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Material Flow Analysis and Sustainable Development

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INTRODUCTION

The aim of this paper is to contribute to the discussion about the role of the flow perspective in the analysis of the development of society-environment interactions. With industrialization, the material flows in the world have grown enormously, expanded geographically and become more open and complex. Traditionally, emissions have been strongly linked to earlier steps in material flows (extraction- and raw-materials-intensive industry), but during the last few decades the emissions from industrial point-sources have decreased radically in the Western industrialized world. The result of industrial "clean-up" is a shift towards the latter steps of societal material flows; the relative importance of consumption emissions has increased. As indicated in studies of the Rhine Basin, important prerequisites for this development have been a dynamic economic and institutional development with structural changes and developing environmental awareness and public opinion increasing pressure on legislators, authorities and industry. Despite often radical emission reductions, problems with acidification, autrophication, diffusion of persistent organic chemicals and climate change still persist on a regional and global level. During the last decade, there has been an increasing emphasis on international and global environmental problems, and materials flow perspective has experienced a major breakthrough. Waste minimization, recycling, life-cycle analysis and environmental auditing have become major themes in most European countries and have also started to influence industry. The importance of the consumer and his attitudes and actions and the relationship between trade and environment are often emphasized in this context. Modern challenges for environmental research no longer concern discovery and confirmation of environmental problems, but an improved understanding of society, its change and relations to nature. Among the relationships and contexts that are necessary for environmental analysis of social development, which have so far been hard to grasp are the linkages between different areas of knowledge and sectors, change in society and nature, power relations, and spatial aspects such as geographical context, flows in space and time, and linkages between different scales and management structures.

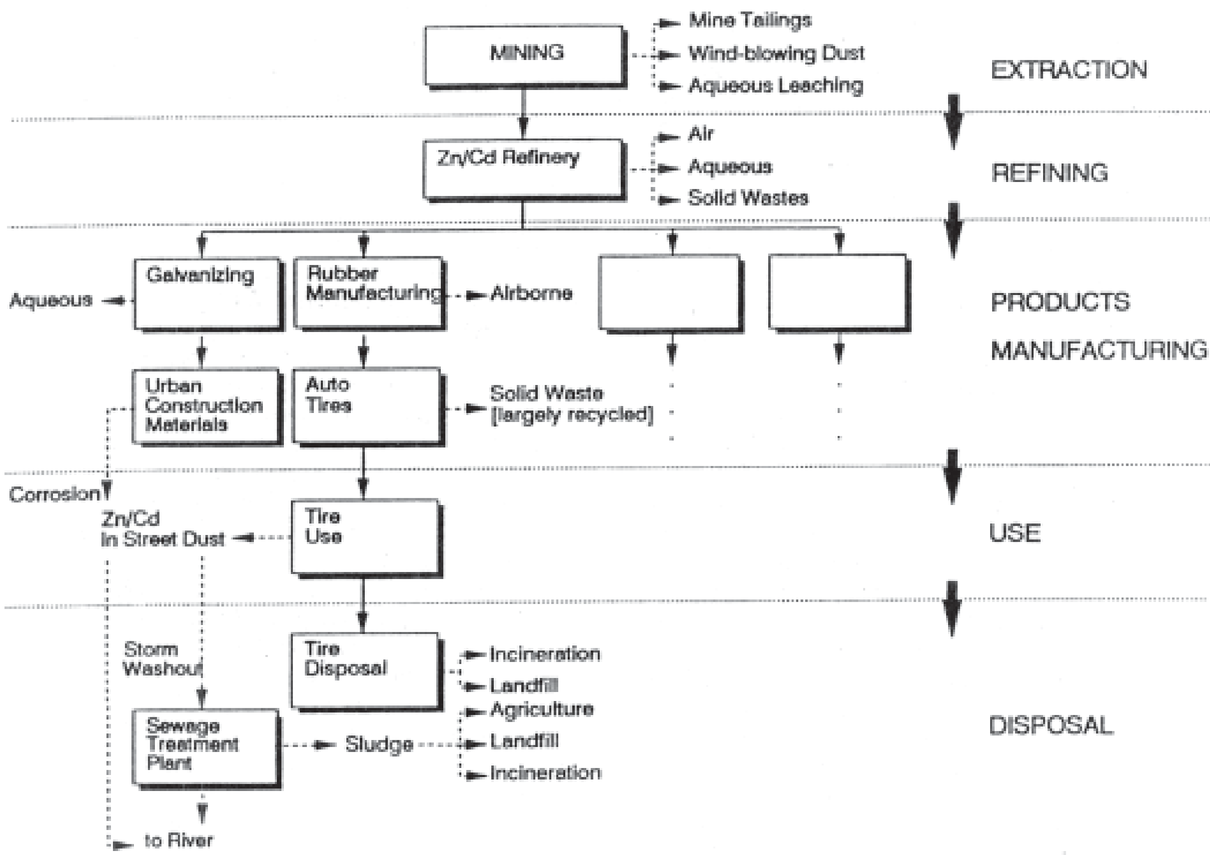
"Industrial Metabolism" studies (*e.g.* Ayres and Simonis, 1994) have been based on a flow perspective and have argued that such a perspective is essential to the search for environmentally sustainable societal development paths and could serve as a basis for integration in environmental research. An evaluation (Anderberg, 1996) of the Rhine Basin Study, conducted at the International Institute for Applied Systems Analysis (IIASA), is used for a more general discussion of the limitations of material flow studies. The Rhine Study is limited in its effort to connect to broad social change related to economic and technological development, and decision making. These limitations stem from the flow perspective and how it has been used, and particularly from the focus on single elements and the delimitation and treatment of the region.

