Dematerialization, Environmental Accounting and Resource Management

– main issues and how they can be translated into public policy initiatives –

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1. Dematerialization and capital maintenance

The chapter presents a brief overview of the two main approaches to operationalizing the opaque sustainability paradigm (see Table 1).

The *dematerialization* approach comprises several related concepts, measures and strategies such as Industrial Metabolism, Factor 4/10, Eco-efficiency, Material Intensity etc. It represents a *physical* view of the environment-economy relationship and aims at identifying sustainable boundary conditions ("guardrails") of how and how much nature may be used. Dematerialization concepts cater to "strong sustainability" (Daly 1990), refuting substitution between natural and other production factors, but allowing some substitution among natural assets (e.g. of non-renewable by renewable resources). Physical indicators are used to monitor the "industrial metabolism" of economies.

The second approach aims at *capital maintenance* and reflects the economists' view of the environment-economy interface. Setting out from the Hicksian income concept but focusing on economic growth, this approach extends the traditional concept of keeping (produced) capital intact to include natural capital. Sustainability is achieved when the total *monetary* value of natural and produced capital stock is maintained or increased ("weak" sustainability). The objective is to cost the consumption of natural and produced capital in order to set signals of (non)sustainability in terms of environmentally adjusted (with regard to natural capital consumption) monetary indicators of value added, net product and capital formation (Bartelmus 1999a).

Table 1: Operational concepts of sustainability

Concept	Dematerialization of economic activities	Capital Maintenance in production and economic growth
Rationale	Industrial metabolism	Sustainable economic growth
Strategy	Assessing physical "guardrails" for economic development (Factor X)	Integrating environmental considerations into economic theory and policy
Strength	"relatively strong" sustainability, i.e. physical preservation of natural capital	"weak" sustainability, i.e. preservation of the total value of natural and produced capital
Accounting tools	Material Flow Accounts (MFA) and derived Indicators (e.g. TMR)	System of integrated Environmental and Economic Accounting (SEEA), based on the System of National Accounts (SNA)
Operationalization/ analysis	Physical indicators related to monetary indicators: eco-efficiency, resource productivity, material intensity per service unit (MIPS)	"Green" accounting aggregates for maximum (optimal) efficiency in resource allocation and economic growth

In both approaches, the term "resources" is used in a broad sense comprising the "source"- as well as the "sink"-functions of the environment. The term "natural capital", as defined in the context of environmental accounting, is explained in section 1.2.

1.1 Material-flow-based approaches

There is no unique dematerialization approach, but rather a pluralism of concepts, methods and strategies related to the physical description and analysis of the environment-economy relationship, all with normative implications. They include Carrying Capacity, Environmental Space, Ecological Footprint, Industrial or Societal Metabolism, Eco-efficiency, Factor 4, Factor 10, Dematerialization, and De-linking or De-coupling (of material use from economic activity). As they are all related to the notion of *Sustainable Development* they mark a paradigmatic shift in the general orientation of environmental and socioeconomic policies.

As illustrated in Table 2, the *normative* concept of *environmental space* is derived from the simple finding that natural resources and absorption capacities of planet Earth are limited. Norms enter the concept by stipulating that the limited resource and waste absorption capacities, defined as carrying capacities, should be shared in a fair way (e.g. through an equal distribution of rights to use). The environmental space of a country refers to the amount of annual resource use or release of emissions which is regarded as sustainable and which is attributed to countries on a per-capita basis.

The *analytical* concept of *Industrial Metabolism* is based on thermodynamics and systems analysis (Ayres 1989). The concept characterizes the industrial/societal/economic system through its physical metabolism, i.e. the extraction of raw materials, their transformation into economic products and the discharge of materials as waste back to the environment.

Table 2: Material-flow-based concepts, methods and analysis of sustainable development

Paradigm	Sustainable development
Concepts	Environmental Space, Carrying Capacity, Industrial Metabolism, Eco-efficiency
Strategies	Dematerialization, Detoxification (pollution control), De-linking material use and economic development
Indicators	Eco-efficiency indicators, *welfare/use of nature* ratios, ecological footprint, critical load ratios, environmental headline indicators, total material requirement, ecological rucksacks, MIPS
Targets	Decrease energy intensity by Factor 4 (=75%), increase resource productivity by factor 2.5, do not exceed critical loads of environmental systems, reduce CO_2 emissions by 25%, decrease material requirements by Factor 10 (=90%) etc.
Actors	Government, industry (producers), private households (consumers), civil society
Policy measures	Policy mix: regulatory measures (e.g. environmental legislation), market based instruments (e.g. eco-tax), information and management tools (e.g. efficiency agencies, ISO-standards)

Dematerialization is based on the same recognition of limited resource availability. Referring to the concept of Industrial Metabolism, dematerialization aims at reducing quantitatively the material throughput[1] of the economic system. The precautionary rationale is that reducing the

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[1] Here, throughput relates to the physical exchange with the environment rather than to the materials used inside the economy (the latter comprises primary and secondary materials).

material throughput automatically reduces the material outputs (releases of pollutants, wastes etc.) as well as resource extractions harmful to the environment. Dematerialization is linked to the sustainable development paradigm by specifying how much dematerialization is needed while still allowing for the human quest for increased economic welfare. This specification has been popularly formulated as the target of Factor 4, calling for the world-wide doubling of welfare or wealth while halving material resource use (Weizsäcker, Lovins and Lovins 1997). Factor X and eco-efficiency (see below) thus integrate wealth/welfare growth and reduced use of resources in terms of a win-win strategy.

The above-mentioned concepts and indicators can be linked to *objectives and strategies*. For instance, the environmental space concept (in conjunction with the carrying capacity concept) calls for a reduction of the per-capita environmental space of industrialized economies, and the concept of Factor X calls for an absolute de-linking of welfare increase (operationalized by economic growth) and use of nature (see section 2.1).

In principle, we can distinguish two environment-oriented strategies: dematerialization stands for the quantitative reduction of the material and energy throughput whereas detoxification (pollution reduction/prevention) stands for the mitigation or substitution of material outputs (such as hazardous waste or emissions). In order to link environmental strategies to the economic dimension of sustainability, the notion of *eco-efficiency* is introduced. Eco-efficiency calls for the quantitative reduction of resource use and the qualitative reduction of specific risks, to be accomplished with the increased provision of "services" from economic production.[2]

Indicators and target-setting help to operationalize and communicate these concepts and strategies. For instance, the highly illustrative "ecological footprint"[3] is related to the concept of environmental space. Energy and material flow indicators refer to the concept of industrial metabolism. Ratios of welfare or value added over environmental (*use of nature*) indicators, are used to operationalize the Factor X concept and to monitor the effectiveness of the eco-efficiency strategy. They are described in some detail in Annex I.

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[2] This focus on the ultimate services of products rather than the products themselves is the objective of the so-called MIPS assessments of production and consumption processes (Schmidt-Bleek et al. 1998).

[3] The indicator translates material and energy flows into area equivalents that are appropriated, given prevailing technologies and production and consumption patterns (Wackernagel and Rees 1996).

Finally, *policy instruments* need to be formulated and implemented in order to reach quantifiable targets (see Ch. 4).

1.2 Capital maintenance

Natural and produced capital preservation represents the extension of economic prudence, contained in the Hicksian (1946, p. 172) income concept, to natural assets. The rationale of capital maintenance is to ensure continuous production and income flows from (natural and produced) capital stocks. Natural capital maintained warrants the continuous flow of nature's capital services of resource inputs and safe absorption of wastes and residuals, both required for economic production, consumption and economic growth. Overall capital maintenance reflects thus an *economic sustainability* notion.

Setting out from the national accounts definition of economic assets, i.e. the conventional economic non-financial capital such as buildings or machines, the System of integrated Environmental and Economic Accounting (SEEA) (United Nations 1993) defines different categories of natural capital in consistency with the world-wide adopted accounting system, the SNA (United Nations et al. 1993). The distinction between economic and environmental assets is at the heart of environmental accounting. It determines the additional information which needs to be incorporated in the extended SEEA accounts.

The text box cites the SNA's definition of economic assets, which include *produced natural assets* such as breeding stocks of livestock. These assets are treated like any other produced capital stock and stock changes, but can also be considered as "natural" capital. As also indicated in the box, there are, however, *non-produced natural assets* to which the economic asset definition also applies. These non-produced economic assets are what is typically deemed to be a *natural resource*[4] like an oil deposit, fish in the ocean or timber in tropical forests. The non-sustainable use of these assets is not costed in the flow accounts of the SNA but is treated as "other volume change" in its asset accounts. The SEEA changes this, introducing natural resource depletion as *cost* of consuming an additional (natural) capital item.

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[4] Note that resource economists, collaborating with geologists distinguish "reserves from resources" on the basis of probability and technical and economic capacity of exploiting estimated resource stocks. Identified (proven) reserves are thus distinguished from speculative resources according to the so-called McKelvey box.

SNA's definition of economic assets including natural assets

The *economic asset* definition of the SNA includes already all natural assets "over which ownership rights are enforced by institutional units, individually or collectively, and from which economic benefits may be derived" (United Nations et al. 1993, para. 10.2). These natural assets can be produced such as agricultural products or non-produced such as land, mineral deposits or forests in the wilderness. Changes in the availability of economic, non-produced assets, resulting from depletion or degradation, are accounted in the SNA as "other changes in volume". The SEEA shifts the value of depletion and degradation as "cost" into the production and income generation accounts.

Implicitly, *environmental assets* are all those non-produced natural assets that do not function as providers of natural resource inputs into production. They supply environmental services of waste absorption, ecological functions such as habitat or flood and climate control, and other amenities such as health or aesthetic values.

