ANALYSIS OF THE FUNDAMENTAL CONCEPTS OF RESOURCE MANAGEMENT

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Authors:
Gottfried STEINER, Dipl.-Ing. - GUA GmbH
Dr. Wolfgang STARK, Dipl.-Ing. - GUA GmbH
Dipl.-Ing. Harald PILZ, Mag. - GUA GmbH
Dr. Harald HUTTERER, Univ. Lektor Dipl.-Ing. - GUA GmbH

Contact:

GUA - Gesellschaft für umfassende Analysen GmbH
Sechshauser Strasse 83, A-1150 Wien, Austria
Tel. +43 1 892 0814   Fax +43 1 892 0882
E-mail: office@gua-group.com, URL: www.gua-group.com

0 EXECUTIVE SUMMARY

Resource management has a long history. Various schools cover a broad field of different approaches and have created several, even contradicting concepts. Therefore, an analysis of the fundamental concepts of resource management is needed: Which concepts have been developed? How can resource management be effectively structured? Above all, before developing a consistent EU policy on resource management, the following questions have to be answered: Is there a need for policies on resource management? Which problems should a policy focus on first?

Classical resource economics takes scarcity - one of the problems connected with resource use - up. However, scarcity of specific resources cannot be easily identified. The static range (proved reserves of a resource divided by its annual consumption gives the remaining range) provides wrong results due to neglecting technological progress and discoveries of new raw material deposits. In contrast to pessimistic reports of approaching depletion of resource stocks, the prices of almost all environmental resources have been declining in the course of history. Therefore, from an empiric point of view scarcity cannot be observed. On the other hand, environmental problems (pollution, waste generation,...) are vital for society. These issues currently build up the more significant part of the problems concerned and have to be addressed first by new policies on resource management.

In order to structure resource management several levels have to be distinguished:

1) The overarching goal is to make the use of natural capital sustainable.

2) On the macro level, measures are used to assess the health of the natural capital. The methods can be divided either by the two main orientations of sustainability: Weak sustainability, which means that the value of all capital is constant, and strong sustainability, which means that the natural capital is constant and cannot be substituted by other capital. On the other hand, the methods can be based on the assessment either of the natural capital (stock assessment) or of the natural interests (flow assessment).

3) Resource economics deals with models and mechanisms of the economy's resource use. It helps to explain behavior of society or economy as far as resource use is concerned.

4) Process and policy strategies as well as management measures are used for interventions.

The concept of dematerialization can be used as a general strategy to decouple the environmental problems from the economic growth. Methods developed are Factor 4 and Factor 10 as well as Eco-Efficiency. Physical measures can be subdivided according to thermodynamic laws. Firstly, in the field of mass flow analyses the concepts of MIPS & rucksacks, Mass Flows - Life Cycle Assessment Approach, Environmental Space and the Ecological Footprint (Carrying Capacity) are identified. Secondly, thermodynamic analyses can be based on the measurement of entropy and exergy.

Despite of the fact that there is a lot of critics on the strictly economic approach in resource management, economics can contribute to an effective concept by addressing the more urgent environmental problems: Prices have to reflect the total value of a good or service including economic, ecological and social costs which arise in the life of a good or service. The externalities have to be assessed "from cradle to grave" and valued. By integrating the methods developed in resource management, Welfare Cost-Benefit Analysis can determine the total advantages and disadvantages of certain projects providing an objective basis for decision making in resource management policies.

At the Earth Summit on Environment and Development in Rio de Janeiro in 1992, the United Nations agreed that the concept of sustainable development is the global strategy for further human development. A major part of the follow-up program – the Agenda 21 – deals with resource management: The implementation of new concepts to stop non-sustainable patterns of production and consumption is demanded on local, national and supra-national level. The conclusion is that an effective EU resource management policy based on a coherent concept is definitely needed.

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1 SCOPE & GOAL

During the last decades pollution of natural resources such as air, water and soil, and increasing waste generation in the member states made the policy-makers in the European Union aware of the essential need to protect environment. Consequently, the institutions and policy-makers have been increasing their efforts to reduce environmental pollution. Since the 70ties and 80ties, policy and legislation on environmental issues have steadily grown in importance. In the 90ties, the limits of these policies became apparent. The awareness has risen that policies should rather focus on action at source. Resource depletion and overburden of the environment are among the reasons why the main aspects of environmental protection switched from “end of pipe technologies” to “producer responsibility” and to “minimization of resource use”.

Consequently, resource management and resource economics have become a major issue in environmental discussions. Policy-makers are aware of the need to implement appropriate strategies.

A landmark in the policy to reduce environmental pollution was set in the Rio declaration and Agenda 21 at the Earth Summit 1992. One of the results of efforts of the European Union to implement the principles of the Rio Declaration is the inclusion of the concept of sustainable development in several articles of the Treaty of Amsterdam. This made the principles of sustainable development and a high level of environmental protection one of the top priorities.

Sustainable development, defined as “development meeting the needs of the present without compromising the capacity of the future generations to meet their own needs” in the Brundtland Commission report 1987, was accepted as the global concept for avoidance of the rising environmental threats. This challenging concept is based on three equivalent columns: Economic, social and environmental aspects. Nowadays, economists from neo-classic to ecological schools define "sustainable development” at least as a constant capital stock in time with two main orientations: “Weak sustainability” and “Strong sustainability”.

Resource management has a long history. Various schools cover a broad field of different approaches and have developed several - even contradicting - concepts. In order to develop a consistent EU policy on resource management, there is a strong need for coherent concepts to underpin future policies on appropriate resource management.

This study focuses, although not exclusively, on non-renewable resources: minerals, oil, gas and coal. Their use as raw material and energy sources leads to depletion of the Earth's reserves and are characterized by the fact that they do not renew in human relevant periods. The purpose of the present paper is to

- Identify a selective list of main schools on resource management including alternative concepts,
- Identify problems, gaps, and needs for more coherence in analyzing of resource management,
- Provide the essential basics for further policies on the implementation of consistent concepts in the field of resource management.

For a detailed research study, it is important to achieve coherence in the most important questions:

- What are the key issues in the field of resource management?
- What should be the role of equity both, between generations and between developing and developed countries?

- How can we define environment's carrying capacity in order to calculate the limits of environmental impacts we can tolerate?
- How can existing schools of thought be brought together to form a consistent and sound picture, which allows us to develop clear and well, defined policies?

2 DEFINITIONS

Sustainable Development. There have been many attempts to produce formal definitions of sustainable development. The most widely used, particular internationally, is the 'Brundtland' definition. The United Nations World Commission on Environment and Development defined the expression sustainable development in its report "Our common future" in 1987: Sustainable development meets the needs of the present without compromising the ability of future generations to meet their own needs. The challenging concept of the Brundtland Report is based on three equivalent columns: Economic, social and environmental aspects. It contains within it two main ideas:

- The idea of needs, in particular the essential needs of the world's poor, to which overriding priority should be given; and
- The idea of limitations imposed by the state of technology and social organization on the environment's liability to meet present and future needs.

"Sustainable development" has mainly been used before in questions of forestry saying that for a long-term development of forests trees may only been cut in the extent of their regeneration rate. Nowadays, economists from neo-classic to ecological schools define "sustainable development" at least as the constant of the capital stock over the period (van den Bergh, Hofkes, 1997). Two main orientations have been developed:

- "Weak sustainability": Natural capital is assessed together with man made capital. The total value of the capital has to be constant. Therefore, substitution of the natural capital is possible. The only exception is that the anthropogenic burden may not exceed a certain extent ('ceiling') dependent on the regeneration rate. Moreover, a critical level of natural capital components has to be ensured to maintain the system according to thermodynamic principles.
- "Strong sustainability": Substitution of capital is allowed only among the same type of capital (natural with natural assets). The total value of the natural capital has to be constant. Substitution of natural capital with other capital is not possible.

For both systems and in particular for the concept of "strong sustainability" reliable indicators are necessary for the quantitative and qualitative assessment of natural resources.

Resources. Regarding one of the definitions of resources used by the OECD – "it is anything directly used by human beings" – it is clear that resources cover a broad field. For a better definition of the term, that is objective of the study, these types of 'natural resources' can be distinguished:

1. Environmental resources (in general "biological" reproducing resources)
2. Material resources (in general non-living elemental resources)
3. Energy resources

Therefore, resources in the objective study do not include human resources (immaterial assets such as knowledge and intelligence) or resources directly connected with labor and capital productivity. In addition, the study does not address non-exhaustible resources like energy from the sun or from the tides, which are non-biological, but non-decreasing resources. These resources are part of the discussion about sustainability, but do not contribute to the scope as outlined in chapter 1.

Another way to define resources is to distinguish them according to their regeneration rate:

- Renewable resources: food, water, forests, and wildlife. For resource use to be sustainable, the consumption rate should be maintained within the capacity of the natural systems to regenerate (or renew) in a human relevant period.
- Semirenewable resources: Types of resources that are in an intermediate stage of their possibility to renew or to deplete.
- Non-renewable resources: minerals, oil, gas and coal. Their use as material and energy sources leads to depletion of the Earth's reserves and are characterized that they do not renew in human relevant periods.

Table 1: Classification of resources. Adopted from Wacker, Blank (1999).

	Time for regeneration	Environmental resources	Energy resources	Material resources
Renewable	< 1 year, controllable by humans	Agricultural products, (non permanent) pollution of water and air	Solar energy, water, ethanol	Salt
Semirenewable	1 - 200 years, no human influence	Fish, forests, ground water, (permanent) pollution of water and air	Geothermal energy, water, firewood	
Non-renewable	No economic relevance	Ozone, endangered fauna and flora	Oil, gas, coal, uranium	Minerals, soil

Energy resources are available either as ‘stream units’ or as ‘stock units’. The sun puts energy in the not perfectly closed system ‘earth’ and provides therefor ‘stream units’. The energy from the sun can be used either as biomass or as photovoltaic energy. ‘Stock units’ are coal, oil, or gas that are derived from agglomeration and transition of biomass. These resources play an important role among non-renewable resources because of their stock degradation due to their use (and transition to monetary or man made capital).

Contrarily, non-renewable resources like minerals are potentially recyclable. Nevertheless, the process of recycling needs again input factors. Moreover, the optimal allocation of resources includes the decision when primary resources or secondary resources should be used. Recyclable resources are metallic resources and environmental resources. For example, water is an “elemental” resource (in form of ground water), but distinguished by source it can be renewable (in form of surface water).

Ownership regimes. Resources can be distinguished by their ownership regimes. These regimes are often chosen due to characteristics such as location, mobility, or separability of the resource.

- Open access ownership regimes: Nobody is excluded from resource exploitation (e.g. high-seas fisheries).
- Private ownership regimes: The right for exploitation is well defined (e.g. forests).
- Common property ownership regimes: An intermediate stage including the types restricted access (by means of convention, norms, rules) and public ownership (the same resource can be subject to different ownership regimes).

Public goods are defined by non-excludability (‘non-exclusion principle’: public share of the benefits of the resources or costs of its degradation) and non-subtractability (‘non-rivalry principle’: consumption by a single individual does not influence the availability for others).

For public goods, at least one of the principles has to be fulfilled. Private goods can be divided up and provided separately to different individuals with no external benefits or costs to others.

Consumptive use is generally easy to value, because it involves observable quantities of products which prices are well known. Non-consumptive use is often more difficult to value since both, quantities and prices may not be observed. In fact, open access ownership regimes cause the missing of realistic prices for goods like air and are responsible for the over-exploitation of natural resources. If one of the two principles for public goods is fulfilled, the price for exploitation or the deterioration is at least partially public shared and is not fully integrated in the market price of the natural asset.

Environmental impacts. Beside of the possible threat of resource depletion, the uncontrolled use of resources causes major environmental impacts due to emissions and pollution. Contrarily to the market failures of public goods, environmental impacts have been integrated in traditional environmental policy (taxes, fees) in order to prevent public goods like air or water from being polluted. However, only direct emissions have been included in these measurements while "hidden" impacts are still neglected. Usually, these burdens turn up at the early stages of resource use and even before the manufacturing starts. As mentioned above, their impacts are often not reflected in the market prices.

Environmental burden. Environmental problems that appeared in the last centuries are the result of discrepancy between demand and supply. As long as the capacity of nature to provide and to absorb material was infinite in relation to material handled (e.g. waste), there was no need for specific supply of environmental services. However, due to the economic and resource consumption growth, the environmental supply-„stock" is in danger to run out. As a result, nature looses its capacity to assimilate and absorb emissions and waste causing environmental pollution.

Resource management. Efficient resource management has to integrate both, efficient resource use and the prevention of environmental impacts. With economic methods of resource management, decision-makers should be able to recognize and to address important scarce resources as well as to correct potential market failures. Reliable indicators should help identifying the optimal use rate and potential over-exploitation. The aim is to quantify the efficiency of economic operations, which involves inter alia questions like who uses how much material and energy, and how it is distributed.

Economics of resource management. Because management of resources and in particular of non-renewable resources is strictly connected with economic interests and development, liable instruments to achieve efficient management have to be based on economic principles. Economics of resource management integrates market principles (scarcity) into environmental management issues.

3 Resource Availability

The investigation of resource use and resource efficiency has to take into account the main resources according to their exploitation rate and use rate. With the use of exhaustible resources the question is unavoidably connected how long resources will be available for the production processes.

Resources and reserves. The availability of raw material is often assessed based on the reserves/production ratio, which describes the range of reserves at a constant rate of consumption (static range). The Club of Rome predicted in 1972 that some exhaustible natural resources will be depleted in the eighties (gold, mercury) and in the nineties (zinc, lead). Obviously, the report was wrong and the point of depletion changed due to several reasons.

