		211
To water	0.1	1
Solid waste	33	188
Material accumulation in the economic sphere/net application to stock (NAS)		89
Total Inputs /outputs	**591**	**591**

[a] This account differs from traditional Economy Wide MFA by including water end ecosystem inputs.

This accounting identity corresponds to the one underlying the economy-wide MFA system as published by Eurostat (Commission of the European Communities 2001: 60)

SEEA-2003 is totally restricted to the recording of *direct* physical flows, i.e. flows that are observable at the borderline of the economy and for which statistical observation is feasible. These accounts can, in principle, be constructed on the basis of resource extraction statistics, foreign trade statistics, production statistics, waste statistics and emissions inventories. Economy-wide MFA goes one step further, and includes *indirect* flows e.g. flows taking place outside the system in focus and the borders of the national economy. For example, the MFA indicator TMR (Total Material Requirement) does not only address physical inputs connected to imports and resource extraction but also certain physical flows in other countries that are the consequence of import flows. For example, indirect flows related to imports of minerals include the amount of resources, which are excavated but end up as wastes during mining and processing abroad. Those flows can only be estimated on the basis of data from other countries. In the SEEA-2003, those indirect flows are not part of the accounting framework itself, but are instead regarded as an analytical extension of the accounts. This is in fact completely in line with similar kind of recommendations made in the Eurostat MFA handbook to calculate indirect flows associated with imports and exports, using input-output techniques in the same way as embedded energy or pollution is usually being calculated (Commission of the European Communities: 2001 para. 3.54). In SEEA-2003, the notion of indirect flows is not necessarily restricted to the natural resource input side (as in MFA), but may also refer to pollution or any other use of the environment. Below, it is described how input-output tables extended with physical flow accounts can facilitate these kinds of analyses and also how input-output analyses can be combined with a SEEA-2003 breakdown of the MFA indicators.

Differences Between SEEA Physical Accounting and Conventional Environmental Statistics

Since SEEA-2003 is a satellite accounting system, it is based on national accounts definitions. For example, the national economy is defined in terms of economic activities under the control of resident units. These units may include persons, legal and social entities. A resident unit belongs to the national economy, in which it has a center of economic interest, that is, when it engages for a period of typically 1 year or more in economic activities on this territory (Commission of the European Communities et al. 1993: para. 14.12). Certain production and consumption activities carried out by resident units, including their environmental consequences, may however appear outside the national territory. This is, especially, the case for (international) transportation and tourism. Both activities may be performed on foreign territory, but are still part of the home economy.

Contrary to this, conventional environment statistics, especially emission inventories, often take a geographic view of the boundaries, irrespectively of the kind of economic activity which lies behind. Thus, pollution and solid waste data, as derived from conventional environmental statistics, must be adjusted to national accounts definitions and classifications before they enter the SEEA-2003 physical flow accounts.

The estimation of pollution according to the resident principle has at least two advantages. Firstly, all world-wide emissions are completely allocated to (the economies of) individual countries, taking fully into account emissions from international transport. Secondly, this total is consistent with macroeconomic indicators such as gross domestic product.

Whether the different accounting principles lead to very different numbers for the emissions depend on the country and type of emission in focus. For countries such as the Netherlands (cf. De Haan and Verduin 2000) and Denmark, these differences are big when it comes to international road transport, marine transport or aviation.

This is illustrated in Table 30.7, showing the Danish fuel consumption for water transport according to the SEEA-2003 principle as well as the IPPC[2] principle. Due to the inclusion of, especially, the emissions from fuel bunkered by Danish ships abroad the difference between the IPPC total for Danish water transport and the corresponding SEEA environmental accounting total is very large, not only when the difference is related to the activity itself, but also when seen in relation to the total Danish emissions. For SO_2 emissions, for example, the inclusion of this single item almost doubles the Danish SO_2 emissions.

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[2] International Panel of Climate Change.