All other scarce natural assets are considered as *environmental assets* (see text box). Valuation problems allow, in practice, only the costing of losses (degradation) of these assets, even if they are considered part of a natural capital concept. The SEEA measures, therefore, the stocks of these assets in physical units only, but does suggest a maintenance valuation of non-sustainable *changes* in these stocks.

To sum up: natural capital includes all natural assets whether produced or non-produced, economic or environmental. Thereof, cultivated (produced) natural assets are part of the conventional economic asset/capital definition. Non-produced economic natural assets (natural resources) are covered in the conventional asset balance sheets, but their changes are not costed in the conventional flow (supply and use) accounts. In analogy to the capital consumption (depreciation) allowance made in conventional accounts for produced (fixed) assets, the SEEA introduces non-sustainable, i.e. permanent, losses of non-produced natural assets as *cost* in its production and income accounts. It further introduces non-economic (in the SNA sense) environmental assets in both stock and flow accounts.[5]

Similarly to Table 2, Table 3 is a synopsis of concepts, indicators and strategies of sustainable economic performance and growth, based on monetary environmental accounting.

Table 3: Concepts, methods and analysis of sustainable economic growth

Paradigm	Sustainable economic performance and growth
Concepts	Natural capital

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[5] For further explanations of these transactions and the treatment of the third – spatial – function of the environment as "transfers" in the asset accounts, see United Nations (2000).

Strategies	Capital maintenance, environmental cost internalization
Indicators	Environmentally adjusted Value Added (EVA) and net Domestic Product (EDP), Environmentally adjusted Capital Formation (ECF), environmental cost, environmental assets and asset changes
Targets	Growth maximization with environmental costing
Actors	Economic agents: government, households, enterprises
Policy measures	Market instruments of environmental cost internalization (fiscal disincentives etc.), regulation, voluntary agreements etc.

National accounts, and by extension the SEEA, do not attempt to measure welfare but economic output and income as indicators of economic performance and growth. As already indicated, the principle of keeping capital intact is to facilitate continuing production and income generation by maintaining key production factors, viz. produced and natural capital. A more comprehensive concept of sustainable growth would have to take the – difficult-to-define and –measure – social and institutional capital categories into account. They are not further discussed here.

The compilation of environmental cost in the SEEA is to generate adequate funds for re-investing into overall capital formation, a strategy of overall capital maintenance and hence weak sustainability. Environmentally modified indicators are the result of this costing. The sustainability of economic growth could thus be measured as an upward trend of EDP, requiring however – usually not available – long time series of the indicator. Perhaps a more pertinent way of looking into the sustainability of economic performance is to measure a nation’s ability to generate new capital after taking produced and natural capital consumption into account. Annex II further elaborates on the definition of environmentally adjusted economic indicators in terms of accounting equations.

Applications of the information from a multi-purpose statistical system like the national environmental accounts, range from microeconomic cost internalization (full-cost pricing) to steering the economy with the help of “greened” macro-indicators on to a “more” sustainable development path (see section 4.3, below).

1.3 Dematerialization and capital maintenance: two sides of the same coin?

Dematerialization, and hence reduction of environmental pressure by a certain factor, can be seen as a notion of *ecological sustainability.* Natural and produced capital preservation, on the other hand, represents the extension of economic prudence contained in the Hicksian income concept to natural assets. *Economic sustainability* is thus to ensure continuing income generation through production and economic growth, taking nature's vital services of resource inputs and waste/residual absorption into account. Moving from the assessment of ecological sustainability to economic sustainability could therefore be viewed as moving from the input side of material flows into the economy to the output side of production and environmental impacts – two sides of the same coin?

At the most generic level, the key physical and monetary sustainability measures, TMR/MIPS and EDP/ECF, appear indeed to have a similar, or possibly the same, underlying sustainability notion: viz. the long-term preservation of environmental source and sink functions or, in other words, the maintenance of environmental assets. They differ, however, when looking more closely at the definition, scope and envisaged use of these aggregates:

- Factor 4 assessments link dematerialization with wealth/welfare generation. Human welfare and the similar concept of the 'quality of life' are usually taken as indicators of development, which would make dematerialization a notion of environmentally *sustainable development*.[6] Maintaining natural capital for ensuring non-declining income or product, on the other hand, aims at *sustaining economic growth*. This reflects the capacities of national accounts which measure economic performance in terms of production, accumulation and consumption, rather than welfare.
- Extending the notion of capital consumption from produced (economic) to non-produced (natural) capital generates an environmental-economic concept of sustainability which appears to be broader than dematerialization. This is because dematerialization refers, as an environmental pressure index, to environmental assets only.

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[6] There is however some ambivalence with regard to the strategy of increasing resource productivity for dematerialization strategies: typically the notion of "ecoefficiency" and its reciprocal value of "resource productivity" refer to output or GDP rather than a welfare indicator.

- Capital consumption reflects the permanent loss (wear and tear) of an asset. Correspondingly, only the permanent, and thus non-sustainable "disappearance" of a natural asset is measured in physical and monetary term as natural resource depletion and exceedings of absorptive capacities by emissions and discharges into the environment. In contrast, material flows cover the total use of materials, whether causing depletion or not (in case of natural regrowth or replenishment) and whether its emissions generated are safely absorbed or not.
- The TMR aims at assessing actual and potential environmental impacts in a precautionary approach. In contrast, accounting for natural capital consumption captures only actually occurred and observed environmental impacts.[7] Non-sustainability derived from material flows refers thus to an unspecified *risk* of transgressing Factor X standards in dematerialization. Such risk is difficult to compare to actual losses of specific natural assets.
- The controversial monetary valuation of natural resource depletion and emissions reflects in principle the preferences of individual economic agents. The TMR weights different environmental impacts by weight – perhaps even more controversially, but also more graphically.
- Calls for overall dematerialization of economic activity by a given factor ignore, or at least do not acknowledge explicitly, possibilities of substituting natural capital by other, human or produced, production factors. The TMR indicator does allow for substitution among different materials, e.g. non-renewable resources by renewable ones, when reference is made to overall material flow reduction by a certain factor. Such a sustainability principle is still *stronger* than the *weak* sustainability of overall capital maintenance, which ignores 'complementarities' in natural capital use.

Dematerialization and capital maintenance: two sides of the same coin? Well, yes, but only as far as the most generic goal of environmental sustainability is concerned. Otherwise, there are important differences in the scope of the sustainability concept, its connection with growth or development, the strength of the underlying sustainability notions, the degree of risk of environmental impacts addressed, and the evaluation (weighting) of environmental impacts. The question is, what do the obviously different

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[7] A certain degree of precaution is reflected in the above-mentioned Hicksian prudence in reserving depreciation costs for maintaining future economic activity, i.e. re-investment in capital maintenance or in avoidance of environmental depletion and degradation.

notions and assessments tell us for monitoring the sustainability situation and drawing strategic and policy conclusions?

2. Scarcity, equity and environmental concerns

Scarcity, equity and related environmental concerns are treated differently by the two approaches of dematerialization and capital maintenance. Dematerialization focuses on physical scarcity and environmental pressures from excessive material use. Capital maintenance on the other hand addresses a concept of economic scarcity, expressing environmental problems as "externalities" of economic activities. Per se, the two notions do not reflect equity in terms of access to or distribution of environmental services and income (rent) gained from their use. However, equity criteria can be explicitly introduced in derived analyses of the level and distribution of dematerialization and – current and future – capital consumption.

2.1. Scarcity and equity in dematerialization concepts

Dematerialization concepts take into account that the human appropriation of nature's source and sink functions is physically limited. Some dematerialization concepts, such as environmental space and Factor X go one step further to proclaim that these limited natural resources should be distributed *equally* world-wide.

Physical scarcity: carrying capacities

Carrying capacities express the physical scarcity of environmental services as the limited ability of ecosystems – and planet Earth as a whole – to bear human environmental pressure without significant damage. For these pressures, thresholds can be formulated as the *critical load* for different substances entered into the natural system. Human pressure can also be expressed as the number of people a territory can sustain at specific standards of living. However, possibilities of exports and imports of environmental services from other territories make the concept unequivocal only at the global level.

A prominent example for physically quantifying the carrying capacity with regard to a particular substance is global CO_2 emission. The 1996 IPCC (1996) assessment report states that a reduction in global CO_2 emissions of 50-70% would be needed to stabilize CO_2 concentrations in the atmosphere at 1990 levels by 2100. Implicitly, this assessment assumes the limit of the globe's carrying capacity for CO_2 emissions to be at 1990 levels.

Scarcity in carrying capacity concepts is thus presented as critical loads or maximum population numbers that can be sustained by a natural (local, regional or global) system. Equity concerns are not explicitly specified but could be introduced by differentiating carrying capacity standards for different regions and populations. Given the large number of harmful substances, in practice, substance- and problem-specific targets need to be supplemented by targets based on aggregate indicators of environmental space such as TMR or ecological footprints, which indicate a generic pressure on the environment rather than a specific impact.

Environmental Space

Like carrying capacity, the concept of environmental space reflects "limits to the amount of environmental pressure that the Earth's ecosystem can handle without irreversible damage to these systems or to life support processes that they enable" (Hille 1998, p. 7).

Introducing explicitly, the equity dimension, environmental space can be defined as "the maximum amounts of natural resources that we can use sustainably and without violating global equity" (Hille 1998, p. 8). In the long term, sustainability can be seen as a criterion of inter-generational equity, whereas current global equity is usually taken to reflect equal allocation of environmental space among regions and countries – as, for instance, in the case of the ecological footprint indicator. This indicator shows when and where the available environmental space is "overshot" – estimated world-wide at about 35% (Wackernagel and Rees 2000). Such overshooting can be interpreted as an indication of physical scarcity in environmental source and sink functions when applying an equal-access equity target.