The time-geographical "process landscape," developed by Torsten Hagerstrand (1993), provides an alternative framework for the analysis of flows. It puts emphasis on the analysis of flows in their context in time and space as well as on the constraints of the flows and their institutional context. This may offer guidance for addressing the limitations of material-flow studies to evaluate the social development and to create a basis for analyzing development strategies.

BACKGROUND

Recently, many studies of "industrial metabolism" and "industrial ecology" (*e.g.* Ayres and Simonis, 1994) have sought to improve analysis of the linkages between society and the environment. These research efforts have tried not only to improve analysis of emissions, but also to offer a more concrete framework for analyzing technological change and political strategies in a future perspective. In connection with "industrial metabolism" studies, flow perspective has been presented as an integrative approach that is able to improve study methods, as well as our ability to develop sustainable strategies. The implications of this perspective are: to change and decrease inflows and to improve efficiency and recycling. They have been summarized in the goal of "closing the loops" and have been widely accepted in environmental politics. For example, in Sweden, "flow thinking" has become a fundamental part of environmental policy. The breakthrough of flow perspective is probably due to growing dissatisfaction with conventional strategies for environmental protection; these strategies have not been completely successful in solving environmental problems, such as dealing with the growing "waste mountain" or how to decrease diffuse consumer-related emissions. In addition, the flow model is an excellent tool for illustrating conditions in a clear way and it communicates very well with the natural and ecological sciences.

For most materials, the flow through society consists of five major steps: extraction of raw materials, refining, products manufacturing, use and disposal. These steps are shown in figure 1 with the example of the flows of zinc and cadmium connected to the use of zinc in tires and



galvanized surfaces. Through recycling, loops back to earlier steps can occur. This model is very crude and needs to be adapted to different types of flows, but it can prove useful for structuring the use of materials and different pollution sources. The extraction step can, for example, be mining or oil production as well as agriculture and forestry. The refining and products manufacturing are most often connected to industrial activities and usually consist of several steps. The use occurs in, *e.g.* households, industry or agriculture. The disposal has traditionally been closely connected to the use, but has become more and more centralized in the industrialized world. In all steps, there are risks for (or occur) losses to the environment. Losses from the earlier steps in the flow, namely extraction and refining, can be called production emissions and from the latter steps consumption emissions (Anderberg et al., 1989). The transport needed between different steps in the flows are often relatively forgotten, even if transport emissions can have a significant impact (*e.g.* via emissions from fuel combustion, corrosion of vehicles, loading, discharging, cleaning or accidents).

The aim of this paper is to contribute to the discussion about the role of flow-perspective in linking society and nature in environmental research. Flow perspective is used for an overview of environmental change, particularly in Western industrialized countries, and the roles of economic and institutional development in this context are discussed. The Rhine Basin, which has been the focus for an "industrial metabolism" study at IIASA (International Institute for Applied Systems Analysis), is used as an example. Some major modern challenges for environmental management and research are outlined. Finally, starting off from an evaluation of the Rhine Study (Anderberg, 1996), flow perspective and "industrial metabolism" studies are discussed in relation to these modern challenges.