Table 30.7 Danish Emissions from Water Transport[a] 2001 – Different Accounting Principles (Olsen and Jensen 2003)

	CO_2	SO_2	NO_3
	Million tons	1,000 t	
1. IPCC principle (fuel sold in Denmark for Danish port to Danish port transport)	**0.4**	**1.4**	**6.9**
2. Fuel sold in Denmark for Danish international sea transport	1.2	10.3	26.0
3. Fuel bunkered aboard by Danish ships	17.5	383.4	476.9
4. SEEA principle , Environmental accounting approach, (=**1**, +**2**, +**3**.)[b]	**19.0**	**395.1**	**509.9**
4. as per cent of total Danish emissions (SEEA principle)	23%	93%	72%

[a] Including fishing.

[b] Bunkering in Denmark by non-residents for Danish port to Danish port transport should in fact be subtracted, but this amount is negligible.

Besides differences in measuring the total sum of environmental pressures of one country, another important difference relates to the classification of activities. Emission registers usually look at the technical characteristics of emission sources: e.g. stationary versus mobile; combustion versus other processes. In contrast, in the national accounts, production activities are classified by the (economic) characteristics of their main product or service output. For example, in traditional environmental statistics all transport is typically combined together, irrespective of which economic activity this transportation relates to. According to the SEEA approach, transport is carried out by households, by transport industries (as services) but also by various other industries (i.e. own account transport).

Aggregating Information: The Need for Consistency

One of the key strengths of accounting is that it provides information at various levels of detail in a coherent and coordinated way. Accounts may deliver detailed data sets to, e.g. researchers for analytical purposes as well as the so-called accounting aggregates used for policy evaluation.

Indicators may contribute to condensed and comprehensible information useful for target setting and score keeping. They allow for direct comparisons between different periods in time and between regions or countries. One advantage of defining and embedding indicators within accounting frameworks is the explicit exposure of definitions and concepts. A consistent representation of indicators *and* accounts undoubtedly improves the communication between different stakeholders: accounting aggregates or indicators provide the main messages while on a more detailed level the accounts deliver the statistical tools required for remedy evaluation.

The aggregation levels of data are presented together with their corresponding target groups by the so-called aggregation and information pyramid in Fig. 30.1. In

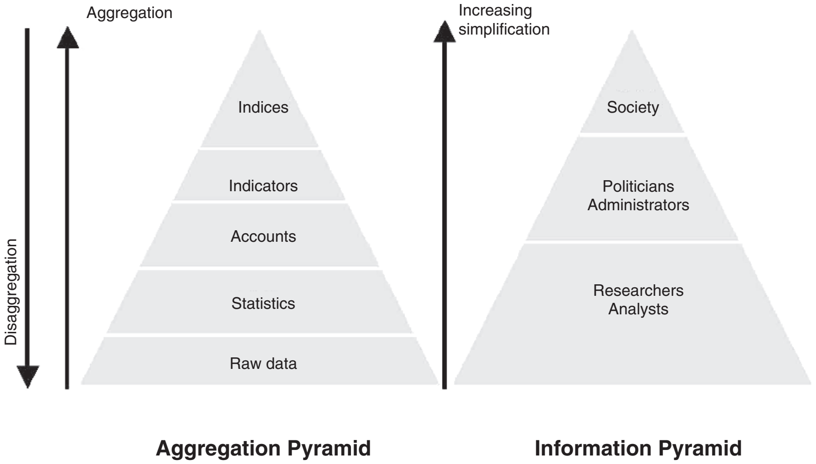

Fig. 30.1 Aggregation and Information Pyramids (Gravgård 2002)

the aggregation pyramid, information from raw data via statistics and various indicators are condensed to composite indicators or indices. The information pyramid shows that the provision of information at various levels serves different users with various backgrounds and interests.

Using an accounting structure is instrumental in ensuring *vertical consistency* (from the bottom to the top) because the strict definitions and identities of the accounts contribute to binding information at various levels together. The accounts provide users with the possibility of going deeper into the data structure underlying indicators targeting driving forces, pressures and responses. Also *horizontal consistency* is ensured by the accounting structure. This means, for example, that the monetary and physical indicators in the information system are consistent in such a way that it is meaningful to compare, e.g. indicators for the economy with indicators for the environment.