The global amount of environmental space has been quantified for some major resources. Assuming a fair, i.e. equal, distribution world-wide, this global environmental space can be expressed as a per-capita share by dividing the global environmental space of a given resource by the number of the world population for a target year. By multiplying this per-capita share with a nation's population one obtains the environmental-space share of a nation.

Factor 4 and Factor 10

Factors 4 and 10 were developed as visionary goals for improving eco-efficiency and resource-productivity in the generation of economic welfare.

Factor 4 and 10 goals have now been included in a number of national environmental plans and programmes, e.g. of Austria, and members of the Nordic Council or OECD. Factor 4 can be interpreted as a target for absolute world-wide de-linking of economic growth from natural resource use in order to obtain a four-fold increase in resource productivity. The rationale is to halve the world-wide use of nature while doubling welfare. At the business and product levels, Factors 4 and 10 serve as a heuristic stimulus for decreasing the material intensity of production and products as elaborated in the Wuppertal Institute's MIPS concept. The feasibility of Factor 4 has been demonstrated by numerous pioneering examples (Weizsäcker, Lovins and Lovins 1997).

Factor 10, as introduced by Schmidt-Bleek (1994), refers to a 10-fold absolute reduction of material input (resource use) in industrialized countries over a 50-year period. The equity principle of the Factor 10 standard is to attain approximately the Factor 4 target, world-wide, by permitting developing countries a doubling of their resource consumption, but compensated by Factor 10 dematerialization in industrialized nations. Considering that industrialized countries, which represent about 20% of the world population, consume 80% of the available natural resources, Factor 10 would indeed make for a more equitable distribution of resource use within the limits of the Earth's environmental space.

2.2 Scarcity and equity in the capital maintenance approach

Economists derive the value of a resource from its *scarcity* and usefulness in meeting human needs and aspirations. Resources that are available in unlimited supply, however essential they may be to survival (e.g. atmospheric oxygen), do not have economic value; they are free. Valuation of scarce economic goods and services, whether traded in markets or not, is to facilitate rational choices by economic agents, with regard to their use in production and consumption. Under perfect market conditions, market prices reflect accurately relative scarcities and the most efficient use of goods and services. They also reflect a utility-maximizing consumption by individual consumers. Environmental externalities are one obstacle to such optimality in the use of scarce goods and services, and the answer to this situation is to internalize the externality into the plans and budgets of households and enterprises by fiscal (dis)incentives or other "market instruments".

Contrary to the above-described ecological standards, economists attempt to define the level of scarcity by measures of the physical availability of natural resources (notably their lifetime under current exploitation patterns), as well as by assessing increasing cost and prices of natural resource extraction and use.

The running out of exhaustible (non-renewable or conditionally renewable) resources has not been demonstrated conclusively.[8] Both, concepts and definitions (notably of what constitutes a natural resource, see section 1.2) and faith in technological development, create a great deal of uncertainty in the assessment of scarcity and future availability of a resource. Nonetheless, green accounting approaches base their assessment of natural resource depletion on (extraction) cost and price development, defining depletion as decrease in the net present value of the resource (discounted over its predicted life time). This can be seen as a "user cost" valuation of the increase in scarcity of the stock of exhaustible natural resources.

Costing economic sustainability by incorporating environmental depletion and degradation into national accounts does not capture the "things that most people think should not be for sale" (Kuttner 1997, p. 300). Those "things" encompass non-economic amenities and values, offered by nature and social institutions, including *equity* in the distribution of income and wealth. In fact, the disruption of environmental services may cause the loss and impairment of human and non-human lives, as well as inequities in the distribution of these effects within and among nations, and between current and future generations. Rational and explicit policy analysis would have to specify these and other social goals in terms of targets or standards, exogenous to the economic exchange system.

Assessing the achievement of these targets and the compliance of human activities with norms and standards is not possible with the above-discussed measures of economic performance or growth. This is because prices or preferences expressed in money terms do not reflect relative scarcities and social priorities and preferences in these areas. For instance, real interest rates might discount much more strongly (over a relatively short period of time) the financial future than social preferences would indicate for the welfare of future generations. A broader concept of "development" is

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[8] Note, however, the controversial conclusions of the "Limits to Growth Model" (Meadows et al. 1992), predicting the breakdown of the economic system within the first half of our century.

needed to address simultaneously economic objectives and non-economic targets and norms.

An operational definition of sustainable development[9] which takes explicitly account of economic and non-economic standards and targets was proposed to this end as "the set of development programmes that meets explicitly set targets of human needs satisfaction without violating long-term natural resource capacities and standards of environmental quality and social equity" (Bartelmus 1994). The consideration of standards, targets or norms turns the question of economic sustainability, defined above operationally as capital maintenance, into one of compliance with social goals or norms. Individual preferences for goods and services, more or less efficiently revealed by markets, may thus be overridden by social fiat – however democratically such fiat might have been achieved.

2.3 Sustainability and environmental concerns

Environmental problems are also treated differently within the two sustainability concepts. In the line with the physical orientation of dematerialization, environmental problems are connected with particular flows of materials. The capital maintenance approach, on the other hand, considers environmental problems to a large extent as externalities, i.e. social costs.

2.3.1 Dematerialization

Traditional environmental policies addressed environmental concerns mainly as "end-of-pipe" problems, resulting from "outputs" (discharges) to the environment. The concept of "Industrial Metabolism", on which dematerialization concepts are based, broadened the approach to environmental problems by linking inputs and outputs. The metabolic exchange of materials and energy between nature and the technosphere constitutes the key to most environmental problems since any resource taken from the environment ends up in the environment sooner or later as emissions or waste. Hence, any strategy of reducing the inputs also reduces the overall

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[9] Sustainable development was popularly defined by the Brundtland report (World Commission on Environment and Development 1987, p.43) as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". The definition fails, however, to specify what are the human needs, omits to clarify the time frame for the analysis of future generations' needs and does not even mention the environment as the current key concern in sustainability.

amount of outputs and may thus contribute to the mitigation of environmental impacts.

We can distinguish two basic categories of *environmental pressure* from human activity:

- resource extraction (by agriculture, forestry, fishery, mining and quarrying, and basic industries) associated with resource depletion and environmental degradation. These impacts are directly related to the extraction processes itself; they include erosion, fragmentation of landscape and eco-systems, and emissions to air, soil/land and water.
- transformation of resources into products by industry (producers) and use of the products by private households (consumers), both associated with the release (emission) of residuals to nature.

In order to relate particular material flows to specific environmental impacts, we have to solve two problems, namely how to assess:

- the specific environmental impacts caused by material flows that have already been recognized as "harmful" and
- the environmental impacts of material flows which are not (yet) known specifically, or are not related to specific material substances.

High-priority environmental concerns of environmental policy such as global warming can be related to associated material flows (e.g. fossil energy carriers and CO_2 emission). All existing knowledge about the property of certain materials and specific substances should be used to derive data for the specific impact per unit of material flow in order to assess the environmental significance of different materials. Scientifically derived "equivalent factors", for instance for global warming or eutrophication potentials, are to "weight" the contribution of materials and substances to different environmental problems.[10] Still, weighting contributions to different environmental problems or themes does not permit inter-theme comparison. In most cases, recourse would have to be taken to personal or societal weighting (Adriaanse 1993, Jesinghaus 1997).

In many cases environmental impacts of material flows are either not yet known or difficult to relate to particular materials. There is no standardized assessment method for most of the potential toxic, nutritional, structural, physico-chemical and directly destructive effects associated with material

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[10] See, for example, the use of equivalency factors to aggregate the contribution of different substances to "environmental policy themes" in the NAMEA accounts of the Netherlands (Keuning and de Haan 1998).

flows. Impacts may result from extracting (e.g. drainage of mines), or from adding something to, nature. Some impacts are unspecific with respect to the nature of the materials, e.g. the destruction of landscapes and organisms due to the extraction of non-renewable, or (over)harvesting of, renewable natural resources. Moreover, from a scientific point of view, it is generally impossible to foresee all possible impacts of human-induced material flows that may be of relevance in the future.

In most cases there is thus only information about the category and volume of the material flows themselves. Any material flow induced by humans may thus reflect indeed a change in the environment and has to be taken as the best proxy for this change. At least, a quantitative flow account will produce indicators that point in the right direction, with increasing material flows indicating increases in environmental impacts.

Measures like the Total Material Requirement (TMR) (see section 3.1 and Annex I) revealed a fairly constant annual material input of 40-80 tonnes per capita in industrial countries. Together with information on the type of major flows, the material flow accounts indicate that a world-wide adoption of such flows by 6 billion people would lead to dramatic changes in the natural life-sustaining environment (Matthews et al. 2000; Adriaanse et al. 1997; EEA 2000; Bringezu and Schütz 2000).

2.3.2 Capital maintenance

The extension of the economic capital maintenance notion to natural assets introduces the loss of environmental (capital) services into economic analysis. These services include the supply of natural resources, the disposal of wastes and residuals and the use of space for economic activity. The SEEA measures such service losses as natural capital consumption, deducting their monetary value as cost from the standard economic indicators like net product and capital formation. As pointed out in section 1.2, not only environmental but also economic sustainability effects are captured in an integrative fashion.

Loss of disposal services manifest themselves as pollution which is typically considered as a negative "externality" of production and consumption. Such external effects are unintended and a-priori non-priced costs and utility losses imposed by households and enterprises onto other households and enterprises. Loss of resource supply, i.e. depletion, does not fit well into the externality definition, since it is usually intended, and its effects are borne directly by the resource extractor (in case he/she is the owner). However, from a long-term sustainability point of view one could consider depletion as an inter-generational effect and hence an externality of current production and consumption processes.