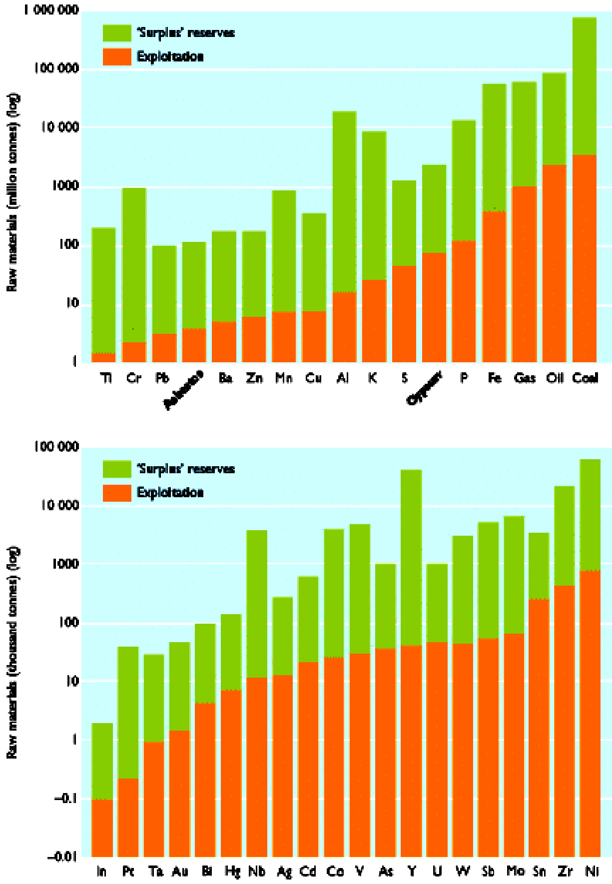

Figure 3.1: World reserves and production of raw material. Reserve estimates will increase if production levels increase, due to increased motivation for exploration. Taken from Source: EEA (1995)

One reason is the definition of resources and reserves: *Resources* are all material stocks on earth. *Reserves* are discovered resources that can be exploited (both, technically possible and economically useful). Moreover, the McKelvey diagram shows the connection between exploitable reserves, identified, but only partly exploitable deposits and hypothetical or speculative resources. The only consequence that can be drawn is that the feasible amount of resources is not fixed. Exploitation of future reserves basically depends on the market price. It has to cover the costs for discovery and exploitation (which may be higher due to increased energy consumption, higher exploration cost,...). Scarcity definitions are therefore difficult due to the dependence on the market price. Therefore, the statistical range (proved reserves divided by the current consumption rate) covers only identified and economically exploitable deposits and is not an appropriate indicator for the total availability.

Exhaustibility and intergenerational equity. Natural resources will be usually not directly consumed, but used as input factors together with labor and capital for production of man made capital. Therefore, it is important how the use of resources is efficiently distributed in time. The optimal allocation of production factors with respect to the rights of future generations on the benefits of resources and capital is a main question. In addition, it has to take into account the optimal input of recyclable and non-recyclable resources.

Availability. Depletion considerations would be little likely to affect geochemically abundant metals, such as iron and aluminum. Most other metals are geochemically scarce, which means that there are quite clear limits to the present accumulations of ore in the Earth's upper crust. For these metals, a case could certainly be made that extraction should be restricted on the grounds of scarcity. Many non-metal minerals occur only in surficial deposits, which would also be exhausted in centuries at current rates of extraction. Where they are being regenerated under present geophysical conditions, the sustainable use rate may equal in some cases the rate of regeneration. Where they are not, a similar problem arises, as in the case of scarce metals with the added complication that most non-metal minerals are difficult or impossible to recycle.

Figure 3.1 identifies the availability of non-renewable resources based on exploited deposits and remaining reserves. It is clear that scarcity cannot be systematically detected or identified on basic geologic assumptions. Resource use and resource availability are too complex to underpin a simple straightforward strategy. Therefore, technological, economic and ecological considerations are important factors for further inquiries.

4 STRUCTURING RESOURCE MANAGEMENT

Resource management has been a major issue for scientists and politicians since Thomas Malthus published his epoch making essay on the principles of population in 1798 (Tahvonen 2000). The economy and long term wealth are largely based on the exploitation of non-renewable and renewable resources although other factors such as human knowledge and labor are to a certain extent complementary. Long before the green movement of the 80ties, the debate on the relationship between natural resource depletion and long-run economic growth appeared. Formerly, the economy considered environmental services as free goods without physical boundaries. Then, some publications (above all: Report to the Club of Rome, Limits to growth, 1972) predicted that raw material will run out very soon. Since the publication of this report, two main orientations have been developed: On the one hand, the "cornucopian theory" emphasized the creative power of technology and free-market to find substitutes for scarce resources. On the other hand, the "neo-Malthusian school" paid attention to the scarcity of critical environmental resources and the need to limit economic growth and population.

Global Issue. The United Nations in the Rio Conference of 1992 could achieve coherence in policy towards sustainable development. The so-called Rio Declaration on Environment and Development says in Principle 4: "In order to achieve sustainable development, environmental protection shall constitute an integral part of the development process and cannot be considered in isolation from it". Therefore, resource management cannot be discussed without considering economic, social and environmental aspects together. The Agenda 21, the follow-up program introduced by the Rio Conference in 1992, states: "The major cause of the continued deterioration of the global environment is the unsustainable pattern of consumption and production, particularly in industrialized countries, which is a matter of grave concern, aggravating poverty and imbalances" (see Chapter 4.6).

Evaluation Criteria for a Sustainable Economy. As demanded in the concept of Sustainable Development in the Agenda 21, highly sensitive measures of sustainability have to be implemented in future policies on resource management. On the one hand, the assessment of resource productivity requires the development of meaningful and reliable indicators. These indicators have to provide good information on the main issues and problems, their magnitude, their causes and the success of the measures. On the other hand, the measurement of sustainability needs reliable indicators reflecting a broader field of impacts on society and on the environment. They are based partly on energy requirements, others on non-renewable resources, or on photosynthetic potentials, all tracing resource and energy flows through human economy.

Structure. In order to organize the broad field of resource management the following structure can help as an orientation (Wackernagel, 2000). The overarching question (sustainability) is the global aim of resource management. Next, it is important to distinguish between the basic principles of resource use, the methods to calculate and evaluate resource use and the measures to steer resource management.

In the following chapters, a selective list of methods and concepts used are explained. It should not give a comprehensive analysis of resource management, but it should provide a good view over the field of resource management.

Resource Management

1) Overarching question
   - How to make the use of natural capital sustainable

2) Macro measures for assessing the health of natural capital
   - Based on the two main orientations of sustainability and
   - On the assessment either of natural capital or of natural interests

	Weak sustainability (Value of all capital = const.)	Strong sustainability (Natural capital = const.)
Stock (or natural capital) assessment	• Satellite Accounts • Measurement of Wealth	Assessments of natural capital health such as: • WWF's Living Planet Index (in their Living Planet Report) • World Resources Institute (World Resources 2000-2001: People and Ecosystems, the Fraying Web of Life) • Outlook 2000
Flow (or natural interests) assessment	Value of ecosystem services • Costanza's value of ecosystem services • ISEW (Daly and Cobb) or Genuine Progress Indicator (Redefining Progress) • Satellite accounts of SNA and green GNP • World Bank's Genuine Saving	• Material Flow analysis • Ecological Footprint and its various measures (such as Ecological Capacity and Ecological Deficit) • Environmental Space • Energy, eMergy, Exergy

3) Models and mechanisms of the economy's resource use (resource economics)
   - Economics and Systems models on the dynamics of resource use (explaining society's or the economy's behavior as far as resource use is concerned).

4) Strategies and management measures for interventions
   - Substitution and Dematerialization (Factor 4, Factor 10, Eco-efficiency), Sufficiency, Depletion criterion for non-renewable resources

Process strategies

Measures of micro processes:
- Physical measures
- LCA (Life cycle assessment)
- MIPS (material intensity per service unit)
- Ecological footprint
- SPI (Sustainable process index)
- Energy, eMergy, Exergy

Policy strategies:

- Taxes and subsidies, Regulations etc.

Monetary measures:

- CBA (Cost benefit analysis)

4.1 Strategy - Dematerialization

Currently, due to the interdependence of population, economy, and resource consumption, environmental problems increase with population and economic growth. If Second and Third World countries raise their resource use to the levels of the industrialized world, the limits of nature's capacity to provide and to absorb material will most likely be substantially exceeded. However, since people's basic right for welfare and prosperity cannot be denied, alternative policies have to be developed and implemented to stop the emerging threat of overburden.

One of the most prominent concepts, which could show the way to these goals, is the concept of 'dematerialization'. This concept states that a de-linking should occur between material use and economic growth during economic development (Weizsäcker, 1998). The strategy is to reduce the material needs and consumption of resources without compromising the global welfare progress by enhancing know-how, services, and knowledge (qualitative progress).

The idea is that a global qualitative welfare growth is achieved with less resource consumption. Both exploitation of resources and their conversion into economic goods and services have to be improved. The objective is to "decouple" adverse environmental impacts from economic growth. Improved resource management and resource efficiency will reduce degradation of resource stocks, pollution, and waste flows.

Material demand is the product of the intensity of use and the level of income. Consequently, dematerialization will only occur if the intensity of use declines at a higher rate than the rate of income growth. If, at a certain point in time, the rate of economy growth overtakes the decline in the intensity of use, the economy starts to re-materialize again.

4.1.1 Eco-Efficiency

Meeting needs with less use of natural and manufactured resources but with more use of people has become an environmental and economic imperative (WBSCD, 1996). 'Eco- efficiency' aims at de-coupling resource use and pollutant release from economic activity. There are two broad ways to enhance Eco-efficiency:

- via the more efficient and equitable use of resources, through innovation in the use of resources and labor; and
- via a focus on meeting human needs more from labor-intensive services than from capital-intensive products.

However, technological innovation does not necessarily decrease environmental burden, but increase only the efficiency of resource use: A higher population can benefit from the same material standard or a constant population from a higher material standard. There may also be a "rebound effect"; i.e. improvements in efficiency save money to consumers, which can spend the money to consume more elsewhere. Moreover, even increased efficiency will not lower the total environmental burden if population (and therefore the total consumption) keeps growing. Frequently, technology innovations increase the short-term energy and material fluxes, which are often based on non-renewable resources. For example, the dynamic innovation progress in the field of electronic devices and personal computers definitely helps to increase resource efficiency, but newly developed products replace other products in a even smaller getting period.

4.1.2 Factor 4 & Factor 10

The core of the Factor 4 concept is that resource productivity should be quadrupled so that wealth is doubled, and resource use is halved ("doing more with less"). The achievement of a global Factor 4 would result in substantial macro-economic gains. The underlying assumption of Factor 4 is that the global welfare progress will be sustained if resource productivity grows. This quadrupling of resource productivity is technically feasible, as the authors argue (Von Weizsäcker, Lovins & Lovins, 1992) in their book "Factor 4".

This efficiency revolution is technically possible. Examples for energy productivity, material productivity and transport productivity are available. Least cost planning, correction of prices and ecological tax reforms are practicable instruments for the implementation of Factor 4 principles. Above all, the final revolution of Factor 4 does not only include tangible materialistic aims, but also a change of people's attitude. Consumption of materialistic values has to be reduced and informal work encouraged. There may also be a case for discussing the term of welfare as a global goal that should be maximized. The authors argue that welfare has to be measured in a different way than classical GDP. GDP is not necessarily a good measure of people's personal welfare (feeling). Factor 4's contribution will be the reduction of the pressure on (price of) labor and increase the pressure on resource use.

However, Factor 4 is a minimum requirement. In some cases, higher rates will be necessary so that the total economy achieves quadrupled resource productivity. In other cases, resource productivity has already reached the highest level and further progress will not be possible. Therefore, Factor four is a symbol for the future development of society to achieve sustainable development. There is certainly a question if Factor 4 should be applied in the same way for all types of resources. While the exploitation of some non-renewable resources has to be decreased at least fourfold (or higher), other non-renewable resources are not scarce.

Factor 4, reducing material needs by quadrupling energy and material productivity, is an effective and promising method to achieve dematerialization. However, it is argued that a factor of four may not be enough for sustainable development and a factor of 10 should be adopted. Schmidt-Bleek (2000) says that reaching sustainability demands an absolute reduction in resource use of at least 50 %: "Moreover, equity demands that the rich make sufficient environmental space available for the poor when moving jointly toward ecological sustainability. As less than 20 % of humankind consume in excess of 80 % of the natural resources at this time, the richer countries need to dematerialize their technical basis of wealth – or increase the resource productivity – by at least a factor 10 on the average."

4.2 Physical Measures

Physical evaluation methods can be distinguished by their original principles. The most general principle in physics is the application of the thermodynamic model.

The idea of the thermodynamics requires some explanation. This can be provided by a short exposition of the laws of thermodynamics in terms of an image borrowed from Georgescu-Roegen (1971) with the example of an hourglass:

- It is a closed system in that no sand enters the glass and none leaves. The amount of sand in the glass is constant. This is the analogy of the First Law of Thermodynamics: there is no creation or destruction of matter/energy.
- Although the quantity of sand in the hourglass is constant, its qualitative distribution is constantly changing: the bottom chamber is filling up and the top chamber is becoming empty. This is the analogy of The Second Law, that entropy (bottom-chamber sand) always increases.