Environmental Pressure Indicators: Aggregation and Weighting

A comprehensive implementation of physical flow accounts may result in the recording of a wide range of materials and substances. As a consequence, communicating the results of physical flow accounts requires some degree of aggregation as indicated above by the pyramids. A fundamental question is how far information can reasonably be aggregated in a sensible way. Indicators such as pressure indices (Jesinghaus 1999), Ecological Footprint (Wackernagel and Rees 1996) and Total Material Requirement (Adriaanse et al. 1997) all attempt to aggregate the variety of material flows or environmental impacts of economic activities. It has been argued that the weighing and aggregation methods underlying these indicators are either rather arbitrary or less relevant from an environmental–economic perspective. There has been a lively debate about the soundness of such aggregate indicator approaches (cf. Van den Bergh and Verbruggen 1999; Kleijn 2001a).

In addition, this journal has published a range of articles discussing indicators that may show trends in de- or rematerialization (cf. Kleijn 2001b; Lifset 2000; Cleveland and Ruth 1999; Reijnders 1998). A repeated point of criticism found in these articles is that most indicators used for this purpose are rather imprecise with regard to the environmental threats that they are supposed to represent. This is, especially, problematic when using indicators addressing bulk material throughputs in the economic system. Cleveland and Ruth (1999: 41) refer to various authors who use material input measures as proxies for environmental impacts, assuming that "…a decrease in the amount of material – measured in tons – that is extracted, fabricated and consumed will decrease the amount of waste material released to the environment".

Obviously, a common unit of account (e.g. weights, energy contents) contributes to accounting consistency according to the material balance principle. However, introducing alternative accounting units may be instrumental in indicating some of the specific environmental characteristics of different kinds of material flows. Accounting units, other than mass or volume related units, may emphasize certain quality aspects of physical flows in relation to specific environmental problems. Potential environmental stress equivalents may indicate the average expected contribution of an individual pollutant to a particular environmental problem. These equivalents can be used for weighting and aggregating a wider range of substances into one environmental pressure indicator. As an example, Adriaanse (1993) developed for the Netherlands a comprehensive system of so-called "environmental theme indicators". These themes correspond to the key environmental problem fields identified in the Dutch national environmental policy plans. Examples of environmental stress conversion factors underlying these kinds of indicators are:

- The conversion of greenhouse gas pollutants into CO_2-equivalents
- The conversion of halogenated hydrocarbons contributing to ozone layer depletion into CFC-11 equivalents
- The conversion of sulfur, nitrogen oxides and ammonia into acidification equivalents, i.e. H^+ moles
- The conversion of nitrogen and phosphor pollution into nutrient equivalents, based on the ratio in which both nutrients appear under natural conditions
- The conversion of toxic pollutants on the basis of predicted no-effect concentrations and dispersion patterns in ecosystems or acceptable daily human intakes

Since Adriaanse, some additional work has, to some extent, been carried out to further develop this kind of aggregation methods, especially in the field of product based Life Cycle Assessment (cf. Udo de Haes et al. 1999; Goedkoop and Spriensma 2000; Guinée 2002). Udo de Haes et al. (1999) distinguish in this context two levels at which indicator aggregation can take place: midpoint indicators at the level of environmental problems (e.g. climate change, human toxicity) and end-point indicators at the level of specifically addressed damaged areas (e.g. human or ecosystem health).

Theme indicators are compiled on the basis of the expected damage of particular pollutants according to objective knowledge on cause-effect relationships. The range of resulting indicators explicitly underline the multidimensional character of environmental depletion and degradation, and the evaluation of these various concerns is explicitly acknowledged as a policy assignment. It must be emphasized that the theme indicators reflect the *potential* stress on the environment. Combinations of various stresses as well as spatial and timing conditions usually together determine the factual environmental consequences of pressures represented by the various theme-indicators.