In principle, externalities should be valued as either costs imposed on other economic agents, as for instance in the well-known smokestag-laundry example (a classical diseconomy of having to rewash the laundry), or as welfare losses in case of health effects of pollutants. Damage valuations are highly controversial and misleading, notably at the national (accounting) level, and are therefore considered inappropriate for national-level assessments. Therefore, only a maintenance costing approach has been applied in practical applications of the SEEA, in analogy to the costing of the wear and tear of produced capital. For environmental externalities this approach determines the expenditures that should have been incurred (and set aside for re-investment) for avoiding or mitigating the emission that took place during the accounting period (beyond the safe-absorption levels). [11]

The source functions of the environment are valued as imputed market prices, i.e. the change in the economic value of a natural resource stock in the case of extraction or harvest, i.e. use in production. Spatial uses, i.e. shifts of natural areas into the economy for purposes of construction or other commercial use, are dealt with in line with SNA conventions as “transfers” or “other volume changes” in the asset accounts. By definition such volume changes do not generate any costs of production and do not affect income generation. Nevertheless, these non-costed asset change categories do provide important information on environmental phenomena, such as natural disasters or natural resource “discovery” which are not directly caused by economic production or consumption.

Costing natural capital consumption and thus allowing for the possible re-investment of these costs reflects a monetary/economic notion of sustainability as overall capital maintenance. Upward trends of an Environmentally-adjusted net Domestic Product (EDP) would therefore indicate the environmental sustainability of economic growth. Compilations of EDP in case studies of environmental accounting (Uno and Bartelmus 1998) did not indicate a reversal in growth trends as conventionally measured by time series of GDP. This is largely because of the relatively short time series available. Given this data restriction, a more pertinent way of looking into the

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[11] A short description of valuation methods in the SEEA is given in the text box of section 3.2. For a detailed description of the rationale of maintenance costing, see Bartelmus (1998).

sustainability of economic performance is to measure a nation's ability to generate new capital after taking produced and natural capital consumption into account, i.e. to compile an Environmentally-adjusted net Capital Formation (ECF) indicator. A number of developing countries, which already exhibited negative or very low positive conventional capital formation, showed a non-sustainable pattern of disinvestment. The performance of most countries seems, however, to have been sustainable, at least for the periods covered, and in terms of produced and natural capital maintenance (Bartelmus 1997, p. 332).

Past overall capital maintenance or increase hide the fact that in the long run complementarities of natural capital might make it impossible to maintain current production and consumption patterns and growth rates. Extending past trends into the future reflects thus a weak sustainability concept: the assumption is that natural capital can be replaced, at least "at the margin"[12] by other production factors. The empirical testing of this assumption should be an important field of sustainability research.

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[12] Pointed out by David Pearce at the Second OECD Expert Workshop on "Frameworks to Measure Sustainable Development" (Paris, 2-3 September 1999), meaning that substitution of *total* stock is, at least in the short- and medium-run, not necessary as sometimes assumed by critics of the weak sustainability criterion.

3. Measurement, prioritization and optimization

This chapter deals with the quantitative analysis of sustainability according to the two basic notions of dematerialization and capital maintenance. Two systemic approaches of data collection and analysis appear to have become international standards for data development and analysis. They are the physical Material Flow Accounts (MFA) (Bringezu 1997a,b; Bringezu et al. 1998a; Spangenberg et al. 1999) and the physical and monetary System of integrated Environmental and Economic Accounting (SEEA) of the United Nations (1993).[13] The two systems are explored as to their respective abilities to facilitate the setting of priorities and optimizing the use of natural resources and environmental services.

3.1 Material flow accounting (MFA) and prioritization

MFA provides the appropriate tools for measuring the entire metabolic performance of the economy in terms of material flows. The purpose is to assess sustainability of economic development according to the dematerialization concept. Aggregated economy-wide material flow balances (MFB) – one particular method MFA – represent the most consistent accounting scheme for measuring the metabolism of economies. Sectoral disaggregations can be provided by physical input-output tables (PIOT), which are compatible with the SNA and also part of the physical modules of the SEEA.

MFA, the acronym for Material Flow Analysis or Material Flow Accounting, refers to accounts in physical units (usually tons). They comprise the extraction, production, transformation, consumption, recycling, and disposal of materials (substances, raw materials, base materials, products, wastes, emissions to air or water). MFA include different approaches such as substance flow analysis, product flow accounts, material balances and bulk material flow accounts.

Economy-wide material flow balances (MFB) are comprehensive accounting schemes, presenting the entire metabolism of economies by means of aggregating material flows in a consistent manner, following widely

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[13] See for a summary description, Bartelmus (1999b). The SEEA is currently being revised by the so-called London Group of national accountants and is expected to be re-issued in 2001.

the SNA and its satellite, the SEEA. The main objectives of economy-wide material flow accounts and balances are to:

- provide insights into the overall structure and development of the physical metabolism of societies and economies
- derive a small set of highly aggregated indicators for resource use and resource productivity (and, more generally, eco-efficiency by relating resource use indictors to GDP and other economic and social indicators)
- organize, structure and integrate available primary data and assure thus consistency by linkage with national accounting and input-output tabulations
- react flexibly and quickly to new policy demands (related e.g. to specific material uses and their impacts) through quick adjustments of the data bases
- facilitate analytical uses, in particular estimation of material and land use induced by imports (notably their "hidden" flows), as well as decomposition analyses, modelling effects of technological, structural and final demand changes.

MFA were prepared in a number of industrialized and developing countries. They are part of official statistics in Austria, Denmark, Finland, Germany, Italy and Japan.

Material flow balances (MFB) permit the derivation of environmental indicators and indicators for sustainability (Berkhout 1999, Jimenez-Beltran 1998, Ministry of the Environment 1999). Input, output and balance indicators can be distinguished. They refer, respectively, to materials which are extracted domestically or imported and their hidden "ecological rucksacks" (as for instance in the TMR indicator), to materials and substances which leave the economy (emissions and wastes) and to the net accumulation of material in the economy.

Annex I provides an overview of the approach and structure of MFA/MFB. It also describes in detail the different indicators that can be compiled from the MFB.

For environmental policy, and even more so for attaining sustainability (because of the environment-economy interaction), environmental problems need to be prioritized, i.e. compared and evaluated. The reduction of specific impacts (e.g. global warming, eutrophication) is a necessary tool of environmental management but cannot do justice to the generic environmental pressure resulting from energy and materials requirements. Also, environmental problems are often interlinked. A more comprehensive approach is necessary, therefore, both at the analytical and targeting level, prior to managerial decisions and for choosing regulatory or incentive policy instruments.

EU targets were formulated for selected material flows at the output and input sides. They can be assumed to reflect high-priority EU concerns. For instance, the Fifth Environmental Action Programme set a target for the reduction of municipal waste generation. The Kyoto targets call for a reduction of the global warming potential by 2012. In the proposal for a national emission ceilings directive (NECD), targets are set for the reduction of selected emissions such as SO_2, NO_x, NMOC and NH_3. The environmental ministers of the EU considered the Factor 4/10 goals as a necessary prerequisite for sustainability.

The reduction of the resource inputs will contribute to the diminishing of certain emissions and a decrease of waste. But the extent to which the different targets may be combined into a functioning metabolism of the economy can only be determined by analytical cross-checks of the different inputs and outputs. Therefore, the existing targets for selected material outputs (e.g. CO_2, SO_x, NO_x, waste etc.) should be combined in a consistent "*Target Material Flow Balance*" (TargetMFB) of the EU. The comparison of the actual MFB and the TargetMFB will generate a *distance-to-target MFB.* As a result, major material input and output flows can be classified as to their deviation from environmental objectives. Such analysis will facilitate the setting of priorities for material uses from an environmental perspective.

Implementation of these priorities requires an assessment of the technical and organizational feasibility of the target bundle and the specification of concrete policy measures. The costing of these measures of target implementation should be conducted on the basis of cost-efficiency criteria, similar to the best-available-technology (BAT) costing in the SEEA. These costs could then be usefully compared to the environmental (depletion and degradation) costs compiled in green (monetary) accounts. Differences in the results would have to be investigated (beyond data problems) so as to assess the implications of different sustainability concepts (see above, section 1.3) for policy making.

3.2 Integrated environmental and economic accounting and (e)valuation of environmental impacts

As discussed in section 1.2, the notion of economic sustainability can be extended in "greened" national accounts like the SEEA (United Nations 1993, 2000) to account for the loss of environmental source and sink functions, i.e. natural resource depletion and environmental degradation. In this manner the natural environment is treated as an additional (newly scarce) *natural capital* stock which provides environmental services of resource supply and waste disposal to the economy. Annex II shows how the SEEA is developed as an expansion of the asset stock and flow accounts of the SNA. The annex also presents environmentally adjusted indicators, resulting from this expansion of the conventional national accounts.

Markets are the prime tool for harmonizing different priorities of economic agents with regard to the use of scarce resources and the consumption of goods and services. This requires the comparison of the relative value of resources and products in terms of the convenient numéraiere, the market price. In the absence of markets, which is the rule in the field of environmental assets and asset services, market prices can be estimated by different valuation techniques or could be modelled for the achievement of environmental targets as "shadow prices". The latter reflect the relative value of environmental services and service losses under the specified constraints (targets, standards) and depend on the particular model assumptions.

However, shadow pricing appears to be more an exercise in shadow boxing, owing to the arbitrariness in model assumptions with regard to real-world situations. Environmental accounting, therefore, stops short of modelling, but does make money estimates of resource depletion and environmental degradation as costs of different economic production and consumption activities. Various valuation techniques have been advanced for natural capital, its consumption and the underlying environmental impacts of depletion and degradation. The imputation of monetary values, which were not necessarily observed in market transactions, has been criticized not only by environmentalists but also by more conservative national accountants. The text box reviews, therefore, briefly the three commonly proposed valuation techniques as to their capability of assessing environmental impacts and repercussions.[14]

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[14] See for a more elaborate discussion of the pros and cons of different valuations in environmental accounting, Bartelmus (1998).