4.2.1 Mass flow analysis

The theory of resource management can be based on the First Law of Thermodynamics, which states that the energy of the universe is constant. Correspondingly, the Material Balance Principle states that material can be transformed or transported within closed systems, but they cannot be made or destroyed. This principle is called the “law of conservation of matter”. It states that due to resource consumption and societal material throughput no material gets lost. Benefits of goods are used and consumed, the material itself becomes waste. In principle, environmental problems occur because the higher the flows are, the higher the environmental burden is.

4.2.1.1 MIPS & Rucksacks

The concept of material input per service unit („Massenintensität pro Produkt-Service MIPS“) was developed by Prof. Dr. F. Schmidt-Bleek of the Wuppertal Institute for Climate, Environment and Energy (Germany) in the year 1992. The approach is a conceptually radical way of simplifying the problem of material-resource consumption. The basic idea is that it is not completely possible to investigate all environmental impacts in a manageable extent. Thus, an alternative method is applied.

Displacement and removal of material as well as the flow of material back to the environment cause changes of the natural system. The concept reflects the idea that the sum of problems associated with material consumption (physical disturbance, pollution through dissipation, waste disposal, etc.) can be roughly related to the total amount of material moved in the course of economic activity. If this amount is reduced, the overall impact of material consumption will be lowered, too. Material input per unit service MIPS can be seen as a basic measure for the impacts associated. The total amount of material used ‘i’, derived from Life-Cycle-Analysis (LCA) including displaced and used material to produce energy, multiplied by its specific material intensity (MIM_i) describes the total material input (MI) in weight units.

The rucksack is the amount of "invisible" MI - moved material - behind consumption of a specific material. Material moved not only include those actually extracted with a view to making products out of them. They also include the earth or rock overburden that must be removed in order to get the economically valuable material. Furthermore, they include the economically worthless material that have to be moved in the course of construction activities, and material unintentionally moved in the course of economic activity, e.g. by accelerated erosion.

There are also some critics and problems. MIPS-calculation does not distinguish between material of different toxicity, only the quantity of material input is important. Although experience has often shown that the main environmental impacts are not simply a consequence of quantity, supporters of the method argue that the interrelations between the material are not known in detail. That is why they think it is better and more exact to analyze only the quantity of material input. To date in literature MIPS is more seen as an approximation or a kind of "screening" Eco-balance. If there are more possibilities to compare the results of other approaches with the result of the MIPS-calculation, the trust in this method could rise.

4.2.1.2 Mass flows - Life Cycle Assessment Approach

Based on a life cycle approach (all effects in a cradle to grave analysis), the method is used to gain information on all toxicologically (and to some extent ecologically) relevant flows caused by a process. The impacts of the flows on the environment or health are evaluated and valued. Therefore, mass and energy flows include the whole life cycle from exploitation of raw material, production, transportation, and generation of waste.

The decisive criteria of the LCA approach to evaluate mass flows are "critical volumes" for the Eco-compartments of air, water, and (top) soil. Critical volumes are derived from the mass flow divided by the critical loads related (limiting values, geological references, etc.). Mass flows can be - roughly - calculated. Critical loads reflect the "ecological scarcity" that is defined as the relationship between the load-bearing capacity of resources and the present environmental burden. Resources are not necessarily defined as natural resources, but for example, as landfill space. Critical loads are taken from current limiting values, which are based on political decisions. The defensive orientation of protecting Eco-compartments does not differ between resource-input limitation and the use of end-of-pipe technologies. Besides, it reflects the competitiveness of a process concerning the current state of the art neglecting future developments (Braunschweig, 1999; Bundesamt für Umweltschutz (Ed.), 1984).

The method has much in common with the method of carrying capacity. However, the final assessment of environmental burden is based on model assumptions. A single, but reliable mathematical function is chosen to calculate the effects on the ecological system. This simplification should simulate ecological scarcity (for a further discussion see chapter 7.2.3).

4.2.1.3 Environmental Space

Environmental space is a new approach toward analyzing sustainable development with an emphasis on the control of the input into society. However, input does not only include material, but is also connected with terms of agriculture and other sectors.

The term 'environmental space' "reflects that at any given point in time, there are limits to the amount of environmental pressure that the Earth's ecosystems can handle without irreversible damage to these systems or to the life support processes that they enable". (Source: Opschoor and F. Weterings, 1994 a, b, cited in Hille, 1997). The concept includes both stocks (of renewable, semirenewable and non-renewable resources) and sinks (i.e. capacities to absorb waste, pollution, and encroachment). In "Towards Sustainable Europe" (TSE), carried out by the Wuppertal Institute in co-operation with Friends of the Earth Europe (Source: Spangenberg, 1994, cited in Hille 1997) environmental space is defined as "the quantity of energy, water, land, non-renewable raw material and wood that we can use in a sustainable fashion". Considering the environmental space for non-renewable material, the concept says that the overall ecological impacts can be roughly correlated with all movement of material humanly induced ("material input" in tones). Consequently, the permissible global level of the total material input should be half the amount of the present (1990) level. The concept is mass-flow based and does not consider scarcity of resources. However, by integration of sustainability, depletion of resources will be avoided, too.

"Environmental space" is a concept related to both carrying capacity and material flow analysis. An important result of the concept is the presentation of per capita environmental space for major resources in a certain area (e.g. the European Union) and of required reductions in consumption from 1990 levels. It improves the mass flow approaches with a more complex view on earth and its ecological system. However, it is still gives less complicated results than other approaches.

4.2.1.4 Carrying capacity

Following classical economics, progress in technology and trade is unlimited. The earth's carrying capacity for an increasing population is infinitely expandable and irrelevant to demography and development planning. Factors of production are infinitely substitutable and an increase in resource consumption is directly followed by an increase in global welfare.

On the contrary, alternative concepts see the environment's carrying capacity as the fundamental basis for demographic accounting. Carrying Capacity is defined as environment's "maximum persistently supportable load" (Catton, 1986, cited in Rees, 1996). Human induced load is not only a function of population, but directly dependent on per capita consumption. Remaining stocks of natural capital have to be husbanded adequately to sustain the anticipated load of the human economy. Rees (1996) argues that despite the increasing technological sophistication, humankind remains in a state of "obligate dependency" on the productivity and life support services of the ecosphere. Therefore, economic assessments of the human conditions should be based on, or at least informed by, ecological and biophysical analyses.

Many Area-based Sustainability Indicators have been developed. Among them are the Ecological Footprint (Appropriated Carrying Capacity - ACC) as well as the Personal planetoid (the per capita land/water requirement at a specific material standard of living), ecological deficit (resource consumption by a defined economy or population in excess of locally/regionally sustainable natural production and assimilative capacity), sustainability gap (a measure of the decrease in consumption required to eliminate the ecological deficit).

4.2.1.5 Ecological footprint

From an ecological perspective, adequate land and associated natural capital are fundamental to the prospects for continued civilized existence on earth. The human population and the average consumption are increasing while the total area of productive land is fixed. Carrying capacity is usually seen as the maximum population of a given species that can be supported indefinitely in a defined habitat without permanently impairing the productivity of that habitat. Human carrying capacity gives the maximum rates of resource exploitation, consumption, and waste generation that can be sustained indefinitely without progressively impairing the productivity and functional integrity of relevant ecosystems. However, non-renewable resources are only included in the concept if they have an significant impact on the health of the ecosystem due to their toxicity potential.

Terrestrial ecosystems and associated water bodies produce many forms of natural income (resource and service flows). The area of productive land that is needed to sustain a defined population indefinitely wherever on Earth that land is located can be calculated. The area of land/water can be calculated that is required to sustainably produce the quantity of any resource or ecological service used by a defined population at a given level of technology. The sum of such calculations for all significant categories of consumption gives a conservative area-based estimate of the natural capital requirements for that population.

The footprint is calculated by dividing the annual resource flow by the yield (per area). It can be defined as the biophysical resource flows and waste assimilation capacity per unit of time from global totals by a defined economy or population. The area that is required to sustainably produce the quantity of any resource or ecological service used by a defined population or economy at a given level of technology is calculated.

Area needed for different purposes is limited. Therefore, a competition for space is ongoing: Agriculture needs the space, which is occupied by roads, by forests, or by industry. The total ecological footprint summarizes the area needed. In Wackernagel et. al. (1997) main categories of ecologically productive areas are arable land, pasture, forest, sea space, built-up land, and fossil energy land.

The ecological footprint measures human's (and nation's) dependence on nature. Every nation depends on ecological capacity to sustain itself. A nation's ecological footprint corresponds to the aggregated land and water area in various ecosystem categories, that is appropriated by that nation to produce all the resources it consumes and to absorb all the waste it generates on a continuous basis, using prevailing technology (dynamic evaluation process). The ecological footprint indicates the nation's pressure on the ecological system. If a nation is using more ecological space than there is within its boundaries, an ecological deficit will result. Consequently, missing ecological capacity will be imported or natural capital stocks will be extensively degraded. Countries with footprints smaller than their capacity are living within their nation's ecological means.

The concept has been developed to show in a simple way what the "real costs" of human activities are. Area is an easily understandable criterion and makes outputs of measures visible. Generally, there is some discussion about the possible use of carrying capacity concepts. Some experts reject the application of this concept to human beings. It is easier to apply it to animals than to humans, because per capita resource consumption for animals is constant over time and constant on individual members of the species. Hence, for human beings we cannot speak of carrying capacity in terms of population alone. Another option is to define carrying capacity not as a maximum population but rather as a maximum load that can safely be imposed on the environment.

4.2.2 Thermodynamic analysis

4.2.2.1 Entropy

In the publication "The Entropy Law and the Economic Process" (1971), Georgescu-Roegen challenged neo-classical economic theory by linking the laws of thermodynamic to economic processes.

Entropy is widely seen as a fundamental natural measurement. In 1931 the physicist Sir. A. Eddington described the steady increase of entropy as one of the primary laws of nature. He called entropy as "the arrow of time". There are several definitions and approaches of entropy (Ayres 1996). However, two of them are fundamental:

Thermodynamic approach. Originally, R. Clausius developed the concept of entropy in 1865. His fundamental law says that the energy of the universe is constant (First Thermodynamic Law). The entropy is striving for maximization at every point of time (Second Thermodynamic Law). It is calculated from heat flow and temperature.

Statistical approach. At the end of the 19th century the statistical thermodynamic or the statistical mechanic was added to the classical or phenomenological thermodynamic. Ludwig Boltzmann's (1923) statistical methods helped to find the basic connection between the characteristics of particles and the macroscopic characteristics of a system with many particles. Entropy has been used in statistics to assess the dissemination of frequency and probability calculations. A separate orientation in the field of the statistical application of entropy is the information approach. Shannon (Shannon, 1948, cited in Rechberger, 1999) defined entropy as a measurement for the uncertainty of information sources. It is used as a statistical tool, e.g. for the assessment of distribution processes.

Economic impacts. Since production processes do not totally convert production factors into goods, by-products occur. According to the First Thermodynamic Law, material and energy are not lost. In the economic process not material, but the benefit connected is consumed. Therefore, sooner or later all material will be moved back to the ecological system as an environmental burden. Due to the Second Thermodynamic Law (Law of Entropy) processes are irreversible and increase entropy of the systems. Consequently, one can state that economic activities without environmental burden are not possible. Every economic process with by-products such as pollutants, waste and waste energy decreases the content of environmental resources available (what can be seen e.g. in recycling processes as “thin out”).

For practical application of the entropic law two examples are given.

Waste potential entropy (WPE). According to Ayres, Martinás (1995), the Waste Potential Entropy (WPE) measures the environmental pressure exerted by a mass flow and indicates ecological deficits. The emission of material fluxes to the environment is more dangerous, the larger the difference is between the chemical state of the material fluxes (e.g. pollutants) and the chemical equilibrium of the local environment. For example, the exhaust air of a car enters the atmosphere, which has a different temperature, pressure, and chemical composition. The higher the differences, the higher the impacts are. Therefore, a “good” process discharges little entropy in wastes and uses little energy.

Substance Concentrating Efficiency (SCE). According to Rechberger (1999), the characteristics of a process to dilute or concentrate substances can be measured by means of substance flow analysis. The formalism is derived from statistical entropy. The method developed allows comparing substance balances of various single processes, which have different emissions and residues. The global aim of the method is that harmful or toxic substances should be highly concentrated in small masses (giving a small entropy). The Substance Concentrating Efficiency measures the extent of the concentration of substances. The higher the concentration, the lower the “entropy” is. Since resource management deals with the availability of material, the SCE is a method to gain efficiency in this field.

4.2.2.2 Exergy

Exergy is defined as the potential work that can be extracted from a system by reversible processes as the system equilibrates with its surroundings (Ayres 1996). It is the “useable” part of energy because only exergy is available for economic processes. The exergy content of hydrocarbon fuels is very closely related to the usual measure of energy (“heat of combustion”) while the exergy content of ore reflects its quality and availability (which can be very low despite of its important quality). Martinas & Ayres (1994) added that “exergy” is the limiting quantity to recycle (renew) material dissipated through economic processes.

For application of exergy three methods are given.

Exergy as a measure of Resource/Waste Stocks & Flows. Ayres (1996) bases the measurement of stocks and flows of resources and waste on their exergy. The approach is to calculate the exergy of inputs and outputs, including wastes and losses. Then, exergy would be a single common and comparable measure. Exergy is not conserved in economic processes, but totally consumed. Therefore, exergy is the measure of potential work embodied in a material. As exergy is calculated using fundamental thermodynamic laws, the approach can be used for both, accounting stocks and measuring flows.