THE DEVELOPMENT OF SOCIETAL FLOWS

The industrial revolution has brought about dramatic changes of human use of natural resources and impact on the environment. Population growth, urbanization, increased production and consumption, intensification of agriculture and accelerated landscape transformation have radically increased the pressure on the natural environment in all parts of the world. Although the physical changes of the landscape in all parts of the world have been greater than ever, the most important effect of industrial development is probably the gradual change of the biogeochemical environment. The flows of materials have grown enormously with industrialization and modernization of agriculture and forestry. Intensification of agriculture and diffusion of mobile urban lifestyles characterized by high consumption of energy, water and all kinds of goods, have made societal flows much more open with increased losses to the environment. Through the development of transport and trade, societal flows have expanded geographically. The flows have also become more complex with the development and increased use of more composite products, perhaps most important innumerable synthetic products, which are not easily degradable in nature.

Traditionally, there has been a strong relationship among economic development, high population density and environmental damage. The regional pollution load has been directly connected to regional economic specialization (type and quantity of industry and agriculture), population density, consumption level and urban development. The dominating sources in the traditional immision landscape (Lohm et al., 1994) have been connected to the earlier steps in the material flows: mining, oil exploitation and raw-materials intensive industries, e.g. iron and steel, non-ferrous metal refining, pulp and paper, petrochemical and chemical industry, which process large volumes of impure raw-materials using large amounts of energy. Industrial point-source emissions have gradually been complemented by increasing loads from rural and urban areas connected to intensification of agriculture, increasing transport and consumption and development of paved areas and water supply and sewer systems.

The environment has been put under extreme pressure over a long time period in densely populated and early industrialized regions in Europe, North America and Japan. Nowhere have physical and chemical changes (of which several are irreversible) been as important as in these areas.

However, during the last few decades the trend of increasing pollution has been broken in most OECD [Organization for Economic Cooperation and Development] countries. This development is related to important industrial and societal change. Increasing environmental awareness, particularly in the most wealthy countries, has led to radical development of regulations and investment in pollution control by both industry and public authorities. The most polluting industries have stagnated, production has in many cases decreased and efficiency in the use of materials and energy has increased. These trends have often been related to the development of the "post-industrial" society, in material flow terms characterized by trends of decarbonization and dematerialization (Grubler, 1994; Simonis, 1994).

THE RHINE EXAMPLE

The Rhine Basin provides an example of dramatic reduction of many types of pollution as a consequence of such a trend-shift. The radical decrease of heavy metal emissions to the river that occurred in the 1970s and 1980s (Fig. 2) was primarily related to a reduction of industrial point-source emissions (Stigliani and Anderberg, 1994; Stigliani et al., 1993). The development in the Rhine is relatively extreme concerning heavy metals, but there are similarities in several other basins in Northwest Europe and the Northeast of the USA. A common trait is that industrial pollutants have decreased radically, while nutrient loads have only been marginally affected. The result of the industrial "cleanup" is a shift towards the latter steps of the societal material flows— the relative importance of consumption emissions has increased. This reduction was primarily caused by:

* A gradual development of wastewater treatment. Especially the introduction of chemical treatment in industry in the 1970s and 1980s had a significant effect. In Germany it was closely connected to the introduction of more stringent legislation.
* Changes and improvement of processes, *e.g.* introduction of closed systems and recycling and reuse of waste products such as gypsum from phosphate fertilizer plants, which was used for construction.
* Reduced and changed production in important branches such as the iron and steel industry. Structural development led to the closing of old, inefficient, heavily polluting plants, that were replaced with larger, newer plants with modern technology and emissions control.
* Abolition of direct abuse of the river as waste dump. One of the findings of the Rhine Study was that a large part of the cadmium emissions could not be explained by direct emissions from production processes, but by the fact that sludges from zinc refineries used