Valuation of environmental impacts in the SEEA

Market valuation, as the name suggests, uses prices for natural assets, which are observed, in the market. It is usually applied to "economic" assets of natural resources, though traded pollution permits could also generate a market value for environmental assets of waste absorption capacities. Where market prices for natural resource stocks, such as fish in the ocean or timber in tropical forests, are not available, the economic value of these assets can be derived from the – discounted – sum of net returns, obtained from their potential use in production. It is at this value that a natural asset such as a mineral deposit or a timber tract would be traded if a market existed for the asset. Market valuation techniques are also applied to changes in asset values, caused in particular by depletion, i.e. their non-sustainable use. These value changes represent losses in the income-spinning capacity of an economic asset. Depletion cost allowances reflect thus a weak sustainability concept, calling for the reinvestment of environmental cost in any income-generating activity such as capital formation or financial investment.

Maintenance valuation permits the costing of losses of environmental functions that are typically not traded in markets. Dealing only with marketed natural resources would reduce drastically economic analysis concerned with scarce goods and services, whether traded or not. Notably in industrialized countries, environmental externalities of pollution can indeed be of far greater importance than natural resource depletion. The SEEA defines maintenance cost as those that "would have been incurred if the environment had been used in such a way as not to have affected its future use" (United Nations 1993, para. 50).

Maintenance costs are the missed-opportunity costs of avoiding the environmental impacts caused during the accounting period. They refer to best-available technologies or production processes with which to avoid, mitigate or reduce environmental impacts. Of course, these costs are hypothetical since environmental impacts did occur. They are used, however, to weight actual environmental impacts, generated during the accounting period by different economic agents. Those agents did not internalize these costs into their budgets but *should* have done so from society's point of view. As with depreciation allowances for the wear and tear of produced capital such costing can be seen as establishing the funds required for re-investing in capital maintenance.

Contingent and related damage *valuations* were also discussed in the SEEA. These valuations have been applied in cost-benefit analyses of particular projects and programmes but are hardly applicable in practice at the national level. They refer to the ultimate welfare effects (damages) of environmental impacts, which are quite impossible to trace back to causing agents. Contingent valuations are also inconsistent with market prices because of their inclusion of consumer surplus and face well-known problems of free-rider attitudes and consumer ignorance. Mixing these 'cost-borne' valuations with 'cost-caused' (maintenance cost) valuations creates aggregates which are neither performance nor welfare measures and quite impossible to interpret (Bartelmus 1998, p. 295).

Market and maintenance valuations cater to the general sustainability goal of capital maintenance. Beyond this goal, these valuations do not set, in principle[15], targets for reducing material inputs or outputs (discharges) of economic activity. Rather than determining exogenously (by governmental or expertocratic fiat) the need for environmental services, economic agents themselves are to decide – through market negotiation – how much they

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[15] In practice, some standard for practical assessments of non-sustainabilities in resource use and pollution had to be set in case studies of environmental accounting.

want (and can) to supply and use of these services. Budgetary constraints will prompt them to account for all options and products simultaneously, to the extent they are aware of them. Of course, lack of market transparency and other, e.g. monopolistic, market imperfections will in most cases prevent achieving a Pareto-optimal equilibrium, but individuals will still have a significant say in what and how much should be produced and consumed.

The extent to which individual preferences should be overruled by governmental ruling – a de facto transition from valuation to evaluation – is of course a political question. As already discussed (in section 2.2), social norms will have to set a normative framework for economic activity to ensure that difficult-to-assess social and cultural amenities and institutions (law and order) are available in sufficient quantity and quality.

3.3 Optimal resource consumption and pollution levels

3.3.1 Allocative efficiency through environmental cost internalization

Natural resource economics deals with the question of determining the optimal use of an exhaustible resource like an oil deposit. The idea is to predict price and (extraction) cost development and to distribute extraction/harvest over time so as to maximize the net present value of the resource stock. As indicated above, such optimizing behaviour is assumed in market valuation of economic natural resources by the SEEA (even in the absence of markets for resource stocks). Rational behaviour and market knowledge of the owners of natural resources would ensure, under perfect market conditions, an optimal use of resources, maximizing (discounted) net returns at any point of time. Since this is conventional economic theory of resource economics it is not further pursued here.

However, markets do not exhibit perfect conditions and do not, in general, guarantee long-term sustainability of economic performance. As already discussed, there are two basic approaches to assessing market failure in this regard:

(1) To determine sustainability targets or constraints and to model minimum costs of complying with these constraints – a cost efficiency analysis. If some kind of objective function can be found with which to weight or price the outcomes of production activities, the maximum value of these outcomes could be determined.

(2) Alternatively, resource use, i.e. resource depletion and related externalities, could be costed, as in green accounting, and allocated to the causing agents according to the polluter/user-pays principle.

Introducing environmental costs into conventional input-output analysis or (less practical) Computable General Equilibrium (CGE) models would indicate the production and consumption patterns to be attained, after cost internalization, through market (utility, profit maximizing) behaviour. It would also indicate "optimal" (in line with model assumptions) levels of natural resource use and pollution after taking environmental costs, as well as the net benefits of production and consumption "into account".[16] Such modelling would provide an indication of the consequences of setting market instruments and/or sustainability standards at levels determined by cost assessments in environmental accounts. Policy instruments, notably market-based financial (dis)incentives, are to prompt economic agents into internalizing environmental cost; they are discussed in the following chapter. The objective is in all cases to implement sustainability goals more efficiently through market forces than by remote bureaucracies.

3.3.2 Optimal resource consumption and dematerialization

Economic optimality in resource use can only be specified in cost/price terms. Physical targets of resource use of material reduction could in principle approximate those resource consumption levels which underlie the optimal (minimum cost, maximum income) levels of economic models. The idea of dematerialization is, however, to circumvent controversial valuation of non-market activities and pressures. Therefore, independent ("exogenous") – physical – targets and rules have been advance to ensure the long-term availability of natural resources. Such "sustainable management rules" (Barbier 1989, Daly 1990, Pearce and Turner 1990, Meadows et al. 1992) were designed not only to safeguard the efficiency of the 'ecosphere' as a natural production system, but ... also [to] emphasize the need to preserve the vital functions of our 'natural capital stock' for the sake of future generations" (Enquete Commission 1997). The rules specify in particular that

(1) the depletion rates of *renewable resources* should not exceed their natural renewal rates. This is tantamount to preserving the ecology's

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[16] Optimal levels of pollution and economic activity are in principle achieved by an optimal (Pigovian) tax rate. Textbook knowledge tells us that the determination of such a tax rate is hardly possible in practice. A number of pragmatic tools have been advanced, therefore, for "second-best solutions", notably the Baumol-Oates (1988) standard setting and costing. See also for a discussion of the transition from optimality to sustainability, Bartelmus (1997).

efficiency, i.e. (at least) to safeguarding the ecological capital and its services. One has to consider that the extraction/harvest of renewable resources is connected with the use of non-renewable resources by several technological and natural factors (e.g. fossil energy, erosion).

(2) the consumption of *non-renewable resources* should be limited to levels at which they can either be replaced by physically or functionally equivalent renewable resources or where consumption can be (partially) offset by increasing their productivity. This rule should enable the transition from "old" technology, based mainly on non-renewable resources, towards "sustainable" technology, based on renewable resources. From a "weak sustainability" point of view, this rule assumes that non-renewable natural capital stocks can be substituted by produced capital stocks. From a "strong sustainability" point of view, the use of non-renewable resources should be reduced to a minimum, taking a normative /political stand on what are the minimum needs of the current and future generations.

(3) the release of substances to the environment should not exceed the absorption or assimilation capacities of natural systems, taking into consideration all their functions. The application of the third "management-rule" is hampered by uncertainties in defining the "critical loads" of different ecosystems (see section 2.1).

4. EU policies for environmental and resource management

4.1 Some strategic considerations

We described non-sustainabilities of economic activity as the result of limited availability of environmental assets and their services. These limits can and have been assessed by costing asset scarcity in terms of capital consumption and by comparing dematerialization with world-wide access to environmental functions. In principle, there are three options in addressing these limits (Bartelmus 1999a):

- ignoring the limits – muddling through
- pushing the limits – searching for eco-efficiency
- complying with the limits – attaining sufficiency.

Many liberal economists seem to believe that muddling through, i.e. just reacting to the worst environmental symptoms when they occur, is preferable to heavy-handed governmental interference with individual decision making. An attempt at justifying such *laissez-faire* empirically was made by advancing the so-called Environmental-Kuznets-Curve (EKC) hypothesis. The EKC hypothesis suggests that, once a certain level of economic development has been reached, further economic growth produces an automatic improvement in environmental quality.[17] The automaticity is explained by structural change (possibly towards a service-oriented and thus dematerialized economy) that is brought about by the transition from poverty to prosperity.

Most recent assessments confirm, however, that the evidence for EKCs is far from conclusive.[18] The reasons are, among others, uncertainty about what really causes the EKC effect. This includes the role of growth-induced policy responses, the use of emission data to measure change in environmental

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[17] Named after Kuznets's (1955) similar assessment of a (inverted U-curve) correlation between the level and distribution of income.

[18] See notably a special edition of *Ecological Economics* 25 (2) (1998) and also Perrings (1998).

quality, and difficult-to-know and -measure long-term irreversibilities from current pollution patterns.