Comparable Physical and Monetary Indicators

The combined physical and monetary accounts facilitate a composite use of physical and monetary indicators such as eco-efficiency indicators. These may be defined as output or value added generated per unit of energy or material used. Such ratio based indicators are quite similar to, for example, labor productivity measures. The numerators and denominators of such ratios should preferably be consistent and refer to the same population. However, this is often not the case. Examples may be domestic energy consumption as published in relation to most energy statistics. It measures the sales of fuels on the national territory, but this is – as illustrated by Table 30.7 above – not the same as the energy used by the resident companies and households, which together make up the entire economy as described in the national accounts. Therefore, there is an advantage of applying national accounts definitions and classifications to resource use and environmental pressure indicators as foreseen by SEEA-2003. A uniform application of accounting rules is an important precondition for achieving genuine comparability and horizontal consistency between monetary and physical indicators and concomitant indicator ratio’s.

In general, combined monetary and physical flow accounts facilitate integrated environmental–economic performance monitoring. The accounts may help to show in what ways industries and households reduce or increase their environmental impacts in relation to their economic performance. The key policy question underlying this performance monitoring is, of course, the extent to which economic growth may coincide with reducing levels of environmental deterioration. The national accounts provide in this context the relevant economic growth measures, i.e.gross or net domestic product at national economy level, the value added at industry level and the consumption expenditure of households. The SEEA-2003 physical flow accounts supplement these mainstream economic measures with their corresponding physical counterparts

Especially on higher levels of aggregation with respect to activities or material flows, material throughput measures inevitably suffer from double counting. This is why national account aggregates such as total output (i.e. the total value of production in the domestic economy) and intermediate consumption (i.e. the sum value of all goods and services used in the course of production) are of limited economic significance. They do not serve as meaningful macroeconomic indicators. Intermediate consumption largely consists of unfinished products which may be transferred several times between different manufacturers. It is the *balance* between output and intermediate consumption that determines the value added or generated income of individual production activities. The sum of value added of all industries in an economy makes up gross domestic product, one of the most well-known indicators included in the system of national accounts.

Similarly, the difference between the total product outflow and product inflow in mass terms equals the balance of natural resource extractions and residual disposals. This analogy is illustrated in Fig. 30.1. This figure shows that the meaningful indicators, which physical flow accounts may put forward, should either address natural resource inputs directly withdrawn from the natural environment or the direct residual outputs. Both types of material exchanges, ultimately determine the state of the natural environment.

However, this does not in any way imply that the recording of material throughputs is irrelevant. Following a thermodynamic perspective, the natural resource inputs are connected to the residual outputs, and understanding the causalities between resource use and waste generation is an important precondition for cost-effective environmental management. The supply–use or input-output tables as represented in SEEA-2003 foresee in a systematic mapping of product flows, either in money or physical terms in such a way that the causalities can be analyzed.

Combining Physical and Monetary Flow Accounts in Environmental–Economic Analysis

In order to juxtapose the physical information in environmental accounts and the monetary information in the national accounts, so-called hybrid flow accounts can be used. The hybrid accounts are a pragmatic approach serving as a data framework for integrated economic–environmental analysis and modeling of the interactions between the economy and the environment. The hybrid approach combines consistently monetary information from the national accounts with selected parts of the physical supply–use tables for natural resources, products and residuals. The acronym NAMEA, National Accounting Matrix including Environmental Accounts, is often used for these types of tables. The NAMEA originates from the work developed by, for example, Leontief (1970), Victor (1972) and more recently, De Haan and Keuning (1996). This approach is now used in some form or another by many statistical offices for expanding the national accounts with information on the physical characteristics of production and consumption activities.