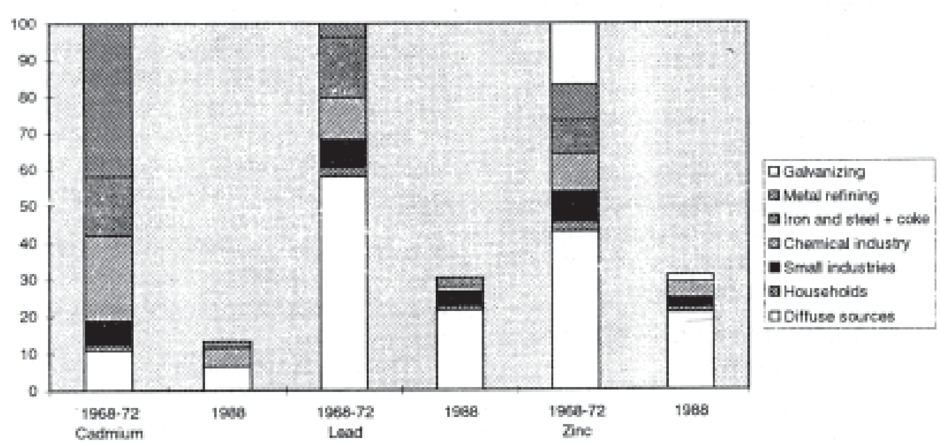


Fig. 2

to be dumped into the river. This practice was abandoned in the early 1980s and the sludges were sold to a cadmium refining plant.

Furthermore, improvement of air quality with decreasing deposition and sulphur concentration also led to reduction of diffuse emissions from urban and agricultural areas, but diffuse and municipal emissions have by far not decreased as much as the industrial emissions.

One finds behind these developments particularly a strengthening environmental legislation, especially at the state and federal level in Germany. This legislation has been used by competent and well-motivated environmental authorities, primarily at the local and regional level. One can also find a certain influence of EC legislation, but it is almost impossible to find any direct influence from the International Commission for the Protection of the Rhine (ICPR), at least until the end of the 1980s, even though this organization is often praised for its achievements (Bernauer and Moser, 1996). The ICPR has primarily been concerned with evaluating the situation, mobilizing public opinion for cleaning up the river and ensuring that representatives from the different countries present their plans to improve the situation. But binding agreements were not reached until after the Sandoz accident in 1986, when the Rhine Action Plan [IKSR (Internationale Kommission Zurn Schutze des Rheins gegen Verunreinigung; German for the International Commission for Protection of Rhine against Pollution), 1987] was introduced. This plan has the goal of cutting emissions in the different nations by half between 1985 and 1995 and ensuring a stable salmon population before the end of the century.

Important prerequisites for this positive development have definitely been a dynamic industrial development with important structural changes and investment in modern technology and emissions control and a radical development of environmental awareness and public opinion. An interesting observation in the Rhine Basin is that competitive branches seem to have had a relatively parallel development of emission reduction, while large differences can be found between France and Germany in the area of municipal wastewater treatment and emissions as well as in less competitive industries such as the Alsacian potash mines. These mines have important salt emissions that have long posed a problem for use of the Rhine water, especially in the Netherlands. This problem must be regarded as a major failure for international cooperation. It was origin of the initiatives which led to the creation of the Rhine Convention; but in 1990 the salt emissions were 35-40 percent higher than in the 1930s, when it first got attention. After decades of negotiations an agreement was finally reached in 1991, which concluded that the other Rhine countries pay the highly unprofitable French state-owned company half a billion francs to reduce its emission (Bernauer, 1995).

The importance of active public opinion and motivation in administration and industry can probably not be exaggerated. The development of Germany can hardly be understood without taking the dramatic increase of environmental awareness since the end of the 1970s into account. Since then, public authorities and industry work under increasing pressure from different environmental organizations that very critically evaluate their activities. In this context, the activities of the Rhine Commission have probably been important. They have helped the Rhine problem to gain a central position in the environmental debate, particularly in Germany. The cleanup of the Rhine has become a key challenge to both environmental politics and industry. The emission inventories of the ICPR have also been important.

Besides illustrating the dramatic decreases of industrial pollution and the changes of emission patterns towards the latter steps of the material flows, this example indicates the importance of both dynamic economic development and the development of environmental awareness. A totally opposite situation has generally been found in Eastern Europe, where large heavily polluting industries have been put under neither economic nor public pressure to increase efficiency and reduce pollution.