Exergy in Life Cycle Analysis (LCA). For more practicability, exergy analysis can also be used in Life Cycle Analysis (Ayres, Ayres, Martinas 1996). The exergetic efficiency can be measured as basic principle. For a global comparison of different resources, exergy provides a reliable parameter with a single comparable unit. Moreover, exergy can be used to calculate the "exergy input intensity" to comparing different activities and processes (similar to MIPS, but based on exergy flows).

SPI - Sustainable Process Index. The Sustainable Process Index (SPI) is a measure developed to evaluate the viability of processes under sustainable economic conditions (Krotschek, 1995). The emphasis of SPI lies in embedding any process into ecological systems rather than in accounting its impacts on the environment. The concept of SPI is based on the assumption that in a truly sustainable society the basis of economy is the sustainable flow of solar exergy. The conversion of the solar exergy to services needs area. Area is both, a recipient of solar energy and a production factor. Therefore, area is the limiting resource in a sustainable economy because the surface is finite. Consequently, the SPI measures the ecological impact of a process with respect on the quantity and the quality of the energy and mass flows it induces. Thus, products needing more area for the same service are less competitive if area is limited. It also relates these areas to the area available to a citizen in a given geographical context (from regional to global). Thus, SPI and Appropriate Carrying Capacity have a great deal in common, although SPI is more detailed. The advantages of the SPI concept are its universal applicability and the high sensitivity for sustainable quantities. The SPI is designated to be reliable for strategic planning and optimization. It allows analyses with different objectives using adequate and well accessible data.

4.2.2.3 What can thermodynamics contribute to the discussion on resource management?

Since economic approaches measure "money flows" instead of "mass/energy flows" and transformations, standard models fail to consider entropy as a fundamental measurement. By contrast, the Second Law of Thermodynamics ("Entropy") supports the idea of carrying capacity since all highly-ordered systems develop and grow (increase their internal order) "at the expense of increasing disorder at higher levels in the systems hierarchy" (Schneider & Kay, 1992, cited in Rees E. W., 1996). Because of the extensive dissipation of energy and material, the complex dynamic systems are in a nonequilibrium state requiring a constant input to maintain their internal order ("dissipative structures"). The human economy can therefore be described as a highly ordered, dynamic, far-from equilibrium dissipative structure. It is dependent on the formation of energy and material in the ecosphere for its growth and development ("consuming system"). This input to the economy from nature is called the "natural income". When consumption by the economy exceeds natural income, the continuous growth of the economy can be purchased only at the expense of increasing disorder or entropy in the ecosphere and would be manifested through the depletion of natural capital.

4.3 Resource Economics

One of the theories of resource economics is that the resource consumption will not be accelerated, but slowly reduced in an extent of approaching depletion. Contrarily to the lack of market self-regulation for waste and emissions, scarcity regulates the extent of resource stocks and resource exploitation.

4.3.1 Brief history of resource economics

According to Tahvonen (2000), resource economics' history can be divided up into 4 parts – mainly dominated by epoch-making publications.

- The First Debate ("The British Classical Economists"): Thomas Malthus published in 1798 his essay on the principles of population giving a rather pessimistic view on the development of humankind: If the limits of resources are reached, humankind will starve. Other economists at this time were not so pessimistic.
- The Second Debate ("The U.S. Conservation Movement (1890-1920) and the Studies by Hotelling (1931) and Barnett & Morse (1963)"): The Conservation movement emphasized the idea that the lower the use of non-renewable resources is the better. Hotelling presented his model that profit maximizing mining companies would extract non-renewable resources at the socially optimal rate (see chapter 7.3). Contrarily to the Conservation Movement, the study of Barnett & Morse (1963) stated that the prices for natural resources (except in forestry) declined in the period from 1870 to 1957. Scarcity could not be detected as a consequence of technological development.
- The Third Debate ("The Limits to Growth Report for the Club of Rome, 1972"): The study for the Club of Rome was rather pessimistic predicting depletion of certain metals by the end of the 20th century and a collapse of the world population level, food production and industrialization during the 21st century (see chapter 3).
- The Fourth Debate: "Pre-Sustainability Research in Economics, from 1974 Onwards"): Starting with the oil crisis in 1974 questions of sustainability became an issue due to scarcity and the supposed threat of depletion of resources. Enduring consumption levels, investment of the capital, and the use the substitution with renewable resources, as well as empirical research on the use of resources are some of the new ideas.

Tahvonen (2000) closes the historical review with his conclusions from empirical analyses that basic economic predictions are too pessimistic. Considering crude oil production level, reserve levels and the relationship reserves to production increased in the last decades. Besides, the oil price is again on the same level as it was in the sixties of this century and prices of several other non-renewable resources are significantly lower than they were in the last century. In brief, Tahvonen (2000) argues that scarcity is not observable.

Consequently, new Economic "Endogenous Growth Models" include technological development as a continuous progress (see chapter 4.3.4). The economic models of sustainable development can be categorized in the following way (van den Bergh, Hofkes 1997):

- Economic growth theory: Including technological progress, pollution, and other factors (see chapter 4.3.3).
- Sectorally disaggregated models: Dealing with the question of a sustainable structure of the economy.
- Models of (Co-) evolution: the basic idea is that changes in economics are so fast that it is impossible to have some stable stationary or equilibrium state of the economic system. The methods are based on evolutionary theories in biology theories of technological change.
- Empirical issues: This approach deals with the empirical description of economic progress, consumption/production indicators and investigation of relationships growth, economic structure and environmental stress or degradation as well as the development of reliable sustainability indicators. Dematerialization and Accounting issues are considered to be within this area of research.

4.3.2 Discussion of the basic assumptions

For further discussion of the basic assumptions in the theory of resource economics, the following structure is given. A brief description of the listed theories is given in chapter 7.3.

- Pricing of exhaustible resources
  - Ricardo's differential rent
  - "R-percent-rule" of Gray
  - Hotelling's rule
- Markets
  - Perfect competition
  - Imperfect competition
- Change of parameters
  - Change of market rate of interest
  - Change of extraction cost
  - Change of reserves
  - Change of backstop technology
  - Change of taxes on the resources
- Trade of non-renewable resources
  - National economy's export of exhaustible resources
  - National economy's import of exhaustible resources
- Production process with environmental exhaustible resources
  - Characterization of efficient paths
  - Characterization of optimal paths
  - Transition to backstop technology
- Recycling of exhaustible resources
  - Recycling of environmental resources
  - Return of raw material
- Recycling and environmental cost
  - Environmental cost influence on resource extraction
  - Environmental resource as input factor

4.3.3 Neo-classical model

A lot of research is undertaken to get a formal analysis of the conditions under which economic growth is sustainable. The main question is to find the link between optimality (efficiency) and sustainability (van den Bergh, Hofkes 1997). For this purpose, alternative social objectives and alternative production relationships have been examined. The neo-classical Solow type of growth model has long served as the benchmark in dealing with the question of limits to growth, either based on resource scarcity or environmental pollution, or both. Over the last decade, attention has shifted to modern growth theory.

Van den Bergh, Hofkes (1997) describe a general neo-classical model with environmental considerations. The mathematical formulation of the growth theory is given in chapter 7.3.8. The model presented still suffers from the fact that is not general enough. The model may again change if additional activities and economic capital are defined such as related to re-cycling, abatement, and innovation (the latter leading to the new growth theory). Van den Bergh, Hofkes (1997) argue that sustainability can be integrated in the general class of models by the following ways:

1. Finding the optimal (efficient) dynamic solution and testing whether it satisfies the chosen definition or interpretation of sustainable development.
2. Explicitly incorporating sustainability as a condition on the stock of environmental resources or assimilative capacity on consumption patterns or more generally on welfare changes.
3. The change of the social objective function, for example by explicitly giving a larger weight to the welfare of generations in the distant future (discounting issues).

4.3.4 Technological Innovation

As mentioned in chapter 4.3.1, since the end of the 1980's new growth theories have been developed that regard technology as endogenous to the economy. Before technological progress was seen as exogenous. The case of renewable resources is mainly analyzed within the context of such endogenous (or modern) growth models (van den Bergh, Hofkes, 1997).

Simpson (1999) describes the technological progress and innovation process in Natural Resource Industries in the USA: The author gives an empirically overview about the trends in resource extraction, resource costs and technological innovation in the industries affected. One main conclusion is that prices are 40 % lower than 40 years ago indicating that there is no scarcity in the field of Natural Resource Industries. This fact can be interpreted as improvement in extraction and reductions of the cost of production through innovation. The reasons for steady technological progress can be summarized:

1. Necessity, because the most easily accessible reserves have been depleted over time.
2. Gradual process of technology adoption, innovations result from synergies with other developments.
3. Ongoing ability of generating innovations (in the case of the United States).

For the derivation of new growth models, the solution is (optimal) balanced growth, e.g. paths with variables growing at a constant (even zero) growth rate. It is shown that under certain conditions with respect to production and substitution elasticities there is an optimal growth path on which the economy grows at a constant positive growth rate, keeping environmental quality (or stock of renewable resources) at a constant level. In such models growth in technology and abatement together with self-regenerating capacities of the natural environment compensate for growth in use of natural resources (van den Bergh, Hofkes, 1997).

4.3.5 Market and state failure

According to the law of supply and demand, environmental problems would not occur (If the scarcity of resources cause higher prices for environmental services, the demand will decline). However, the fact that environmental problems appear, indicates certain failures (Binswanger, Minsch, 1992).

Market and state failure. External effects of production or consumption, which impair the wealth or welfare of other people, are not integrated in market prices (market failure). In the case of public goods, this may cause uncontrollable exploitation. The price mechanism fails to ensure adequate extraction of these resources with a view to future generations. In order to correct inadequate prices, artificial prices (which are accepted by everyone as long as everyone is affected) should be created directly (economic instruments) or indirectly (environmental laws). An adequate price may be reached if the state-induced mechanism is properly working. It will not be achieved if it fails to set rational decisions. Does the legislator interpret people's preferences correctly? Are the preferences of citizens correct if analyzed on a rational basis? People claim rights on "energy supply", "mobility", "waste disposal", "liability of risks" (e.g. risks from atomic power production) etc. However, they are diametrical to the requirements of environmental protection. The state failure is to invest in these claims causing environmental burden instead of reduction of environmental pressure.

Binswanger, Minsch (1992) claim that the theory of resource economics does not go along with the findings of the resource markets due to several reasons:

- After depletion of a resource stock, simply the next reserve will be exploited as long as new beds are discovered. Scarcity cannot be observed.
- Not all resource owners think in a capitalist way and therefore exploit stocks to maximize the short-term profit.
- Costs of extraction are not considered as decisive factor in resource economics. However, costs can only be neglected if the profit per resource unit is so high that the price is approximately identical with the profit. Usually, competition forces market players to reduce average costs. Through an increase of the amount produced (or resources extracted), the total costs increase, but the average costs decrease due to the allocation of the fixed costs to a higher production amount. Prices decline, the consumption rate increases. The market rate of interest supports this effect: The lower the rate, the cheaper the capitalization process, and the faster the exploitation.
- Contrary to heterogeneous goods (qualitative differences), the competitive factor for homogeneous goods (e.g. material and energy resources) is the market price. The good with the lowest price has the best chances. Therefore, dynamic competition in the field of resources leads to the strong need to reduce prices and increase exploitation rate. The calculation of the owner (except of monopolists) cannot compensate this tendency, and there are no incentives for resource conserving investments.

4.4 Valuation of Externalities

As noted in chapter 2, resource use may have two different consequences:

- Over-exploitation may lead to depletion of resources making them unavailable for future generations or for other people on earth. However, as outlined in the chapters 3 and 4.3 scarcity can neither be easily measured nor detected.
- The second consequence is that resource use may cause emissions and waste (and – what is not objective of the study – social and economic abortive developments) which lead to pressure on the earth's ecosystem. Due to the still increasing actual evident environmental problems and the absence of indications for depletion of resources environmental

problems should be addressed first. In fact, currently the reduction of environmental pressure is the more important issue in the field of resource management (Bartelmus 2000).

Some of the costs of production may not be fully reflected in the market price for a certain good. For some goods and services, the market provides prices that are good reflections of the values society places on that good or service. In other cases, major environmental problems are connected with the extraction and use of resources which are not internalized. Conceptually, the externality problem is quite simple and can be described as a difference between the benefits (costs) that accrue to society and the benefits (costs) that accrue to the project entity. Real market prices either do not exist or only capture a small part of the total value. Environmental externalities are identified as part of the environmental assessment, quantified where possible, and included in the economic analysis as costs or benefits (See chapter 4.4.2). After a monetary value is assigned to the costs and benefits, they are entered into business cost tables as any other costs and benefits are. Therefore, environmental problems can be addressed by including the pressure on the ecosystems in the prices for resources and goods.

4.4.1 Total Economic value

To analyze the situation, it is often useful to disaggregate any environmental impact into individual components of value (The World Bank, 1998). One approach to doing this is called the Total Economic Value (TEV) approach. The idea behind the TEV approach is that the analysis of goods and services is dependent on certain attributes. Any good or service is composed of various attributes, some of which are concrete and easily measured, while others may be more difficult to quantify. The total value is the sum of all of these components, not just those that can be easily measured.

USE VALUE			NON USE VALUE	
Direct use value	**Indirect use value**	**Option value**	**Existence value**	**Bequest value**
Outputs directly consumable	Functional benefits	Direct and indirect future values	Use and non use value of environmental legacy	Value from knowledge of continued existence

Source: Based on Pearce et al., 1992

Figure 4.1: Total economic value.