The physical flow accounts in the NAMEA primarily focus on the material transfers from and to the natural environment. Normally, the underlying physical flows of commodity transactions do not enter these accounts. Table 30.8 shows an example of a highly aggregated hybrid industry by industry input-output table. Monetary entries are shown in italics. In this case, the economic part comprises a monetary

Table 30.8 Hybrid Industry-by-Industry Input-Output Table – Currency Units (Italics) and Million Tons (SEEA-2003: Table 4.14)

		Industries				Capital formation CF	Final consumption C	Row exports X	Total use	Residuals R
		I1	I2	I3	I Total					
						Currency units				Million tons
Industries	I1 Agriculture, fishing and mining	*19*	*97*	*14*	***130***	*31*	*3*	*66*	***229***	35
	I2 Manufact., electricity and construction	*28*	*206*	*30*	***264***	*204*	*63*	*159*	***690***	187
	I3 Services	*11*	*90*	*14*	***115***	*152*	*28*	*72*	***367***	58
	I Total Industries	***58***	***393***	***58***	***509***	***387***	***94***	***297***	***1,286***	280
	MROW Imports	*16*	*100*	*14*	***130***	*95*	*47*	*91*	*363*	6
	Taxes on products	*3*	*19*	*3*	***25***	*24*	*5*	*16*	*70*	
	Total final uses					*146*	*506*	*403*	*1,719*	
	Value added	*152*	*179*	*292*	***622***					
	Total production	***229***	***690***	***367***	***1,286***					
					Million tons					
	CF Capital formation									73
	CFinal consumption									48
	NNatural resources	196	65		261		2	1		
	EEcosystem inputs	15	81	25	121		24	2		
	Absorption of residuals	0.2	2.7	3.9	6.8	25.8				

input-output table including product deliveries between industries, product deliveries to final demand and furthermore taxes, value added and the value of total output. At the bottom of the table, *inputs* (in million tons) of natural resources and ecosystem inputs are shown, and at the right the total sum of residual *outputs* from the various industries and other economic entities are shown.

Hybrid accounts can be used as the data framework to derive eco-efficiency indicators and for analytical applications based on a hybrid input-output model. A number of applications are illustrated below.

Environmental Effects from Foreign Trade

Determining the total environmental consequences of consumption or international trade is one example of the way in which hybrid accounts can be used. Trade liberalization and the opening of domestic markets will generally increase shares of foreign supply in domestic commodity consumption as countries specialize according to their comparative advantages. As a result, the product composition of domestic output will increasingly differ from the product composition of domestic consumption, So-called 'de-industrialization' and transformation towards a services or knowledge-based economy has been considered a strategy to increase simultaneously social (employment) and environmental performance. However, sustainability on a worldwide scale is not improved when the specialization in services of some countries implies an increasing reliance on foreign supply of environmentally unfriendly products. For the global environment as a whole, this substitution may not be optimal, since pollution is principally 'exported' and not necessarily diminished. This implies that information about resource use and environmental impacts displaced via international trade, the so-called foreign indirect effects, is essential in appraising the environmental performance of an economy.

However, the direct mass flow coinciding with imports or exports is less relevant from an environmental impact perspective. What matters is the resulting environmental impacts. The so-called 'environmental balance of trade' determines for specific pollution types (or any other environmental requirement such as energy, a natural resource or the land disruptions resulting from mining operations) the balance of environmental requirements embodied in exports minus pollution embodied in imports.

An accurate input-output based modeling estimate of the environmental balance of trade requires knowledge about the production technology applied in countries from which imports originate. However, based on the assumption that the domestic production technology is representative of other countries as well, the domestic input-output model in the hybrid accounts can be used to obtain a first estimate of the indirect environmental impacts in foreign countries, displaced via imports to the country in question

Table 30.9 shows an example of such estimations for the Netherlands. The 'environmental balance of trade' (indicator II in Table 30.9 brings about a shift in focus from the producer oriented direct recording of environmental requirements

Table 30.9 Environmental Balance of Trade and Environmental Consumption, The Netherlands, 1997 (de Haan 2002)

	Co_2	No_x	So_2	NH_3	P	N
			1,000 t			
Emissions attributed to imparts	125,420	313	134	155	53	610
Emissions attributed to exports	155,850	521	239	181	73	854
II. The environmental balance of trade	**30,430**	**207**	**105**	**65**	**20**	**244**
I. Net emission by resident units	**201,020**	**701**	**236**	**188**	**78**	**917**
III. Environmental consumption (I–II)	**170,590**	**494**	**131**	**122**	**59**	**673**