THE RELATIONSHIP BETWEEN ECONOMIC DEVELOPMENT AND ENVIRONMENT

Outside the OECD countries pollution loads have generally not decreased. The most environmentally damaging industrial activities are not widespread, but where they occur, the local and regional effects are often severe and there is still a distinct relationship between production and pollution. This is particularly the case of the industrial regions of Eastern Europe, East Asia and Latin America and around oil fields in , *e.g.* the Gulf of Persia, the Gulf of Mexico, Venezuela, Nigeria, Indonesia and Siberia. The pressure on many coastal areas in the south has also increased as a consequence of dramatic, uncontrolled big city growth and development of tourism connected to a certain introduction of Northern consumption patterns (for rich people and tourists), but without sufficient investment in waste treatment. Intensification of agriculture with increasing use of artificial fertilizers and pesticides and cutting of forests, in, *e.g.* Indonesia, the Himalayas and the Amazon, have greatly influenced erosion and run-off with often dramatic effects in estuaries.

Figure 3 shows the present "conventional wisdom" view of the relationship between economic wealth and development. According to this view, pollution is increasing with industrialization and rising economic wealth up to a certain point, then it starts decreasing as a result of rising environmental awareness, increasing efficiency, introduction of clean technology and decreasing importance of heavy industrial production. The parable is most often referred to as the environmental Kuznets curve. It has been supported empirically by Grossman and Krueger (1995), who, *e.g.* found a breaking point for sulfur dioxide emissions at a GNP of about 5000 US dollar per capita. The advanced industrial regions are presently moving downhill, while the poorest OECD countries like Portugal and Greece are close to the summit. Other regions are still on the uphill side, where the Far East is moving rapidly upwards, while Eastern Europe got stuck close to the summit and the agrarian regions still climb only slowly.

This crude model does not take important factors like population density, culture and societal organization into account, and its relevance, can (and should) of course be questioned. The development of different regions are almost impossible to compare, because of major geographical and historical differences. The industrial revolution in the NICs [New Industrial (or Newly Industrializing) Countries] in Asia, takes place under totally different circumstances in terms of, *e.g.* technology and trade than the industrial revolution once did in Europe, Japan and North America. In large areas of the world, radical

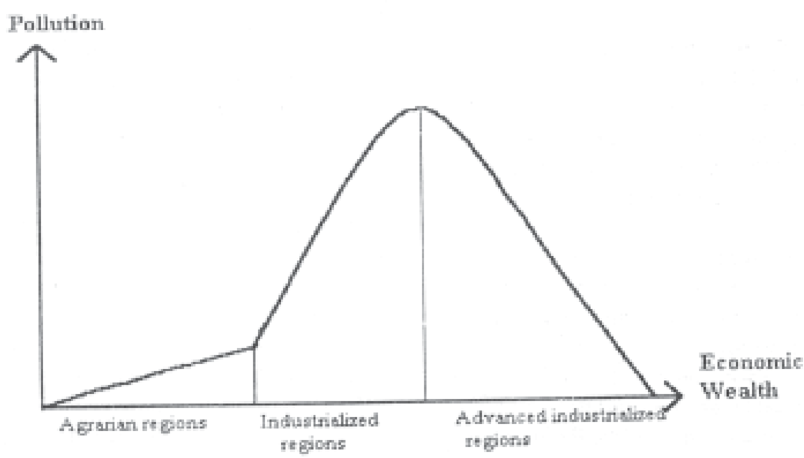


Fig. 3

economic changes, also connected to industrial growth, have occurred without a significant increase of economic wealth, but with increasing pollution.

But there is definitely evidence that support the basic ideas. Development of industry has generally brought a radical increase of pollution. An improvement of the situation has only been observed in the richest parts of the world. The socialist Eastern Europe never achieved the economic welfare or level of investment "necessary" for making a trend-shift in terms of pollution. During the last few years there has been indication that the NICs, *e.g.* Hong Kong, Taiwan, Singapore and South Korea, where economic welfare has increased substantially, also seem to be approaching the turning point in terms of pollution and have started development of stricter environmental regulations.