The following distinction outlines the values related (see Figure 4.1). However, it is neither complete nor generally accepted. However, it categorizes the attributes.

1. Use value:

- Direct (extractive) use value: also known as extractive, consumptive, or structural use value, derives from goods which can be extracted, consumed, or directly enjoyed. In addition to these directly consumed goods, direct use values can also be non-consumptive.

- Option value: is the value obtained from maintaining the option of taking advantage of something's use value (whether extractive or non-extractive) later.
- Quasi-option value: derives from the possibility that something appears unimportant now. Information received later might lead us to re-evaluate it.
- Indirect (non-extractive) use value: also known as non-extractive use value or functional value, derives from the services the environment provides. For example, wetlands often filter water, improving water quality for downstream users, and national parks provide opportunities for recreation.

2. Non-use value:

- Bequest value: is the value derived from the desire to pass on values to future generations. Derives from the benefits the environment may provide which do not involve using it in any way, whether directly or indirectly.
- Existence value: the value that people derive from the knowledge that something exists, even if they never plan to use it.

4.4.2 Valuation methods

In principle, several valuation methods may often lead to very different results. Basically, two methods can be distinguished (direct methods and indirect methods of valuation). The following list is based on this distinction. Furthermore, it is important to separate the effects assessed. Usually, tangible effects are easily to quantify and monetarise. These are costs that are developed from market approaches (damage, production). Intangible effects which cannot be directly valued by market approaches are more difficult to quantify and monetarise (landscape, scenery, human life).

4.4.2.1 Direct valuation

The direct approach comprises techniques, which seek to detect preferences for environmental goods directly by experimental methods, such as the contingent valuation method. Generally they are based on questionnaires. The advantage of direct methods is to obtain certain market information. Basically, the law of supply and demand regulates the market and the use of resources. The "demand" can be investigated by direct methods. Therefore, direct methods help to get the prices right according to the market's preferences.

Contingent valuation: In contingent valuation studies various questions are asked to assess the maximum willingness to pay or willingness to accept. The idea underlying this method is that people have true, but hidden preferences for all kinds of environmental goods. It is assumed that they are capable of transforming these preferences into monetary units. The respondent is asked directly what he is willing to pay for a benefit or to avoid a negative effect (cost). Another possibility is to ask the person what he is willing to accept to forego a benefit or tolerate a negative effect (cost). These models are used to infer the respondent's willingness to pay or willingness to accept compensation (e. g. willingness to pay for prevention of further environmental damages).

4.4.2.2 Indirect valuation

The indirect approach tries to infer preferences from actual market-based information. For example markets for goods, which are complements or substitutes for the goods in question, are observed. The indirect techniques infer environmental values from markets in which environmental factors have an influence. They relate on actual choices instead of hypothetical choices.

Loss in productivity: In many cases, the environmental effects of projects manifest themselves (at least partly) in changes in output of marketable goods: loss of forest, for example, results in the loss of timber products, of fuelwood, of fodder, and a variety of non-timber products such as fruit, herbs, and mushrooms. The value of the unintended benefits and costs can be estimated by using the simple technique of valuing the change in output.

Defensive Expenditure: This approach takes the cues from what people are observed to spend to protect themselves against a potential or an actual decline in their environmental quality. People buy goods and services, which help them to preserve the environment. These goods may be regarded as substitutes for environmental quality.

Averting cost: The approach of averting costs is very similar to the technique of defensive expenditure as mentioned above. Costs are valued, which are necessary to avoid negative externalities. One tries to estimate the costs necessary to avert the damage before it can occur. In other words, the costs necessary to install a filter to clean the emissions of a factory are used to determine the costs of the effects of the emissions. In reality there is a number of possibilities to calculate the averting costs (e. g. using only investment costs, investment costs combined with external costs or the costs required for meeting the regulations) . One possibility is to estimate averting costs as revealed in the costs of meeting regulations and standards (control costs). These costs can be derived from operating and construction costs, which are necessary achieving a given standard.

Replacement cost: The replacement cost approach is often used as an estimate of the cost of pollution. This approach focuses on potential damage costs as measured by ex ante engineering or accounting estimates of the costs of replacement or restoration. Damage costs will arise if externalities cannot be prohibited at the source or it is not possible to adapt to the consequences. They indicate the society's loss of wellbeing. Damage costs are perceived as higher than averting costs.

Relocation cost: Similar to the replacement cost approach, the relocation cost approach uses estimated costs of a forced relocation of a natural or physical asset due to environmental damage (e.g. irrigation facilities, domestic water supply...).

Dose-response: Many environmental impacts, such as air and water pollution, have repercussions for human health. Valuing the cost of pollution-related morbidity (or sickness) requires information on the underlying damage function (usually some form of a dose-response relationship) which relates the level of component pollution (exposure) to the degree of health effect. The costs of an increase in morbidity (sickness) due to increased pollution levels can then be estimated using information on various costs associated with the increase: any loss of earnings resulting from illness, medical costs such as for doctors, hospital visits or stays, medication, and any other related expenses.

Hedonic analysis: We know that environmental quality affects the price people are willing to pay for certain goods or services. Ocean front hotels, for example, charge different rates depending on the view (rooms with ocean views cost more than the same size room with a "garden" view). Hedonic models have been widely used to examine the contribution of different attributes to prices for housing and to wage levels, including the contribution of environmental quality.

Travel cost: The travel cost (TC) method is an example of a technique that attempts to deduce value from observed behavior. It uses information on visitors' total expenditure to visit a site to derive their demand curve for the site's services. The technique assumes that changes in total travel costs are equivalent to changes in admission fees. From this demand curve, the total benefit visitors obtain can be calculated. In some cases it is possible to do both a CV and a Travel Cost analysis for the same valuation question. This allows the analyst to "cross check" the two estimates and get an idea of the robustness of the results.

Benefits transfer: Benefits transfer is not a methodology per se, but rather refers to the use of estimates obtained (by whatever method) in one context to estimate values in a different context. For example, an estimate of the benefit obtained by tourists viewing wildlife in one park might be used to estimate the benefit obtained from viewing wildlife in a different park. This approach also has considerable risks. For many reasons, estimates derived in one situation can be inappropriate in another (The World Bank, 1998).

4.5 Accounting

Counting wealth is a core issue of economics. However, not only monetary assets, but in particular the values of natural capital (which is in fact the basis of societal welfare) have to be measured.

Depending on the intended use of the data, there are different possible approaches to accounting for natural and environmental resources. Therefore, governments and decision-makers have to choose from the variety of schools and areas of investigation according to their national economic and environmental goals and interests.

Production and Income accounts. A complete set of production accounts helps to identify relationships among industry, households, government, and natural resources of emissions or residuals, as well as the non-marketed current account input. The set includes resource use, production of residuals, flows of residuals from abroad, final uses of residuals, identifying effects on final consumption, and contributions to capital stock as well as the price of the effects.

Accounting for capital assets. Information on general trends in resource using, magnitudes of different assets, and the sustainable economic growth is based on data about volumes and values of the nation's natural assets. Besides, accounting can show if the economy is generating environmental burdens or tangible assets, human and technological capital that can substitute the negative impacts of depletion of natural resources. Statistics about resources will include not only "made assets" (houses, computers, etc.), but "renewable resources" (timber, fertility of land, etc.) and "non-renewable resources" (oil, mineral resources, etc.).

Main statistical products are:

- Natural resource accounts
- Resource and pollutant flow accounts
- Environmental expenditure accounts
- Integrated economic and environmental accounts
- Adjusted national aggregate (shadow prices for environmental damages and resource depletion).

Policy decisions. Accounting capital assets and production and income accounts are analytical tools. Since analysis itself cannot change any situation, it is important to use the information obtained. Policy-decisions are set due to these results.

4.5.1 Accounting for Mineral Resources

To achieve sustainable development, it is necessary to know the relative scarcity of resources. However, appropriate methods for accounting mineral resources as a form of capital and for identifying over-exploitation of mineral resources are missing. Sound policy decisions in areas relating to productivity and budgeting depend on reliable data about the stocks. Obviously, there are methodological problems. According to the Bureau of Economic Analysis (BEA, 1994), three main differences between accounting of natural assets and man made capital are evident:

1. No entry for additions to the stock of natural resources parallel to the entry for additions to the stock of structures and equipment.
2. No entry for the contribution of natural resources to current production as measured by gross domestic product (GDP), parallel to the entries that capture the value added of structures and equipment.
3. No entry for the using up of the stock of natural resources parallel to the entry for the depreciation of structures and equipment used to arrive at net domestic product (NDP) — which is used by some as a shorthand measure of sustainable product.

BEA (2000) has developed a method to compensate the deficiencies noted above.

4.5.2 Accounting for Ecosystem Services

Innovative concepts to measure general welfare which includes environmental, social and economic aspects are listed in the following sub-chapters.

4.5.2.1 Index of Sustainable Economic Welfare

The Index of Sustainable Economic Welfare (ISEW) was originally pioneered for the United States (Daly and Cobb, 1989) and further developed in the UK (Jackson et al., 1997). The index includes the GNP and adjusts the general measurement for

- inequalities in the distribution of incomes using non-monetarised contributions to welfare from services provided by household labor;
- certain defensive expenditures against pollution;
- changes in the capital base, e.g. the human capital stock;
- and the loss of future ecological services as a result of the depletion of natural resources, the loss of habitats and the accumulation of environmental pollution.

4.5.2.2 Genuine Saving

Genuine savings measures the true rate of savings in an economy after taking into account depletion of natural resources, damage caused by pollution and environmental degradation. "Genuine" savings is derived from the concept of wealth as the foundation of generating well-being. While in standard national accountings the rents on natural resource extraction are integrated, genuine savings makes this explicit by deducting the value of depletion of the underlying resource asset. Deducting pollution damages, including lost welfare in the case of human morbidity and mortality, is appropriate as long as it is assumed that society is aiming to maximize welfare. National wealth takes on a much broader definition and is embodied in natural capital; human resources that include education, raw labor, and social capital; and produced assets (machinery, equipment, buildings, and urban land). The results show that human resources play a predominant role, thus lending support to investments in education and health.

The “genuine saving” considers educational expenditure (expenditures on books, teachers' salaries, and so on), net foreign borrowing, net official transfers, and depreciation of produced assets. But, the important innovation is to value resource depletion and pollution damage. Negative genuine saving rates imply that total wealth is in decline; policies leading to persistently negative genuine savings are policies for non-sustainability

4.6 Welfare-Cost benefit analysis

“Welfare” cost-benefit analysis (W-CBA) represents an excellent tool to provide an objective basis for decision making in environmental policy. As Richard D. Morgenstern, a former leading official of the EPA in Washington DC, once stated: „Economic analysis may be the worst approach to environmental policymaking except for all the others that have been tried.“ Welfare Cost-Benefit Analysis is now the most common method of appraisal of projects and policy, which tries to weigh up gains and losses, advantages and disadvantages.

CBA is used to find an answer to the following two central questions:

- Is it reasonable from the economic point of view to carry out government projects at the expense of the revocation of financial resources from the private sector?
- Which government intentions or projects should be selected and realized from a number of potential alternatives?

CBA tries to determine and quantify the total advantages and disadvantages of a certain project in terms of a common monetary unit. The main question is whether costs of carrying out the project exceed the benefits, which result from the realization of a certain project. CBA should make implicit evaluations comparable by means of economics. Cost-Benefit Analysis in terms of financial cost is a well known method for the evaluation of private and public projects.

For public matters such calculations can be extended to include non-financial aspects. If the relevant externalities (ecological or social) are included in monetary values the resulting cost-benefit balance expresses the loss or gain of welfare of the scenario examined. A comprehensive cost-benefit balance of a given measure includes all important economic and environmental effects in monetary values. Social aspects should be included, too. Effects that cannot be expressed in money value are at least described adequately with respect to their relevance.

The Welfare-CBA developed by two Austrian institutions, GUA (Society for Comprehensive Analyses) and the Institute of Public Finance and Infrastructure Policy at the Vienna University of Technology represents a coherent methodology which can purposefully be applied to various problems in practice. The method considers economic, ecological and social aspects. The final result of a Welfare-CBA provides the comparison of different scenarios. The scenario with the best cost-benefit balance yields the highest gain in welfare and its realization is therefore recommended.