(I) to the indirect recording or imputed environmental requirements to the final commodity consumption in an economy. The latter is labeled in Table 30.9 as ‘environmental consumption’ (III). This indicator also includes the direct environmental impacts from intra-household activities, such as own account transportation and house heating. Further, this indicator includes all pollution from foreign and domestic production processes that are attributable to domestic consumption. The significant amounts of pollution displaced by imports and exports reveal the highly open structure of the Dutch economy. These results underline the necessity to take into consideration import and export flows when analyzing the total environmental requirements of domestic consumption.

Indicator (I) in Table 30.9 principally results from direct statistical observation. The second indicator is determined by imputing pollution to the international trade (i.e. measuring the indirect effects). This imputation is accomplished by reallocating the environmental impacts from industries to their outputs and subsequently to imports and exports. The third indicator is calculated as the difference between the total emissions by residents and the environmental balance of trade. As such it represents a kind of environmental consumption of the residents, i.e. the emissions created globally as a result of the domestic final demand of the residents.

Material Use and CO_2 Emissions of Private Consumption

Hybrid input-output analyses can be used to rank and prioritize within environmental policy by assessing the whole upstream production chain and corresponding resource use and environmental pressures derived from the consumption of various products. To exemplify this, Table 30.10 shows an attribution of total material requirements, TMR[3] and CO_2 emissions to the Danish consumption of food. TMR is here used as an indicator for the resource inputs to show the link to MFA indicators. The approach can, of course, be used for specific types of resource inputs, for example, energy or metallic minerals.

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[3] TMR is an economy-wide material flow indicator for the total amount of natural resources needed to feed the national economy with resources and imported products.

Table 30.10 TMR and CO_2 Emissions of Danish Private Food Consumption, 1997 (Gravgård 2002; Statistics Denmark (www.statbank.dk))

	Total material requirement, TMR		CO_2 emissions	
	Direct	Direct and indirect	Danish indirect emissions	Global indirect emissions
	1,000 t		Tons	
Private food consumption, total	3,800	22,709	2,598	4,670
Bread and cereals	186	1,989	385	657
Meat	2,365	8,941	670	1,084
Fish	44	315	98	221
Eggs	22	506	43	62
Milk, cream, yoghurt etc.	33	2,870	297	403
Cheese	182	1,256	139	220
Butter, oils and fats	202	1,098	104	170
Fruit and vegetables except potatoes	361	2,059	373	947
Potatoes etc.	116	464	56	94
Sugar	33	156	28	35
Ice cream, chocolate and confectionery	146	1,928	307	588
Food products n.e.c	111	1,127	97	189

Direct TMR of consumption is the TMR calculated for the specific products that are consumed. Direct and indirect TMR of a consumption group includes in addition all resource requirements related to the intermediate deliveries of supporting industries, for example, inputs such as energy and packing materials used during the processing and distribution stage. Production of these inputs requires further production in other industries, which again requires inputs and so on. For milk, cream, yoghurt, etc. and, to a lesser extent, also for eggs the input-output calculation shows a very large indirect TMR of the consumption. This result relies on the fact that a part of the large TMR of agriculture (biomass) is related to the domestic consumption of milk and eggs via the input-output calculations.[4]

This calculation approach does not affect the estimate of the national TMR, it only relates the TMR to the demand components and ensures that all relevant parts of TMR are attributed to the relevant products. Input-output modeling avoids double counting problems in the sense that no part of the total economy TMR is attributed to more than one type of consumption.