However, the generality claims, redu-ctionism and implicit determinism of these theories are very questionable. If only sufficiently high economic growth is realized, environmental problems will more or less be solved automatically. This is to overlook other important factors for environmental, *e.g.* connected to institutional development, which for example have been necessary prerequisites for improvements in Western Europe (where many environmental problems still persist). It is also interesting to note how the research of Grossman and Krueger has been used by GATT-WTO to legitimize liberalization and non-interventionist approaches concerning environmental issues (Damian et al., 1996). The questions— "Is it really necessary to pass the summit?" or "Would it not be possible for developing countries to cut the summit and introduce the modern clean technologies directly?"— that are raised in connection to this model (*e.g.* by Simonis, 1994; Stigliani, 1995) are also important, even if they often seem based on false premises. Even though it might be rare with modern environmental controls in the Third World, industrial technology is hardly totally obsolete, and transnational companies in particular should not have much incentive to invest in technology on the level of the 1950s or 1960s. In any case it is interesting that economic development is not only connected to increasing environmental stress, but together with technological and institutional development, it also seems to be a major prerequisite for improving of the situation. More sophisticated analysis of the particular local and regional situation is necessary to be able to evaluate the situation and the development in a more useful way. This should include an analysis of societal flows and the dynamics of activities of particular importance to regional pollution.

THE MODERN CHALLENGES

In countries, like Sweden, Germany and the USA, the local environmental situation in industrial regions has improved considerably during the last decades. But this improvement, which has primarily been caused by radical reduction of industrial point-source emissions has created a new situation. Problems with acidification, eutrophication, diffusion of persistent chemical and climate change still persist on a regional and global level, but the pollution sources connected to these problems are not so easy to control. The "marginal benefit" of further end-of-pipe pollution control has decreased radically. The dominating sources are either widespread and diffuse, connected to different steps in the use of various materials (fossil fuels, metals, organic chemicals) in society and not only in connection to production (even if industry is probably also a major source of diffuse emissions), or they are located in foreign countries, *e.g.* Eastern Europe. One can see the recent developments in environmental debate and politics in the most developed countries as a result of this new situation.

The materials flow perspective has experienced a major breakthrough in countries like Germany, Sweden and the Netherlands. What was considered fairly new and radical in the end of the 1980s (*e.g.* Anderberg et al., 1989) is now conventional wisdom. Goals like "closing the loops" and minimizing waste with reuse and recycling of materials and life-cycle analysis and environmental auditing are major themes in most European countries. The importance of the consumer is often emphasized in this context. Environmental concern is considered important, not only for more or less possibly influencing the development of legislation, environmental authorities or companies' investments in pollution control, but also for active participation in, *e.g.* recycling and conscious choice of environmentally benign products and avoidance of the opposite. Low-waste technologies, life-cycle analysis and recycling of products seem to experience a breakthrough in major industries like the chemical or electrical industry (Nelson, 1994; Paton, 1994). In Germany, the major chemical corporations now advertise that, by introducing low-waste technologies, they are cutting their emissions radically and at the same time making a profit (Die Welt 8/11, 1994). Consumers, mobilized by environmental groups, have definitely been an important factor behind this development. Large companies are held responsible in Germany for their total product flows, and companies like IKEA [Ingvar Kamprad Engaryd Agunnaryd; The Swedish Furniture Company] has been subject to criticism and boycotts because of the use of certain chemicals and poor working conditions by their subcontractors, particularly in Poland.

During the last decade, there has also been an important development of international environmental cooperation with increasing emphasis on international global environmental problems. But agreements, outside of the EU, remain fairly weak and without much possibility for controlling achievements or installing sanctions to countries that do not comply. The relation between trade and environmental degradation has also received increasing attention in this context, mostly in connection with the direct influence of international trade and especially transnational corporations on deforestation in, *e.g.* Southeast Asia, Latin America and the Himalayas. The debate on international trade and environment has so far been rather polarized (Williams, 1993; Soderbaum, 1994) between those (environmentalists) who consider that international trade is inherently bad for the environment and those (liberals), who emphasize the beneficial sides of trade, *e.g.* that it encourages efficiency also in environmental terms. Research on the relationship between international trade and environment, even if it has increased during the last few years (*e.g.* Thomas, 1993; Bengtsson et al., 1994) and is still fairly undeveloped, seems to indicate that it is not an area where one can draw such simplified conclusions. It is filled with myths like the industrial flight hypothesis, *i.e.* that pollution producers flee from countries with stringent environmental standards; this however, seems to be only a marginal phenomenon (Williams, 1993). Protectionism seems definitely to lead to stagnation and very limited environmental improvement. Free trade and competition can often have beneficial effects, but these also depend strongly on institutional setting, and there is definitely very much in the development in Europe and the world, characterized by increasing trade liberalization, that is highly questionable from an environmental point of view. A major future challenge is definitely to be able to combine the goals of free trade and sustainable development.