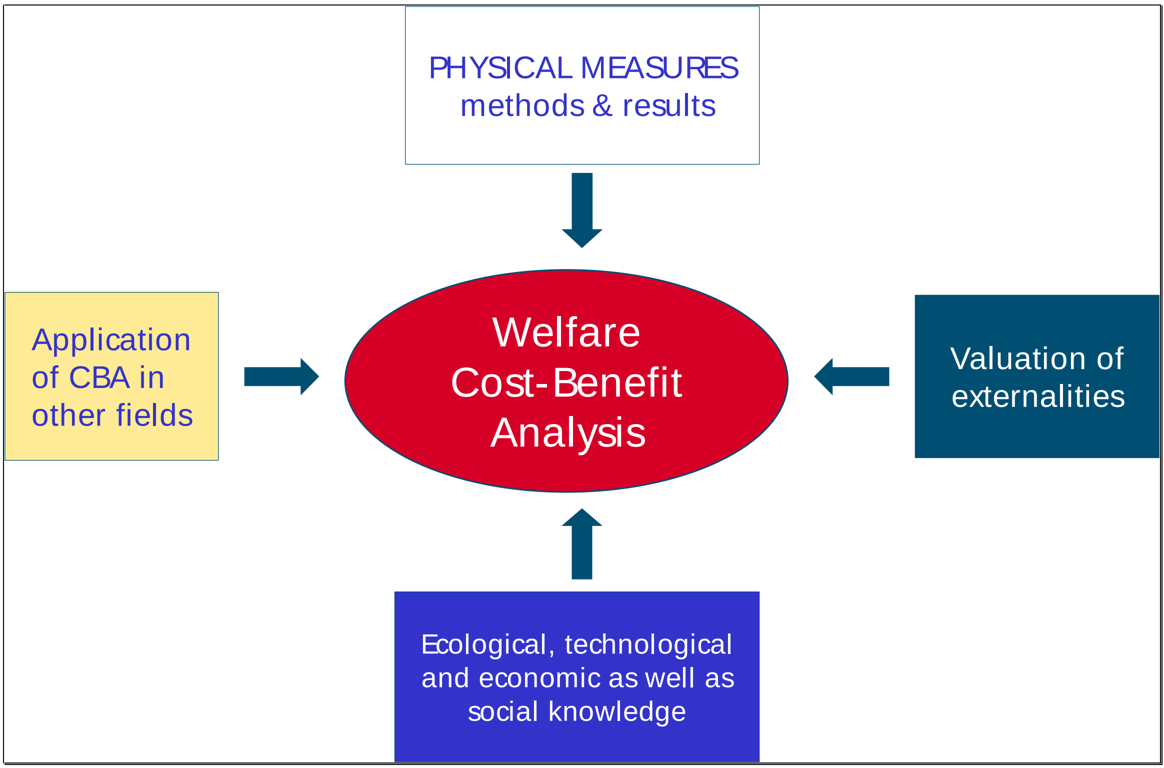

Figure 3: Integration of other concepts into the method of Welfare Cost-Benefit Analysis.

The Welfare Cost-Benefit Analysis is a tool which integrates other methods used in the field of resource management (see Figure 3). The W-CBA combines their different results and calculates a final assessment. Welfare CBA yields clear and comprehensive results for complex systems analyzed. Those results give the opportunity for consensus between all stakeholders involved. Thus the Welfare Cost-Benefit Balance can really be used as a consensual measure for the political and ethical quality of human activities.

Sustainable Development comprises the three pillars economy, ecology and social aspects. Although there is still some scientific work to be done regarding the valuation of resources it is a declared objective to include resource management into Sustainable Development (see chapter 2 and 5). This scope is totally congruent with the comprehensive view of Welfare Cost Benefit Analysis. Thus Welfare Cost Benefit Analysis is the perfect method to bring Sustainable Development to life.

5 The Need for New Concepts

To repeat, concepts in the wide field of resource management cover a broad field of fundamental approaches. Due to different schools and even contradicting results, there is no fully consistent concept developed in this field. Both, economic principles and alternative approaches offer well-developed ideas and instruments. Despite of the differences all their interpretations of the current resource extraction and consumption rate is clear. Rees (1996) states that “the aggregate human load already exceeds, and is steadily eroding, the very carrying capacity upon which the continued human existence depends. Ultimately this poses the threat of unpredictable ecosystems restructuring (e.g., erratic climate change) leading to resource shortages, increased local strife, and the heightened threat of ecologically induced geopolitical instability.” However, for policy-making the main aspects have to be identified and a common basis elaborated.

The objective for the need of policy decisions in resource management is well defined: Since the Earth Summit 1992 there is no doubt environmental problems need to be addressed. Resource consumption and the threat of depletion of natural resources are one of the major issues. Chapter 4 of the Agenda 21 gives a detail view of the United Nations on changing unsustainable patterns of production and consumption and the development of national policies and strategies to encourage changes in unsustainable consumption patterns. They have to address the cross-linking of the three pillars economy, ecology and society ("retinitaet"). Research is necessary to understand the relationship between production and consumption, environment, technological adaptation and innovation, economic growth and development, and demographic factors: How can economies grow and prosper while reducing the use of energy and material and the production of harmful material? Which patterns of consumption can the Earth support in the long term? Moreover, the Agenda 21 demands basic measurements in the field of resource management:

- Greater efficiency in the use of energy and resources
- Encouraging the environmentally sound and sustainable use of renewable natural resources
- Minimizing the generation of wastes
- Need for new concepts of wealth and prosperity which allow higher standards of living through changed lifestyles and are less dependent on the Earth's finite resources and more in harmony with the Earth's carrying capacity
- Environmentally sound pricing that makes clear to producers and consumers the environmental costs of the consumption of natural resources and the generation of wastes

Resource management needs special attention in the near future. It is a key-problem on the way towards sustainability.

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7 ANNEX

In the following sub-chapters technical description of methods listed in chapter 4 are given. It should help to understand the underlying assumptions of the theories used in resource management.

7.1 Strategy

7.1.1 Eco-efficiency: WBCSD approach

The term "Eco-efficiency" describes business activities that create economic value while reducing the ecological impact and the consumption of resources (WBCSD, 1999).

The World Business Council on Sustainable Development (WBSCD) has developed a broader concept of eco-efficiency, where "Eco" combines a range of economic and ecological values. The WBSCD Eco-efficiency includes a range of performance criteria for innovative companies which are inter alia reducing material and energy intensity of goods and services, reducing toxic dispersion, enhancing recycling of material or increasing the use of renewable resources.

Eco-efficiency criteria of the World Business Council for Sustainable Development:

1. minimize the material intensity of goods and services;
2. minimize the energy intensity of goods and services;
3. minimize toxic dispersion;
4. enhance material recyclability;
5. maximize the use of renewable resources;
6. extend product durability;
7. increase the service intensity of goods and services.

The WBCSD's working group 'Eco-efficiency metrics & reporting' recommends the use of the following ratio as a general equation to measure and report Eco-efficiency:

Eco-efficiency = value provided/ environmental burden [value unit/burden unit]

7.2 Physical Measurements

7.2.1 MIPS & Rucksacks

The concept of "material input" (MI) is a conceptually radical way of simplifying the problem of material-resource consumption (GUA, IFIP, 1999).

The displacement and the removal of material as well as the flow of material back to environment cause changes of the natural system. The concept reflects the idea that the sum of problems associated with material consumption (physical disturbance, pollution through dissipation, waste disposal and so on) can be roughly related to the total amount of material moved in the course of economic activity. If this amount can be reduced, then so will the overall impact of material consumption. Material input per unit service MIPS can be seen as a basic measure for the impacts associated. The total amount of material used 'i' (M_i), derived from Life-Cycle-Analysis (LCA) including displaced and used material to produce energy, multiplied by its specific material intensity (MIM_i) describes the total material input (MI) in weight units (Schmidt-Bleek, 1994).

$$\sum (M_i * MIM_i) = MI = MIPS * S \qquad \text{[weight units]}$$

The total material input is in other words the material intensity per service unit (MIPS) multiplied by the service unit (S). The ecological rucksack of a product is defined as its MI minus its own weight.

The procedure of MIPS-calculation

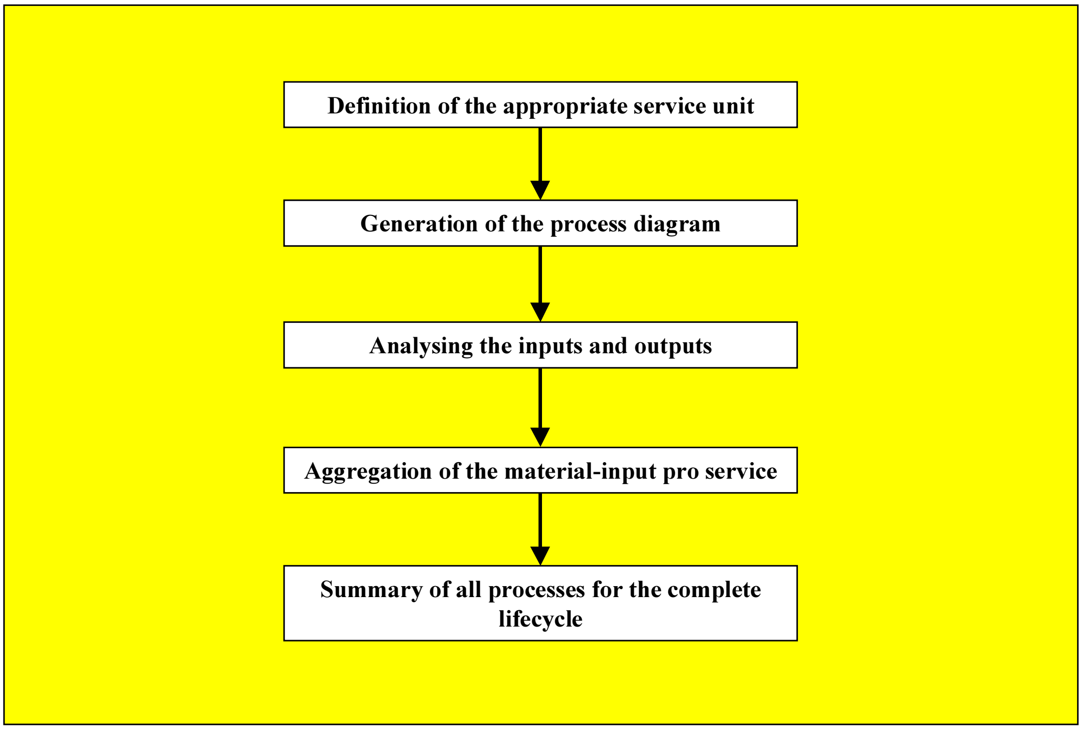

Figure 7.1: Procedure of the MIPS-calculation.

Procedure of MIPS-Calculation (see Figure 7.1):

- At the beginning of the calculation the appropriate service unit as standard for comparison has to be defined (e. g. "tons of moved nature" per service unit).
- Next stage is the generation of a process diagram for the complete lifecycle, separated for each process in order. The material needed for the service are listed. It is also necessary to generate a diagram for all the transports (including all inputs and outputs). In some cases this stage can cause difficulties, because the complete lifecycle of the certain service has to be respected, which makes assumptions necessary.
- Third stage is the survey. For each process unit a survey is made. Inputs are analyzed in five categories: biotic raw material, abiotic raw material, soil movement, water and air. Outputs include all products, by-products and all emissions. Beyond that the data source

with detailed spatial and temporal specifications for each form of energy and each intermediate product should be listed.

- Next stage is the calculation of the material-input per service unit by aggregating the material inputs of a process in each category (e. g. 3 tons of biotic raw material, 2 tons of abiotic raw material, 45 tons of water and so on).
- Last stage is the summary of all processes over the complete lifecycle. The data of the different alternatives is now comparable per process unit or per life period (i. e. production, use or disposal) or between different alternatives.

7.2.2 Ecological footprint

The area of productive land, that is needed to sustain a defined population indefinitely, wherever on Earth that land is located, can be calculated. Since many forms of natural income (resource and service flows) are produced by terrestrial ecosystems and associated water bodies, it is possible to estimate the area of land/water required to produce sustainably the quantity of any resource or ecological service used by a defined population at a given level of technology. The sum of such calculations for all significant categories of consumption would gives a conservative area-based estimate of the natural capital requirements for that population (Wackernagel, 1997).

The per capita land area appropriated (aa) for the production of each major consumption item 'i' is estimated by dividing average annual consumption of that item ['c,' in kg/capita] by its average annual productivity or yield ['p,' in kg/ha] per hectare:

$$aa_i = \frac{c_i}{p_i} \qquad \text{[ha/capita]}$$

The total ecological footprint ('ef') per capita is calculated by summing the individual areas calculated:

$$ef = \sum_{i=1}^{i=n} aa_i \qquad \text{[ha/capita]}$$

Thus, the ecological footprint (EF_p) of a study population is the per capita footprint multiplied by the total population size (N):

$$EF_p = N(ef) \qquad \text{[ha/population]}$$

7.2.3 Mass flows - Life cycle approach

Based on a life cycle approach (all effects in a cradle-to-grave analysis), the method is used to gain information on all toxicological (and to some extent ecological) relevant flows caused by a process. The impacts of the flows on the environment or health are evaluated and valued according to scientific reliable criteria. Therefore, mass and energy flows include the whole life cycle from exploitation of raw material, production, transportation, and generation of waste (Bundesamt für Umweltschutz (Ed.), 1984).

The decisive criteria of the LCA-approach to evaluate the flows are “critical volumes” for the Eco-compartments of air, water, and (top) soil according to the following formula.

$$V_c = \sum_i \frac{m_i}{L_i} \qquad [m^3, dm^3 \text{ or kg}]$$

V_c= critical volume, index c for the compartment, m_i= mass flow

L_i= critical load (limiting values, geologic references, etc.)

The relationship of mass flow to critical volume creates artificial scarcity of the item analyzed. However, to base the limitation on political or societal preferences (which can strongly vary or be influenced by various factors, e.g. personal preferences of decision-makers) is from an ecological point of view at least to discuss (GUA, IFIP, 1999).

The method can be varied in order to aggregate the critical volumes on the base of area (1000 m^3 air + 1000 dm^3 water + 1000 kg soil per square meter). Therefore, the critical volume can be standardized, and possible shifts of burdens between the compartment are possible.

Eco-factors are another approach to standardize the critical volume method. Based on different functions (logarithmic, parabolic, linear, Müller-Wenk function) the graph of the critical load until the maximal capacity of an eco-compartment is calculated.

7.2.4 Waste potential entropy

The entropic load indicates ecological deficits. The waste potential entropy (WPE) is based on three basic ideas (Krotschek, 1997):

(1) All resource flows and all economic goods and services can be characterized as stocks of flows of "useful" embodied information,

(2) The economy is an information processor, in the sense that large quantities of low grade "physical" information are converted, by intention, into smaller quantities of higher grade "morphological" and "symbolic" information,

(3) The most general pollutant is the physical information in the waste (which is lost, e.g. by dissipation).