As tempting as it may seem to liberal economists, leaving the solution of environmental concerns to unfettered markets is probably a "foolhardy way" to learn about transgressions of environmental limits (Perrings 1995, p. 63). A first step toward tackling dematerialization and capital maintenance is to recast these notions in more strategic terms. Reduced use of materials can be achieved by technologies which generate the same or even better ultimate "services" from physical outputs with less resource inputs. Such increase in *resource productivity*, facilitated by innovative technologies, is the mirror image of a decrease in material intensity of production – the object of the Wuppertal Institute's MIPS approach to furthering eco-efficient production processes (Schmidt-Bleek et al. 1998).

For policy purposes the question is to what extent environmentally sound innovation can be steered into a desirable direction, for instance by market incentives or disincentives. It is generally held, however, that technology alone cannot be the saviour: it needs to be reinforced by more or less voluntary re-evaluation of consumption levels and the development of sustainable consumption patterns. "Eco-efficiency" in production needs to be combined with "sufficiency" in final consumption. Otherwise, efficiency gains could be offset by increased consumption, made possible by the very same efficiency gains.

4.2 Principles of Sustainable Resource Management (SRM)

Historically, materials management policy addressed the tail end of societal throughput, i.e. waste management through controlled waste disposal. For instance, Germany's 1986 Waste Act assigned high priority to waste disposal and recycling. The *Kreislaufwirtschaft* Act of 1994 later called for the comprehensive recycling of materials and products in the production and consumption cycle. At the European level, a Community Strategy for Waste Management was adopted by the Commission in 1989 and strengthened in the 1996 review of the strategy, focusing on recovery of materials rather than energy conservation. All in all, most regulations of waste and environmental policy addressed specific waste and emissions problems (EEA 1999a, pp. 218-220).

However, the inter-relationships of different input and output flows of the economy require an integrated approach and a comprehensive systems perspective with regard to analysis and management. Based on such a perspective, the Enquete-Commission (1997)of the German Parliament called for a "cradle-to-grave" materials management. The European Environment Agency (1999a) stated in this context that "increasing waste quantities cannot be solved in a sustainable way by efficient waste management and recycling alone. There is an urgent need for integration of waste management into a strategy for sustainable development, where waste prevention, reduction of resource depletion and energy consumption and minimization of emissions at the source is given high priority. Waste must be analysed and handled as an integrated part of total material flow through the society" (EEA 1999a). Sustainable Resource Management aims thus at restructuring the material throughput of economies in a way that the resource requirements at the input side and the generation of emissions and waste at the output side do not exceed the natural and societal capacities for reproduction and assimilation.[19]

Problem shifting between different production lines, between production and consumption, between regions and environmental media (land, air and water) and between the current and future generations must be avoided. An *integrated approach to resource management* would involve relevant actors from different sectors (vertical integration from "cradle-to-cradle"). Integration would also implement the above strategies, considering all relevant flows of resources and wastes/emissions (horizontal integration).

As shown above, the current status of industrialized economies can be characterized as unsustainable with regard to the quantity and quality of the resource requirements and residuals. Sustainability requires therefore a significant reduction of primary resource requirements. A Factor 4 to 10 increase in *resource productivity* was proposed for implementation within the next 30 to 50 years. The Factor 4/10 goal has attracted wide attention. It was mentioned by the Special Session of the United Nations General Assembly (UNGASS 1997) and the World Business Council for Sustainable Development (WBCSD 1998). The environmental ministers of the OECD (1996) anticipated progress towards this end. In Japan, a Factor-10 Institute was founded. Several countries included the goal in political programmes (e.g. Austria, Netherlands, Finland, Sweden). In Scandinavian countries, research was launched by the Nordic Council (1999) to test the feasibility of Factor 4/10 implementation. In Germany, the draft for an environmental policy

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[19] Cf. the "management rules", elaborated in section 3.3.2.

programme (Federal Ministry 1998) refers to a factor of 2.5 in productivity increase of non-renewable raw materials (during 1993 to 2020).

The current sustainability status of industrialized and developing countries can also be characterized by the physical growth of the stock of durable products. As shown in section 3.1 and Annex I, this is because the input of materials may exceed the output of waste and emissions to the environment (because of "fixing" materials in additional buildings and infrastructures). Two policy implications are the consequence of material accumulation. First, the physical growth must be halted, eventually, because the extension of the technosphere diminishes the existing space for life-sustaining functions. Second, the growing physical stock of the technosphere constitutes future waste problems. SRM aims therefore at *slowing down the physical growth of economies*.

Currently, industrialized countries depend predominantly on non-renewable abiotic resources. A tremendous part of this resource extraction is not even used. "Hidden flows" of unused extraction affect the resource efficiency of primary production in mining and quarrying. SRM is to reduce the proportion of non-renewable resources and to increase the resource efficiency of primary production.

A significant proportion of resource requirements of industrialized countries stems from foreign countries where raw materials are exported while wastes and emissions from the extraction process burden the country of origin. Currently, exports of industrialized countries do not balance the imports – also with regard to the associated hidden flows. This imbalance in the import and export of sustainability needs to be monitored and urgently addressed by international regimes of SRM, including and beyond the EU.

The amount of naturally renewable resources can be increased only to a certain extent, depending on natural production capacities and available technologies. Production of agriculture, forestry and fisheries, and water supply and use are complex processes. A minimum supply of these resources needs to be assured for sustaining production. Resource quality certificates, e.g. for organic farming, could be issued to increase the proportion of renewable resources used in sustainable cultivation.

4.3 Searching for the best policy mix

Integration into various policy fields is the means of effective implementation of SRM. An integrative policy framework should provide guidance and incentives for dematerialization and eco-efficiency. Broad-based implementation requires the involvement of the market, and synergism of economic, social and environmental benefits (triple-win-strategies) should be used as much as possible.

Economic, financial, industrial and regional policy can and should contribute to sustainable resource management. Sectors with high resource efficiency could be supported by tax incentives. Public investments should use dematerialized construction processes. Structural change policies for (old) industrialized regions should be coupled with targets for resource consumption of their industries. Subsidies, originally designed for social concerns, could support dematerialization. EU regional policy should take account of SRM requirements. Clear and reliable targets should be set in agreement with stake- and shareholders, encouraging long-term, gradual, continuous steps towards enhancing the sustainable metabolism of the economy.

At the same time, monitoring, accounting and controlling of resource efficiency and natural capital maintenance should be fostered at all levels: the European, national, regional and local levels, and in particular the microeconomic level of enterprises, households and products.

At the *micro/meso-economic level*, the compilation of environmental costs permits the setting of market instruments at a level at which natural capital could be preserved with currently available technologies and market conditions. For instance, such cost calculations could defuse the current, emotionally loaded discussion about eco-taxes in several European countries. While being more efficient than top-down regulation, drawbacks in applying these instruments are their time-lagged efficacy, high monitoring and enforcement costs, short-sightedness of economic agents, a general resistance to any kind of taxation and the neglect of “environmental debt”, i.e. accumulated environmental effects from previous accounting periods. The comparative advantages of regulatory and incentive measures in different situations and at different levels need further exploration.

At the *macro-economic level*, the comparison of the availability of different categories of produced and non-produced natural capital facilitates the setting of priorities for exploitation or maintenance of natural wealth. Assessing ownership of these stocks allows to make informed decisions about allocating property rights, in the case of common-access resources – in an equitable fashion among individuals, countries and the present and future generations. Such allocation is not only a matter of equity in assessing a tolerable "environmental space" but might also bring about a more caring treatment of this space by its owners. The availability of productive wealth also determines the long-term growth potential of an economy. A declining (natural) capital base would alert to limits of growth, nationally and globally. The World Bank (1997, p. 28) even considers comprehensive wealth assessments as a new model for "development as portfolio management".

Changes in stocks through exploitation, discovery, growth, natural disasters and capital consumption are particularly important for investment decisions, as is capital productivity which includes natural capital. Capital productivity may change and differ (among different economic sectors) considerably after incorporation of natural resource stocks. Altogether different investment, price and growth policies should be the consequence of this information.

Obviously not one policy instrument – be it for dematerialization or capital maintenance – will suffice for implementing sustainable development. An appropriate policy mix should cater to the particular environmental and economic conditions and priorities in different countries. Of course such differences hamper any policy prescription beyond the generic description presented here.

Possible policy measures in the field of resource management range from "soft" information-oriented measures, via corporate agreements and market-based instruments, to "hard" regulatory measures (command and control legislation). They should be combined in an integrated and synergetic way.

New information and education programmes

A pre-requisite for integrative environmental and socioeconomic policy, including SRM, is the provision of adequate information to the various actors. The capabilities of MFA and SEEA in this regard were discussed in Chapter 3. There is also a need to further develop curricula for training and education of (environmental) engineers and economists. Continuing education programmes should be enriched by aspects of SRM and sustainable development in general.

New service institutions

In order to support the widespread use of best-practice experience new service institutions should compile and communicate examples, methods and contacts to industry. For instance, in the German State of North Rhine-Westphalia an Efficiency Agency was founded to serve as a catalyst between research institutions, government and industry.

New focus for Research and Development

Research and development programmes at the EU level, and at national and regional levels, should include practical solutions for dematerialization. Nano-technologies and function-oriented design of products for the environment are examples of enhancing eco-efficiency. However, so far dematerialization, eco-efficiency and ecological economics were not yet stipulated as priority policy objectives for research and education.

Technology policy and innovation

Frequently, technology policy is oriented toward "hard high-tech", involving enormous budgets in high-calibre investments, e.g. for nuclear fusion or the mining of resources. Instead, the same budgetary support, taking SRM criteria into account, could effectively contribute to "soft high-tech" for the more sustainable use of resources. The intelligent coupling of natural and technical processes could be consistent with long-term requirements of balancing the society-nature interaction. It might include technologies for integrated resource management, combining waste and waste water minimization and management with raw materials and energy supply. Furthermore, high-risk technologies such as nuclear power and genetics need to be assessed as to their trade-offs between risks and environmental and economic benefits.