The modern situation poses very demanding challenges to environmental research. These challenges no longer concern discovery and confirmation of environmental problems, but an improved understanding of society, its change and relations to nature. Research on areas connecting society and nature is fairly undeveloped, particularly the society's use of natural resources and the way in which this use has developed as a consequence of changes in consumption and production systems, development of new technology, and political actions. We lack knowledge and understanding of central areas and ability to handle the complex linkages between society and nature in a changing world. Also problematic is the lack of analysis of environmental problems (particularly in industrialized countries) from a power perspective (who can influence what, when, how and why?), which leads to an exaggerated belief in the influence of politicians and consumers. There is an urgent need for more coherence in these areas. Among the relationships and contexts that are necessary for an environmental analysis of the social development, but which so far have been hard to grasp, are the linkages between different areas of knowledge and sectors, societal and environmental change, and geographical aspects such as extension, diffusion, spatial flows, and spatial context, and linkages between different scales and management structures.

The challenge here is to develop perspectives and methods that improve the picture of how societal activities and resource use and pollution are linked, A common framework of reference must be constructed for studies with different emphasis in a way that these can be linked and together contribute to the development of a more complete picture. This framework could differ in detail and geographical scale, but for such a framework to be relevant it must be able to handle relationships between emissions and environmental effects as well as their linkages to political and administrative structures and economic, social and technological change. Several efforts have been made to develop a common framework of reference for studies of nature and society. It is, however, rare that all desirable aspects are dealt with. Investigations have attempted to describe the use and emissions of substances and analyze different ecological problems and risks. Another example is environmental futures studies, where scenarios form a common framework for the analysis of environmental effects and possible political actions. Recent "industrial metabolism" studies (see, *e.g.* Ayres and Simonis, 1994) have analyzed material flows in society and nature, and can be considered a response to the problems encountered in emission estimations and environmental futures studies.

FURTHER DEVELOPMENT OF THE "INDUSTRIAL METABOLISM" APPROACH

Flow perspective has, in connection with industrial metabolism studies, been deemed as a useful framework for integrating analysis of nature and society, analyzing technological change and environmental effects and improving the basis for emission estimations, environmental actions and developmental strategies in an environmentally sustainable direction. The implications of flow perspective to change and minimize flows and increase efficiency and recycling experienced a remarkable breakthrough in environmental political debate as the goal "close the loops" implies. This breakthrough is probably connected to growing dissatisfaction with conventional environmental protection strategies that have not been successful in handling problems related to the growing waste mountain and diffuse consumer-related emissions. The flow model is also an excellent tool to illustrate and summarize complicated matters coherently and it communicates well with the natural scientific world view. After a growing stream of studies and initiatives based on a material flow perspective, the introduction of this perspective seems completed. Geographical scale, methods, data sources, study objects, and analyses of the flows and emissions vary in studies of societal material flows. Most studies focus on determining total flows in a region in one particular year, but during some projects also try to identify the historical development and the geographical distribution of the flows and emissions in the region. The studies are often preliminary and presentations spend considerable amount of effort arguing for the advantages, implication, and potential of their approach. Efforts are seldom made to discuss difficulties, uncertainties, and constraints of the studies. The difficulties encountered in these studies are rather obvious. Statistics and other relevant information about different activities do not adapt very well to the needs of this type of study. The challenge is now to develop perspectives and methods so that they can contribute to improving analysis of the modern situation. To find out the shortcomings of the studies, it is definitely necessary to include critical evaluations of the performed studies and the flow perspective as it is used in industrial metabolism and related studies such as life-cycle analysis. A recent study (Anderberg, 1996) has made an attempt to provide a critical analysis of the Rhine Study as a starting point for a more general assessment of the limitations of the "industrial metabolism" or societal material flow studies. The results and discussion of this study are summarized below. The discussion considers the work of Torsten Hagerstrand, who has developed an alternative framework.