Production means the conversion of low information-content raw material into high information-content goods and services. Generation of waste, emissions and pollutants is usually the opposite process, the conversion of high information content goods into low information-content material. However, the state of the pollutants (or waste, emissions) is still likely to be different to the state of the environment. This difference can be used as an indicator for the potential of the emissions to cause negative impacts on the environment. Therefore, the emission of material fluxes to the environment is more dangerous, the larger the difference is between the state of pollutants and the chemical equilibrium of the local environment.

Π-Potential as general measurement is defined as the stock of physical information as the difference between the actual entropy (o) of a system (s) and its final entropy in equilibrium with its local environment (e):

$$\Pi = (S_s + S_e)_o - (S_s + S_e)_e \qquad [J/(kg*K)]$$

S= entropy

The maximum amount of work that is done by or on a subsystem that is internally in the state of equilibrium is calculated by the Π-Potential and gives the distance of the subsystem to equilibrium. The method uses the difference of the Gibbs potential to a steady equilibrium as an indicator for the potential pressure on environment (Ayres, Martinas, 1995).

The entropy is derived by simplification from thermodynamics. The WPE measures the pressure exerted by a mass flow in relation to the quality of the flow and the standardized environment. This theoretical basis allows for a proven and tested method of calculation. Due to the basic guilty of thermodynamic laws, all processes are comparable and can rationally be discussed. The disadvantage of the method is that the ecosphere is not in (chemical) equilibrium at all and that there is a lack of reference values because the three eco-compartments are not in equilibrium, too. In addition, it does not reflect the flows, reactions and interactions within the system and effects like accumulation, catalytic processes or overloading natural cycles.

7.2.5 Sustainable process index

The SPI is based on the assumption that in a sustainable economy the only real input that can be utilized over the long-term is solar exergy, and that its utilization per se is bound to the surface (of planet earth). Furthermore, area is a limited resource in a sustainable economy because the surface is finite. But area is not only seen as a recipient for solar radiation. Life in general is dependent on solar energy and the quality of environmental compartments (most notably top soil, water and air) that are influenced by these flows from and to the surface. So any given area of the planet's surface is not only defined by the amount of solar exergy received, but also by the quality of the environmental compartments attached. By taking into account the dual function of area as a recipient of solar energy and as a sustaining basis for all ecosystems, SPI can measure and relate ecological impact of a process with respect to the quantity and quality of energy and mass flows it induces. Thus, products needing more area for the same service are less competitive if area (the base of global generation and degeneration potential) is limited (Krotschek, 1997).

The calculation of SPI starts with the computation of the total area A_{tot} assigned to embed a process into the ecosphere.

$$A_{tot} = A_R + A_E + A_I + A_S + A_P \qquad [m^2]$$

Where A_R (all areas in m^2) is the area requirement to produce raw material, A_E is the area necessary to provide process energy, A_I is the area to provide the installations for the process, A_S is the area required for the staff and A_P is the area to accommodate products and by-products. These areas will be computed for one year of operation. Within this year a number S_{tot} (in unit/yr.) of unit-services (e.g. passenger kilometers, heat, electricity) will be supplied by the process in question. The area a_{tot} is called the specific service area.

$$a_{tot} = \frac{A_{tot}}{S_{tot}} \qquad [m^2 \text{ yr unit-1}]$$

This specific area is already a possible comparative measure of sustainability. In order to make this measure more striking it is divided by the area per inhabitant (ain in m^2yr/cap; ‘cap’ is used as unit for one person) in the region being relevant to the process. E.g., this area is the theoretical (mean) available area for the supply of all services for each person.

$$SPI = \frac{a_{tot}}{a_{in}} \qquad [\text{cap/unit}]$$

7.3 Resource economics

7.3.1 Pricing of exhaustible resources

The price of non-renewable resources is equal to the marginal cost (of the extraction) plus opportunity cost.

Price = Marginal cost (of the extraction) + opportunity cost

Compared to renewable resources, at the same point of time less amount is provided for a higher price.

7.3.1.1.1 Ricardo's differential rent

David Ricardo (1817) argued that a farmer achieves a monetary benefit , called differential rent, if his field is of higher quality than of other farmers, who can cover with the market price the marginal cost. Following Ricardo's theory, owners of non-renewable resources with higher quality (or cheaper exploitable resources) achieve market prices higher than the marginal cost despite of perfect conditions for market competition (Wacker, Blank, 1999).

7.3.1.1.2 "r-percent-rule" of Gray

L. Gray (1914) described that the price per unit of an exhaustible environmental resource has to include in addition to the marginal cost a rent which indicates the opportunity cost. The rent reflects the loss of future benefits if the resource is extracted and used today. Gray solves the case as a dynamic optimization problem to determine the time of exploitation (T) and the extraction amount (R_t with t = 0,1,...,T) for the maximization of the present value of the profit during the total extraction time (Wacker, Blank, 1999).

$$r = \frac{[p - c(R_{t+1})] - [p - c(R_t)]}{[p - c(R_t)]}$$

r...market rate of interest (r); p...marginal proceeds; c (R_t)...marginal cost

Gray's model assumes that the real price of the resource unit and the market rate of interest (r) are for the total exploitation time exogenous and constant, that the stock is at the time t=0 known, homogeneous and fixed, and that the marginal cost are directly dependent on the extraction amount. The resource will not be extracted if the future profit exceeds the present value plus the rent (Wacker, Blank, 1999).

The opportunity cost of the present resource sale reflect the cost of lost future utilization and the scarcity of the resource. The quantity extracted is in the first year largest and declines afterwards. The marginal cost decrease with the amount and due to a constant market price the economic rent (called with different termini: scarcity rent, royalty, opportunity cost, Hotelling rent,..) is increasing.

7.3.1.1.3 Hotelling's rule

While Gray's model is based on fixed and unchangeable resource prices, Harold Hotelling (1931) stated that the conciliation of demand and supply assesses the scarcity rent. Hotelling presumed inter alia that perfect competition prevents a market player from influencing the market price and that all stocks are known. Besides, the cost and prices of the resource and the exploitation are well-known at every point of time. Then, it can be assumed that the price course is defined by a walrasian auctioneer, who perfectly balances the price according to demand and supply. Hotelling derived that the dynamically efficient depletion of a non-renewable, non-recyclable natural resource occurs when the resource is allocated so that the present discounted value of marginal Hotelling Rents is equalized over time.

$$p_t = c + \lambda_0 * e^{r*t}$$

r...market rate of interest; p_t...price; c...marginal cost,; t...time, λ_0...opportunity cost at time 0

Marginal Hotelling Rent is created by future demand for the natural resource, and is defined as price minus marginal cost. The optimal resource price path starts with a balanced first price (according to arbitrage calculation) and is calculated with the principle of Pontryagin. The rule for dynamic efficiency, sometimes called Hotelling's Rule, requires that Hotelling rent for the last unit sold in year 0 must equal the present discounted value for the last unit sold in year 1, and all other years. When this condition holds, the present discounted value of total surplus over the various years will be maximized. Then, the resource market is dynamically efficient. Hotelling's models also has implications for the time path of extraction: with a stationary demand curve, extraction decreases as the resource price increases over time (Wacker, Blank, 1999). However, theoretically the non-renewable resource stock will never be depleted if it is vital for the economy. Tahvonen (2000) states that the optimal consumption rate can be defined in respect to the remaining reserves.

7.3.2 Markets

7.3.2.1.1 Perfect competition

Two possibilities to describe market competition are given: According to a linear market-demand function, maximizing surplus assumes that all the stock has to be totally exploited at the prohibitive price. Contrarily, an iso-elastic function prevents that the resource is exhausted in a non-infinitive range. The Herfindahl-Problem approach takes into account that optimal exploitation has to consider different extraction costs. The resource owner will not exploit his resource stock if a cheaper resource is available. The reserve with the higher marginal cost for extraction will be extracted when the price path reaches the marginal cost plus the Hotelling rent of the more expensive stock. In an economic sense, the "cheaper" stock has to be depleted at this time (Wacker, Blank, 1999).

7.3.2.1.2 Imperfect competition

In the case of an iso-elastic demand, the price of a monopolistic player will not differ from the perfect competition market. Assuming a linear function, the monopolist will change price and extraction path. According to Solow (1974), cited in Wacker, Blank (1999), "the monopolist is the conservationist's best friend", because the resource will be exploited slower. From the point of view of the economy as a whole, it is inefficient because the classical optimal welfare path has to be the optimal competition path (Wacker, Blank, 1999).

7.3.3 Change of parameters

7.3.3.1.1 Change of market rate of interest

Since the opportunity cost of an exhaustible environmental resource increases with the market rate of interest, an increase of the market rate of interest causes a steeper price path. Considering that the resource stock has to be fully exploited at the prohibitive price, the first price will be lower if the market rate of interest is higher. The extraction time will be shorter (Wacker, Blank, 1999).

7.3.3.1.2 Change of extraction cost

In case of sharp falling extraction cost the starting price for the resource unit will be lower, but the price path steeper. The prohibitive price will be reached earlier. Considering a discrete fall of the marginal cost, the reduction effect will decrease the price at the beginning. But with increasing time the dominantly influencing opportunity cost will higher the price due to the dependency on the market rate of interest (Wacker, Blank, 1999).

7.3.3.1.3 Change of reserves

If new deposits are discovered, the total reserves will be larger than originally assumed. Therefore, the optimal price path will be recalculated and will restart at a lower level. The opportunity cost will be lower, but still increasing according to Hotelling's rule. The prohibitive price will be reached later. A continuos increase of reserves due to new discoveries leads to a sequence of revised price paths. The total price path tendency may even decline despite of the increase due to Hotelling's rule.

7.3.3.1.4 Change of backstop technology

According to William D. Nordhaus (1973), a backstop technology produces a perfect resource substitute on infinitive scale with constant marginal cost. Assuming perfect competition, the marginal cost of the resource substitute are the upper price limit for the exhaustible environmental resource. The original price path will be recalculated: The deposit has to be used up at the point when the price reaches the marginal cost of substitute. Therefore, the starting price revised is lower than the original price, the demand will be higher and the time of depletion will be reached earlier. To maximize surplus the resource stock has to be completely exploited when the price equals the marginal cost of the substitute. Another new backstop technology repeats the modification of the price path.

7.3.3.1.5 Change of taxes on the resources

There are two reasons for taxes on exhaustible resources in the competition market. First, the state wants to change the fact that usually only the resource owner benefits from the scarcity rent. Taxes only on the rent cause a redistribution without changing the extraction or price path (assumed that the supplier does not change his own optimization behavior). The tax can be levied as a fixed rate of the profit. Second, to counterpart a low discount rate of the economy as a whole taxes on the resource lead to changed (reduced) resource extraction. Depending on the measurement to be set, two types of taxes can be distinguished:

Taxes based on the quantities have an effect similar to an increase of the marginal cost of the extraction. Thus, the market price is equal to the extraction cost plus the tax rate and the opportunity cost. Since the opportunity cost have to increase with the market rate of interest, the demand curve is flatter. Consequently, quantity taxes make the time of extraction longer. Ad valorem tax is a surcharge on the total resource price. The price of the resource supplier is still calculated as marginal cost plus the opportunity cost, the latter is still increasing according to Hotelling's rule. Since the ad valorem tax affects the supplier price, the market price is increasing with a rate lower than the market rate of interest. Therefore, the present value of the tax is decreasing in the course of time. To maximize surplus the extraction will partly shift to a later point of time except the case that the supplier price is increasing with the market rate of interest. The latter has the same effect as the tax on the rent. The ad valorem tax cause an alteration of the supply-demand-function. As the opportunity cost have to be lower, the market price will be lower and the prohibitive price will be reached later (Wacker, Blank, 1999).

7.3.4 Trade of non-renewable resources

7.3.4.1.1 National economy's export of exhaustible resources

Because of geographical conditions environmental resource deposits are unevenly distributed among the regions of earth. Since some of the states have rich resource deposits, trade of resources (raw material) is a very important part of world wide trade. With the export of resources national economies obtain the financial capital to import consumer or capital goods (Wacker, Blank, 1999).

National economies behave like suppliers in a perfect competition trying to maximize surplus. Even in the case of a steady linear resource demand, the environmental resource of an economy will not be depleted due to market laws: the price of the resource will asymptotically strive for the prohibitive price. Considering that the profit of the resource trade can be either used for import of consumer goods or for re-investment in foreign economies, the resource price and extraction decisions are fully independent of the consumers' decisions ("Fisher separation theorem"). The investment of capital in foreign assets acts as an incentive to export a larger part of the resource deposit earlier. In the course of time, the amount exported will be reduced and stopped after infinitive time. However, consuming can be still continued after the depletion of the resource due to the interest proceeds. The quantity consumed will also tend to zero at a given positive discounting rate.

7.3.4.1.2 National economy's import of exhaustible resources

In general, states levy import taxes due to two reasons: First, the state needs income to offer public goods. Second, taxes on the import of resource are Pigou-taxes to internalize extern effects and provide efficient allocation. For non-renewable resources there is another reason: The market price of a resource unit is equal to the extraction cost plus the scarcity rent. A tax on market prices of imported exhaustible resources means that the state benefits from the scarcity rent. However, for a "small" country taxes on the import of exhaustible resources will not be the "optimal" welfare measurement if the benefit for the consumers should be maximized. In other cases, importers optimize their income in respect to the taxes and will siphon off the scarcity rent at the best possible rate.