Product policy and product design

The design of resource-efficient and low-waste products was discussed at the Environmental Council in April 1999 in the context of a European Integrated Product Policy (IPP). In this context, the criteria for eco-labelling could be adjusted to the requirements of resource management and waste prevention. Product responsibility should be extended in this regard as well.

Voluntary agreements

Further examples of information-based measures include self-commitments and declarations – such as the declaration of the German Association of Construction Industries on the reduction of the construction wastes. Such commitments would be facilitated by the provision of information, technological solutions and environmental management tools, and by optimizing the material and energy throughput of firms.

Market-based measures

Incentives or subsidies for particular economic sectors and activities are prone to social pressures, risking deviation from the original or proclaimed policy purpose. There seems to be an advantage in using *dis*incentives, rather, to prod economic agents into internalizing their environmental costs. Facing effluent charges or fees for excessive uses of environmental resources, producers and consumers are likely to search for techniques, which replace harmful production and consumption processes by environmentally benign ones. The idea is to combine competitive and fiscal pressures to meet environmental goals in a more efficient manner than by command-and-control strategies of remote bureaucracies.

Market-based disincentives could thus be used to prevent waste generation. For instance, landfill taxes have been applied in Denmark, Austria, the Netherlands, UK, Finland and France, in conjunction with taxes on incineration (Denmark and Norway). Taxation of raw materials is probably the most effective way (EEA 1999a, p. 225) to induce lower material consumption and potential waste generation. Levies on resource extraction have been established in Denmark[20] and are planned in the United Kingdom[21]. As discussed above, environmental impacts are also best addressed through fiscal disincentives for purposes of “full-cost-pricing”.

Regulatory measures

Regulatory measures include quotas, e.g. for recycling rates as defined in the EU Packaging Directive or the ordinances associated with the German Closed Substance Cycle and Waste Management Act, also in combination with licences for waste recycling. Regulation would apply in particular where high environmental risk and irreversibilities of environmental impacts call for rapid preventive action.

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[20] Excise duty on raw materials (stones, gravel, sand, clay, limestone, chalk, peat, top soil, and similar deposits).

[21] For 2002, a levy on construction materials, such as sand, gravel and other aggregates, is to encourage recycling in the construction sector.

5. Suggestions for future research

The following just lists, not in any order of priority, a number of research activities which would address unresolved or unclear concerns and issues of the sustainability debate.

- Development of a Target Material Flow Balance (TargetMFB), which integrates the existing and proposed material- and substance-flow-related targets into a consistent framework for policy support
- Comparing the methods and results of case studies of material flow and green (national) accounting, taking the current revision of the SEEA into account
- Modelling scenarios of sustainable resource management, and back-casting to evaluate the effectiveness of potential implementation measures
- Use and usefulness of modelling cost internalization and targeted dematerialization effects
- Policy relevance of possible substitution and complementarities in the use of environmental assets and other production factors
- Harmonizing ecological (based on ecological economics) and economic (based on environmental economics) approaches to sustainability in growth and development, with a view to providing balanced policy advice
- Search for the appropriate national policy mix under different environmental, socioeconomic and institutional conditions
- Assessment of the needs for and possibilities of expanding or modifying current EU policies, with regard to achieving sustainability in growth and development.

Annex I: Material flow accounting and indicators

I.1 MFA concepts and methods

Table A-1 presents a synopsis of different physical accounting approaches, focusing on economic agents (firms, sectors), regions, or materials and products.

Table A-1: Types of material-flow-related analyses

Type of analysis	I. Specific environmental problems related to certain impacts per unit of flow of			II. Problems of environmental concern related to the throughput of		
	a.Substances	b. Materials	c. Products	a. Firms	b. Sectors	c.Regions
	e.g. Cd, Cl, Pb, Zn, Hg, N, P, C, CO_2, CFC	e.g. wooden products, energy carriers, excavation, biomass, plastics	e.g diapers, batteries, cars	e.g. single plants, medium and big companies	e.g. production sectors, (chemical industry, construction etc.)	e.g. total or main throughput, mass flow balance, total material requirement of different territories
	within certain firms, sectors, regions			associated with substances, materials, products		

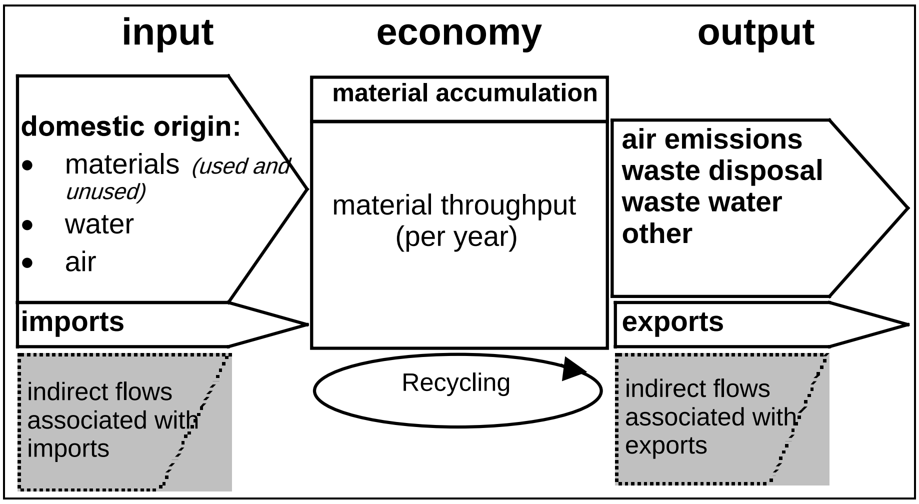
Source: after Bringezu and Kleijn (1997).

Category Ic relates to LCA and IIa represents corporate accounts. The remaining analyses are usually addressed as MFA. MFA and their indicators provide information for policy making and its evaluation. For that purpose, bulk material flow analyses and substance flow analyses can be combined, and the monitoring of progress towards sustainability could be gradually improved in a stepwise approach (Bringezu et al. 1998b).

Economy-wide material flow balances comprise domestic resource extraction and resource imports (inputs), as well as domestic releases of substances to the environment and their exports (outputs) (see Table A-2).

Similar to national accounts statistics, MFB are using existing statistics and re-organize the data sets in a consistent accounting scheme. Recently, a methodological guide for MFB was prepared by Eurostat (2000) as a response to political demand in EU member States. It is designed to enhance international comparability of economy-wide material flow accounts and material balances and their indicators.

Table A-2: Simplified general material flow balance scheme (including air and water)



I.2 Material-flow-based indicators

Table A-3 gives an overview of the different input, output and balance indicators derived from MFB.

Table A-3: Economy-wide material balance with derived indicators

INPUTS (origin)	**OUTPUTS (destination)**
Used domestic extraction	**Emissions and wastes**
Fossil fuels (coal, oil…)	Emissions to air
Minerals (ores, sand…)	Waste landfilled
Biomass (timber, cereals…)	Emissions to water
	+ Dissipative use of products
+ Imports	(Fertilizer <***?***>, manure, compost, seeds..)
= DMI - direct material inputs	***= DPO - domestic processed output to nature***
Unused domestic extraction	**+ Disposal of unused domestic extraction**
from mining/quarrying	from mining/quarrying
from biomass harvest	from biomass harvest
Soil excavation	Soil excavation
TMI – total material input	***= TDO - total domestic output to nature***
	Exports
	TMO – total material output
+ Indirect flows associated with imports	
= TMR - total material requirements	***Net Additions to Stock***
	Infrastructures and buildings
	Other (machinery, durable goods, etc.)
	Indirect flows associated with exports

Note: excludes water and air flows (unless contained in other materials).

I.2.1 Input Indicators

Direct Material Input (DMI) measures the input of used materials into the economy, i.e. all materials which are of economic value and are used in production and consumption activities. DMI equals domestic (used) extraction plus imports. Materials which are extracted by economic activities but that do not normally serve as input for production or consumption activities (mining overburden, etc.) are termed "hidden flows" or "ecological rucksacks"[22]. They are not used for further processing and are usually without economic value. DMI plus unused domestic extraction defines *Total Material Input* (TMI) of a country or region.

Total Material Requirement (TMR)[23] includes, in addition to TMI, the upstream hidden material flows which are associated with imports and *predominantly* **<?>**burden the environment in other countries. It measures the total material base of an economy, i.e. the total primary resource requirements of the production activities. Adding up these upstream flows converts imports into their "primary resource extraction equivalent".

Data for TMR and DMI (incl. their composition, i.e. the input structure of the industrial metabolism) were compiled for China (Chen and Qiao 2000), Germany, Netherlands, Japan, USA (Adriaanse et al. 1997), Poland (Mündl et al. 1999), Finland (Juutinen and Mäenpää 1999; Muukkonen 2000) and the European Union (Bringezu and Schütz 2000). DMI is available for

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[22] Hidden flows (Adriaanse et al. 1997) or rucksack flows (Schmidt-Bleek et al. 1998, Bringezu et al. 1996) comprise the primary resource requirement which do not enter the product itself. Hidden flows of primary production are the unused domestic extraction; hidden flows of imports are the unused and used predominantly foreign extraction, associated with the production and delivery of the imports.

[23] Studies before Adriaanse et al. (1997) defined TMR as TMI (Total Material Input).

Sweden (Isacsson et al. 2000). Work is ongoing for Italy (de Marco et al. 1999) and Amazonia. TMI was compiled for Australia[24].