For CO_2 emissions related to consumption of food no direct emissions exist, only indirect emissions via the derived production in industries. Table 30.10 shows

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[4] Probably, the calculations overestimate the direct and indirect TMR of dairy products and underestimate the direct and indirect TMR of, for example, meat consumption. This is due to the quite simplistic assumptions about constant scale – and proportionality between physical flows and monetary outputs – that are built into traditional monetary and hybrid input-output models.

both Danish and global indirect CO_2 emissions related to the Danish consumption of food. The Danish indirect emissions include all the emissions from Danish industries related to the entire upstream chain of production. The global indirect emissions include emissions generated by the upstream production activities abroad due to exports of food for direct consumption as well as all kinds of intermediate consumption by Danish industries related to the food consumption. The approach used here is the same as that used for the calculations of the environmental trade balance in the previous section.[5]

Similar examples of such analysis in a policy-oriented context are reported for example in Moll et al. (2004). It has also been suggested that input-output analysis can function as supplement to conventional life cycle assessment (LCA). Thus, Lenzen (2000) shows that conventional process based LCA might involve a truncation error of the order of 50%, since LCA is based on a bottom-up process analysis in which only a limited number of processes are included. Contrary to this, analysis based on input-output modeling can provide a rough, but a more complete estimate of the total resource use and environmental pressures created by the consumption.

Structural Decomposition Analysis

Another application of integrated sets of monetary and physical accounts is the so-called structural decomposition analysis based on input-output modeling systems. This method may help to quantify the underlying determinants of eco-efficiency or eco-productivity (the latter being defined as GDP per money unit of resource input or residual output) developments. Structural decomposition analysis quantifies several economic driving forces, which together determine the development of resource inputs or residual outputs over time. Figure 30.2 illustrates an example for the Netherlands derived from de Haan (2001). For the period 1987–1998, the bold line indicates the cumulated total annual percent change in CO_2 pollution from domestic production. The remaining three lines show how these annual changes are broken down according to the following three economic driving forces:

- Eco-efficiency effects (pollution per money unit of output)
- Structure effects (changes in the industry and household demand composition)
- Volume effects (volume growth of GDP)

Basically, two major forces have determined the development of CO_2 pollution over time. On the one hand, GDP growth strongly triggered CO_2 pollution. On the other hand, eco-efficiency improvements led to a downward movement. Structure effects such as shifts from manufacturing to services production were less strong.

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[5] Since the global emissions are calculated on the assumptions that all production takes place with the same (average) technology as used in Denmark, the interpretation of the global emissions should rather be taken as what the emissions would have been in Denmark if all imports were produced in Demark with the given Danish technology.

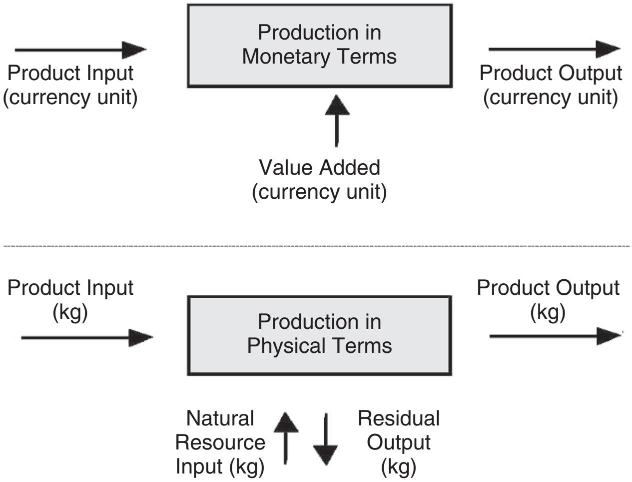

Fig. 30.2 Simultaneous Monetary and Physical Indicators (de Haan 2004: Figure 3.6)