7.3.5 Production with environmental exhaustible resources

Beside of capital, labor and knowledge, resources are the only factor in production processes of national welfare economies. The main questions are to optimize the use of the production factors in the course of time and to maintain the production in the long run.

7.3.5.1.1 Characterization of efficient paths

As solutions of inter-temporal allocation problems several possible efficient paths can be calculated among the possible paths within reach. Therefore, the efficient paths have to be filtered from the reachable paths: A path, which leaves the resources in the deposit, is within reach, but not efficient. There are two basic criteria for efficiency:

- Static efficiency requires full employment of the capital and not wasting of the environmental resource.
- Inter-temporal efficiency requires the fulfillment of the "Pareto-Criteria": Consume of one period may not be increased, if the consume of another period is reduced. Two conditions are given: The resource has to be depleted over the range of planning. At the efficient path the marginal productivity of the capital is equal to the growth rate of the marginal productivity of the environmental resource (Hotelling's rule). In other words, the increasing capital use can substitute the environmental resource use.

Marginal productivity of the resource is optimized when it equals the price of the resource, which increases in the course of time. The price of the resource will steadily grow, but the growth rate will decline (Wacker, Blank, 1999).

7.3.5.1.2 Characterization of optimal paths

The optimal path of the "utilitarianism" maximizes the benefit from extracting resources and invested capital considering the market rate of interest. The benefit will be determined by the point of time of use of the exhaustible resource and by capital invested.

The Ramsey-rule gives the optimal state for economic models permitting the accumulation of capital as sort of bridge between current and future consume. As long as the marginal productivity is higher than the societal rate of pure time preference, consume will be allocated in future and the growth rate of consume is positive. If the marginal productivity is lower than the societal rate of pure time preference, the consume will be brought forward and the growth rate will be negative.

The rate of pure time preference reflects the assessment of benefits for different periods or generations. In general, society calculates the benefit the lower the later it will be obtained. A unit will be used now if the current benefit missed through investment is lower than the benefit growth discounted in future. In the long term the consume will be tend to be zero. As long as the consume is not zero, the Ramsey rule prefers later generations with the consequence for the current generation to accumulate capital.

The alternative view of the British philosopher John Rawls (1971) is the Max-Min-criteria: Every individual is behind a "veil of ignorance" of his position in society. Regarding inter-temporal problems, it is not known in which period the individuals are living or will be living. Rawls says that the individuals decide for maximization of the minimal position to maintain enduring highest possible consume level. In other words, the maximization of the lowest enduring maintained benefit standard also maximizes societal welfare. The benefit from consume has to be constant for all periods, too.

This is the Rule of Hartwick (1977): investment of the Hotelling scarcity rents from exploitation of the non-renewable resource in man-made capital results in maximum constant consumption over time, given the initial conditions. This is the alternative position which strives for weak sustainability, i.e. keeping total capital intact (Wacker, Blank, 1999).

7.3.5.1.3 Transition to backstop technology

A backstop technology produces a perfect substitute of a resource with constant price. The exhaustible resource price will have as an upper limit the marginal cost of the substitute. Consequently, the environmental resource has to be totally exploited at the time when the upper limit price is reached enabling a higher consume standard and better capital accumulation. According to the Hotelling's rule the environmental resource will be substituted by capital during this period. In the following period of use of the substitute, society needs a high capital stock (Wacker, Blank, 1999).

7.3.6 Recycling of exhaustible resources

7.3.6.1.1 Recycling of environmental resources

Since production processes or consume do not totally convert production (input) factors into goods, by-products (transformed material, non-transformed material, energy) occur as waste, emissions or waste heat. In the economic process not material, but the benefit connected is consumed. However, according to the mass maintenance law, material and energy used are physically not lost. In a closed loop system without net accumulation, the flow of residues has to be equal to the flow of removals from environment. Sooner or later all material will be moved back to the ecological system.

According to the First Thermodynamic Law, material can be recycled. However, due to the Second Thermodynamic Law (Entropy-Law) natural processes are irreversible and increase entropy of the systems. In this case, entropy is a measure of energy that is in the system fixed and not available for carrying out of work. Based on the Entropy-Law, one can state that economic activities without environmental burden are not possible. Every transformation of material to energy decreases the content of environmental resources available, what can be seen in recycling processes as "thin out".

Recycling is an important method in waste treatment issues. It helps to close the circle of material and energy flows and enlarges the quantity of resources available for production processes. The theory of economics of resource management has to adopted and optimal paths für primary and secondary resources have to be developed. New characterizations of resource use in economic processes are necessary:

- The resource is lost after use (present standard assumption).
- Fixed in long-lasting goods the resource is (periodically) repeatedly usable.
- After single use the resource becomes waste and is available after a recovering process.

If resources are fixed in long-lasting consume and investment goods, the demand for primary resources will decline and the optimal paths for consume and resource consumption will change. The derivation of inter-temporal and intergenerational efficiency rules for recycling processes has to solve the following problems (Wacker, Blank, 1999):

- Should waste be accumulated in an unlimited extent in favor of present consume?
- Should waste be disposed of or stored as a potentially secondary resource?

The possibility of recycling changes the utilization path for environmental exhaustible resources. Beside of the negative effects of waste generation, recycling processes and the flow of secondary raw material in an economic process influence the opportunity cost. The utilization cost of waste are made up by the marginal negative benefit of the waste unit plus the reduction rate of the waste stock and the societal rate of pure time preference (in the case waste is a stock capital). Hence, the optimal path of primary raw material utilization, recycling and waste disposal are dependent on model assumptions of utilization functions, production techniques and cost parameters.

7.3.6.1.2 Return of raw material

If recycling is seen as return of raw material in the economic process, the time-variable assessment of environmental resources as a production factor will be of major interest. Society has Society has two basic sources for raw material: extraction of primary resources from nature, and extraction of secondary resources from waste (Wacker, Blank, 1999).

The societal welfare is composed of the consume and the negative effects of the waste stock. If production processes are not considered, the return of raw material will be calculated as a cake-eating problem. From both stocks, waste and environmental assets, the resource is extracted and used. It is assumed that the extraction cost of the resource unit is lower than the cost of recycling (e.g. cost for recovering returnable bottles). If utilization losses are not considered, the recycling model will by calculated as a backstop-model. Basically, the cheaper environmental resource will be used first. However, in the economic assessment one has to consider not only the extraction and recycling costs, but the opportunity cost of the environmental resource. Dependent on the utilization losses after consume, natural breakdown of the waste stock and the extraction and recycling cost, different efficiency rules for the use of raw material can be calculated:

- If transition losses are accepted and minimized by higher work intensity, primary and secondary resources will be simultaneously used.
- If capital goods are not worn out, but scraped, they will be economically of interest as a raw material deposit due to their high specific content of resources.
- If capital goods are worn out, their recycling will not be limited by technical capabilities, but by economic interest. On the other hand, considering capital goods wear in infinite planning range problems occur in the theory of the use of environmental resources. Recycling of non-renewable resources from scraped capital goods does not help against the depletion of resource deposits if the recycling rate is lower than one (imperfect recycling: material is lost in the recycling steps what is called "thin out"). The total usable resource quantity is limited and the long-term breakdown is unavoidable (Theory of Cobb-Douglas).

7.3.7 Recycling and environmental cost

Because recycling is per se not a clean activity, environmental cost have to be considered in the model assumptions. Furthermore, the derivation of cake-eating problems has to include negative effects of waste generation (Wacker, Blank, 1999).

7.3.7.1.1 Environmental cost influence on resource extraction

Derived from a cake-eating problem the influence of environmental burden from resource extraction (no extraction cost) and from recycling (cost for recycling) is a very important factor:

- If the marginal benefit from consume equals the marginal damage from the waste stock including the cost of recycling, the primary resource stock will be fully extracted in the first calculated period and recycled afterwards.
- If it is efficient not to deplete the resource deposit, only a part of the resources will be extracted. The extraction quantity will be the smaller the lower the recycling cost are.
- If damage and extraction cost are very low, the resource will be exploited according to Hotelling's rule (Wacker, Blank, 1999).

7.3.7.1.2 Environmental resource as input factor

Assuming that the exhaustible raw material is the only source of well-being a production and recycling process can be calculated by maximizing the following welfare problem (Herfindahl problem):

$$\max_{C_t, R_t, Z_t} J = \int_0^\infty U(C_t, W_t) * e^{-\delta * t} dt$$

J...welfare benefit, t...time, δ... rate of pure time preference, U...Marginal benefit as a function of consume C_t and waste stock W_t, R_t...Primary resource, Z_t...Secondary resource

It is assumed that the recycling cost include the wastage of environmental resources in the recycling process. The efficient path includes that the in-situ price of the primary resource increases according to Hotelling's rule. Because of the lack of extraction cost, the opportunity cost are equal to the price of the extracted resource. Considering Hotelling's rule in the extraction period, the scrap-price for a waste unit (λ^2_{t+1}) can be calculated in the following ways:

$$\lambda^2_{t+1} = \lambda^2_t * (1 + \delta + \alpha_1) - U_{W_t}$$

- With rate of pure time preference (δ) reflecting the preference for present waste recycling than future waste recycling
- With the natural breakdown rate of waste (α_1) because the waste unit available for recycling decreases.
- Positive discounting effect for present recycling (U_{Wt}) because of a decline of the future environmental burden from the recycled waste unit.

Waste will not be recycled today, if the future scrap price is higher than the present price including the prior stated positive effects. In case of equality, society is indifferent in the choice of inter-temporal recycling decisions.

The opportunity cost of the waste stock measures on the one hand with negative sign the increase of the environmental burden for an additional unit of waste, on the other hand with positive sign the scrap price of an additional unit of waste which can be positively used in recycling processes. For the calculation of the exact opportunity cost λ^2_t, both effects have to be analyzed and compared. However, also in the case of negative opportunity cost recycling will be an optimal solution, if damage effects are very strong. The optimal paths can be calculated according to the following assumptions:

Extraction, if $\frac{\lambda^1_t}{F_R} > \frac{\lambda^2_t}{F_Z - k}$ Unit: $\left[\frac{\Delta benefit / \Delta resource}{\Delta output / \Delta resource}\right]$

Extraction plus recycling, if $\frac{\lambda^1_t}{F_R} = \frac{\lambda^2_t}{F_Z - k}$ Unit: $\left[\frac{\Delta benefit / \Delta resource}{\Delta output / \Delta resource}\right]$

Recycling, if $\frac{\lambda^1_t}{F_R} < \frac{\lambda^2_t}{F_Z - k}$ Unit: $\left[\frac{\Delta benefit / \Delta resource}{\Delta output / \Delta resource}\right]$

$\frac{\lambda^1_t}{F_R}$...marginal change of benefit per consuming good produced with a primary resource unit.

λ_t...scrap-price for a waste unit, k...positive recycling cost, F_Z...marginal benefit of recycling, F_R...marginal benefit of primary resource use

In case of limited resources, society does not suffer from waste, but considers the waste as a raw material deposit. This has major consequences on the opportunity cost: If the resource is not scarce, the damaging effect of the waste stock will predominate and opportunity cost will be negative. The cost will be positive, if the productiveness of waste predominates (Wacker, Blank, 1999).

7.3.8 Neo-classical model

A general neo-classical growth model with resources and pollution is presented by van den Bergh, Hofkes (1997). Van den Bergh, Hofkes (1997) describes a general neo-classical model with environmental considerations. According to modern economic theories the neo-classical model includes the following requirements. The numbers listed refer to the numbers listed below.

(1) A social objective, possibly reflecting welfare of multiple generations over time including environmental stocks (preservation goal) and bequest values (intergenerational equity goal)

(2) A production function, combining man-made and environmental stocks and flows as primary inputs to produce final goods and services.

(3) A dynamic description of the economy, resulting from investment in, and depreciation of man-made capital.

(4)-(6) A dynamic description of the environment, resulting from resource exhaustion (4), natural regeneration (5) and pollution assimilation (6).

(7) The distribution of output, usually restricted to consumption (C) and investment (I); when more activities and capital stocks are distinguished between, this will be reflected by more categories of outlays in this balance equation.

(8) Initial conditions on all cumulative (state) variables.

The mathematics of the formulation of the model is presented:

$$\max_{\{C\}} \int_0^T U[C, N, P]\exp(-rt)dt \quad (1)$$

s.t.:

$Q = F(K,R_S,R_N ,W ,N ,t)$ (2)

$dK/dt = I(t) - \delta K(t-\tau)$ (3)

$dS(t)/dt = -R_S (t)$ (4)

$dN/dt = g(N,R_N) - R_N$ (5)

$dP/dt = W + C(t-\tau) + \delta K(t-\tau) - A(P,W)$ (6)

$C + I = Q$ (7)

$K(0)=K_0, S(0)=S_0 , N(0)=N_0 , P(0)=P_0$ (8)

Where notation has the following interpretation (note that all variables have a time index and are non-negative):

Functions:

- A : rate of natural assimilation of pollution
- F : instantaneous production
- g : rate of natural regeneration
- U : instantaneous utility

Stocks:

- K : man-made productive capital (machines)
- N : renewable resource stock
- S : non-renewable resource stock
- P : pollution stock

Flows:

- C : value of consumption
- I : value of investment
- Q : value of production output
- R_S : physical non-renewable resource extraction, serving as input in production
- R_N : physical renewable resource extraction, serving as input in production
- W : physical waste
- t : time

Parameters:

- K_0 , S_0, N_0 , P_0 are initial stock levels
- δ: depreciation rate of productive capital
- τ: time delay