I.2.2 Output indicators

Domestic Processed Output (DPO) represents the total mass of materials which have been *used in the domestic economy*, before flowing into the environment. These flows occur at the processing, manufacturing, use and final-disposal stages of the economic production-consumption chain. Exported materials are excluded because their wastes occur in other countries. Included in DPO are emissions to air from commercial energy combustion and other industrial processes, industrial and household wastes deposited in landfills, material loads in wastewater, materials dispersed into the environment as a result of product use (dissipative flows), and emissions from incineration plants. Material flows recycled in industry are not included in DPO.

Total Domestic Output (TDO) is the sum of DPO and disposal of unused domestic extraction. It represents the total quantity of material outputs to the environment released on the domestic territory by economic activity.

Direct Material Output (DMO) is the sum of DPO and exports. It represents the total quantity of direct material outputs leaving the economy after their use in the economy. They are either discharged into the environment or sent to the rest of the world.

Total Material Output (TMO) equals TDO plus exports. It measures therefore the total of materials that leave the economy.

I.2.3 Consumption indicators

Domestic material consumption (DMC) measures the total amount of material directly used in an economy, excluding hidden flows (e.g. Isacsson et al. 2000). DMC equals DMI minus exports.

Total material consumption (TMC) measures the total primary material requirement associated with domestic consumption activities (Bringezu et al. 1994). TMC equals TMR minus exports and their hidden flows.

I.2.4 Balance indicators

Net Additions to Stock (NAS) measure the physical growth rate of an economy. New materials are added to the economy's stock each year (gross additions) in buildings and other infrastructure, and materials are incorporated into new durable goods such as cars, industrial machinery, and household appliances. At the same time, old materials are removed from stock as buildings are demolished, and durable goods disposed of. NAS may be calculated indirectly as the balancing item between the annual flow of materials that enter the economy (DMI), plus air inputs (e.g. for oxidization processes), minus DPO, minus water vapour, minus exports. NAS may also be calculated directly as gross additions to stock, minus the material outputs of decommissioned building materials (as construction and demolition wastes) and disposed durable goods, minus materials recycled.

The *Physical Trade Balance (PTB)* measures the physical trade surplus or deficit of an economy. PTB equals imports minus exports. Physical trade balances may also be defined including hidden flows, associated with imports and exports (e.g. on the basis of TMC accounts).

I.2.5 Efficiency indicators

Services provided or economic performance (in terms of value added or GDP) may be related to either input or output indicators to provide efficiency measures. For instance, GDP

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[24] Although the authors use different acronyms (Poldy and Foran 1999).

per DMI indicates the Direct Materials productivity. GDP per TDO measures the economic performance in relation to material losses to the environment. Setting the value added in relation to the most important inputs and outputs provides information on the eco-efficiency of an economy. The interpretation of these ratios should always consider the trends of the underlying absolute parameters. The latter are usually also provided on a per-capita basis for international comparison.

Annex II: SEEA – structure and indicators

Figure A-1 shows in a simplified manner how the SEEA is developed as an expansion of conventional stock (asset) and flow (supply and use) accounts. Environmental components are added by incorporating environmental assets and asset changes in the shaded vertical column of the asset accounts. At the same time, natural resource depletion and environmental quality degradation are reflected as additional environmental costs in the use accounts (as indicated in the shaded row of natural asset use). Environmental costs reflect the consumption of natural capital and are therefore recorded in both the asset and flow accounts. Expenditures for environmental protection are a social response to environmental impacts. They are shown as 'thereof' elements of conventional aggregates.

The inclusion of natural assets and asset changes in national accounts permits the compilation of environmentally modified aggregates. Summing up the rows and columns of Figure A-1 obtains most of these aggregates. The aggregates can thus be presented as the sum totals and elements of the following accounting identities:

- supply-use identity:

  $O + M = (IC + EC) + C + (CF - EC) + X$

  indicating that the supply of goods and services produced (O) and imported (M) equals their use in intermediate (IC) and final consumption (C), capital formation (CF) and export (X);

- value-added (environmentally adjusted) identity for industry i:

  $EVA_i = O_i - IC_i - CC_i - EC_i = VA_i - EC_i$

  describing value added generated by an industry i (EVA_i) as the difference of output (O_i) and cost, including intermediate consumption (IC_i), fixed capital consumption (CC_i), and environmental depletion and degradation (EC_i);

- domestic-product (environmentally adjusted) identity for the whole economy:

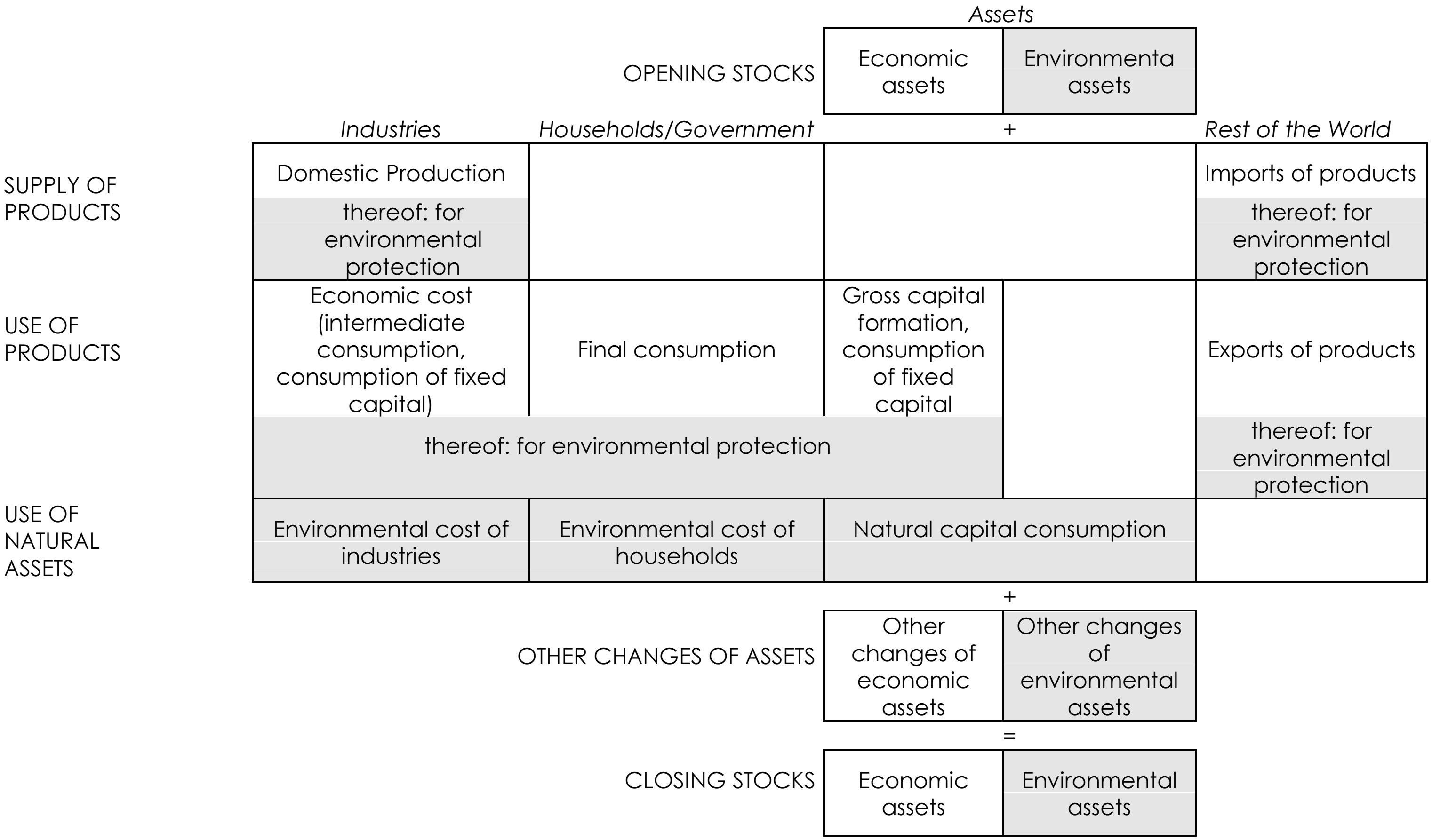
  $EDP = \sum EVA_i - \sum EC_h = NDP - EC = C + CF + X - M - CC - EC$

  defining Environmentally-adjusted net Domestic Product (EDP) as the sum of environmentally adjusted value added of industries, with a further deduction of environmental costs generated by households (EC_h). Alternatively, EDP can also be calculated as the sum of final uses of consumption (C), environmentally adjusted net capital formation ($ECF = CF - CC - EC$) and the balance of exports (X) and imports (M).

Environmentally-adjusted net Capital Formation (ECF) is an indicator that can be used for demonstrating the non-sustainability of economic performance (see section 2.3.2).

The incorporation of asset balances in Figure A-1 adds another set of identities relating opening and closing stocks. They explain the changes in the value of stocks during the accounting period as produced and natural capital consumption (CC and EC) and other changes in assets. The stocks of economic and environmental assets are measures of wealth, which reflect the endowment of a country with economic and environmental assets at the beginning and end of the accounting period.

Fig. A-1: SEEA Structure



			Assets		
OPENING STOCKS			Economic assets	Environmenta assets	
	Industries	*Households/Government*	+		*Rest of the World*
SUPPLY OF PRODUCTS	Domestic Production thereof: for environmental protection				Imports of products thereof: for environmental protection
USE OF PRODUCTS	Economic cost (intermediate consumption, consumption of fixed capital)	Final consumption	Gross capital formation, consumption of fixed capital		Exports of products
	thereof: for environmental protection				thereof: for environmental protection
USE OF NATURAL ASSETS	Environmental cost of industries	Environmental cost of households	Natural capital consumption		
			+		
OTHER CHANGES OF ASSETS			Other changes of economic assets	Other changes of environmental assets	
			=		
CLOSING STOCKS			Economic assets	Environmental assets	

Source: Bartelmus (1999b)

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