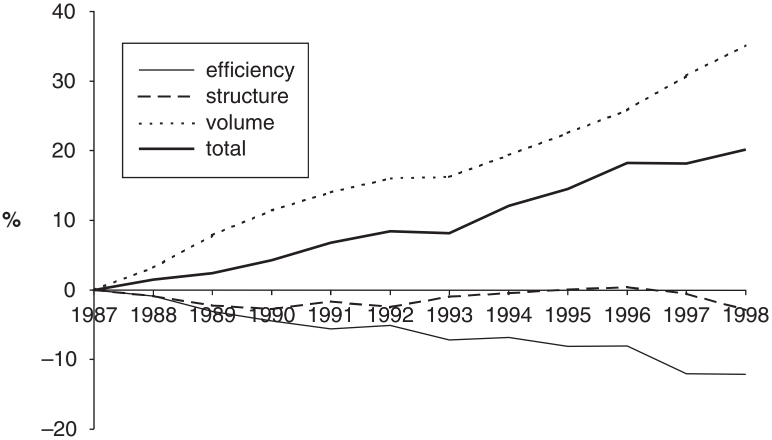

Fig. 30.3 Decomposition of Annual Changes in Production Related CO_2 Pollution in the Netherlands (de Haan 2001)

In general, structure related changes may have been somewhat underestimated due to the fairly condensed input-output tables used in the analysis. However, similar structural decomposition analysis (Olsen and Jensen 2003) for Danish air emissions based on a 130 industry by 130 industry input-output table also indicates that structure related changes in the period 1980–2001 were rather small (Fig. 30.3). Furthermore, the same conclusion is reached by Harris (2001). In spite of substantial efficiency gains of more than 12%, production related CO_2 emission increased between 1987 and 1998 by 20%. Without the eco-efficiency improvements and structure changes, pollution growth would have reached 35%.

Conclusions

Physical flow accounting is a fundamental step in understanding the interrelationships between the natural environment and the economic system. SEEA-2003 provides a comprehensive system for physical flow accounting based upon the definitions and concepts as laid down in the System of National Accounts. SEEA-2003 ensures a (horizontal) consistency in the description of the economic and monetary flows. This is in contrast to most other conventional systems for environmental information and emissions inventories. This article illustrated the benefits of physical flow accounting according to national accounts principles. Firstly, national accounts guidelines contribute to a sound attribution of pollution to individual economies. Secondly, this delineation contributes to a sound comparability of national accounts indicators and environmental pressure indicators and thus for the construction of eco-efficiency indicators and the analysis of the so-called decoupling of economic development and environmental pressures. The representation of physical flow accounts in a national accounts framework illustrates the economic relevance and dependencies on material exchanges. Furthermore, a consistent linkage of environmental and economic indicators guarantees a consistent comparison of environmental burdens to economic benefits, or environmental benefits to economic costs.

At the same time the use of an accounting structure ensures a (vertical) consistency in the sense that it is possible to move from one level in the information pyramid to another. When indicators derived from the accounts display certain interesting developments, it is possible to further analyze these developments in more detail based on the detailed information system provided by the accounts.

If a uniform physical unit (e.g. tons, PJ) is used when various physical flows are accounted for, aggregation of the flows is conducted without problems. The corresponding totals (total product weight imported, total SO_2 emitted and total energy used, for instance) are well-defined and easy to understand. Thus, using physical units avoid the problems of monetary valuation of natural resources and emissions, and difficulties with interpretations of indicators based on such valuations are also avoided.

However, controversies over the aggregation of physical flows also exist. Probably, the most controversial is the summing up of all physical flows in a few or only one number as found, e.g. in economy-wide MFA. The total flow of materials (total weight per year) is a meaningful and interpretable concept as such, but we doubt that this in itself indicates anything meaningful about the pressure on the environment, since for instance 1 kg of rather harmless sand is included in exactly the same way as 1 kg of hazardous chemical product. However, these aggregates seem to appeal to politicians and the public, and they have been useful in raising debates. We have shown that the SEEA-2003 physical supply and use tables provide most of the information for compiling MFA type of economy-wide measures. At the same time, it is emphasized in the paper that rigorous aggregation methods may ignore the fact that physical flows may bring about a wide variety of different environmental problems. Therefore, it is argued that alternative weighing schemes may in specific cases provide more meaningful indicators.

Finally, for reasons of transparency, consistency and analytical purposes, this article shows that such measures should preferably be derived from an accounting system. The national accounts provide a very good basis in this respect. A national accounts based physical flow accounting system allows for presenting and analyzing physical flows in connection to the underlying economic driving forces. This is illustrated by several examples in this article.

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