EVALUATION OF THE RHINE STUDY

In many ways, the Rhine Study is a unique pioneering effort. The project has tried to analyze how the flows of three heavy metals (cadmium, lead and zinc) have changed between the early 1950s and the late 1980s in the Rhine River Basin, one of the most industrialized regions in the world. The study places more emphasis on the location of different activities and emissions than other industrial metabolism studies. The presentation of results focuses on emissions and their development, but attention is also given to environmental effects and the risks connected to long-term accumulation of chemicals in agricultural soils ("Chemical Time Bombs," see, *e.g.* Stigliani et al., 1991). In this study as in other industrial metabolism studies, flow analysis is considered an important instrument for evaluating environmental impact of social activities. Historical perspectives are also emphasized. Analysis shows that in recent decades emissions to both air and water have decreased dramatically. The decreases are related primarily to improved pollution control at the industrial point sources, but they are also related to decreased consumption of some uses of metals (such as lead in gasoline and cadmium for surface treatment), as well as stagnation of some industries and structural change (new processes, concentration of production and consumption) connected to large flows such as coal, steel and phosphates, where heavy metals are present as trace elements. A large part of emissions have been connected to inadvertent flows of the metals. It is only in connection with lead emissions to air (primarily car exhaust) and zinc emissions to water, where the intentional use of the metals have been responsible for the major part of the emissions. Emission-control development has lead to a redirection of flows from air and water to solid waste, which is deposited, incinerated or used in some way, *e.g.* sewage sludge in agriculture. Studies of the historical development of uses and emissions have been used as a basis for construction of future scenarios of materials use and emissions and for analysis of risks connected to accumulation in agricultural soils. Further studies analyze the causes behind the emission reductions that have been occurring in the Rhine Basin since the 1950s.

The challenge to find perspectives for common framework for the study of interaction between society and the environment was the basis for the evaluation. This analytical framework should be able to consider pollution as well as decision-making processes and different forms of economic, social and technological change, that are of relevance in this context.

The most valuable aspect of the study is to test the methodology of material flow analysis in a large region. Such a study can definitely contribute to an improved overview of the flows, emissions, and environmental effects of society. The analysis of the Rhine Basin give a certain view of the variation in time and space of emissions and flows. The study provides a certain basis for an environmental assessment system for evaluating the environmental effects of production and consumption, risks connected to accumulation of pollutants and effects of economic and technological change and political actions. But it needs to be emphasized that this study is only the first step toward such goals. The study provides an opportunity for evaluating difficulties that are connected to studies based on material flow perspective. Statistics are far from ideal and available information about emission sources is seldom sufficient for making generalizations. Therefore the study must be regarded as preliminary. The study is severely limited in its effort to connect to broad social change related to economic and technological development and decision making. No effort has been made to reveal structures that direct and change the flows and emissions. The analysis of heavy metal emissions is rather isolated and not linked to the total environmental impact of society or the development of different activities, uses, products, infrastructures, and institutions.

These limitations stem from the flow perspective and how it has been used. The analysis of flows is rather limited and intended mostly as a framework for estimating emissions. Conventional flow models focus primarily on flows as linkages, but do not encourage contextual analysis of different parts of flows, analysis of flows in time or analysis of the interlinkages of different elements. It is difficult to conduct a broad analysis of the flows and their preconditions in the Rhine Study because the focus in this study is on single elements and because of the delimitation and treatment of the region. This region is inappropriate for studying international relations. For such an analysis national boundaries are necessary because of the organization of trade statistics. The region serves primarily as a summary unit and the analysis becomes too one-dimensional, which makes it difficult to connect the analysis to social, political, and economic developments. This also makes the study and its analysis insufficient as a basis for broader future scenarios or historical studies of the social, economic and political development of the Rhine Basin. To evaluate social change and construct scenarios that can serve as frameworks for analyzing and discussing strategies for societal development, it is insufficient to focus only on a few elements in society. It is also necessary to analyze the physical, economic and social structures in society that influence the flows.

THE PROCESS LANDSCAPE

The "process landscape" framework (Swed. Forloppslandskapet), developed by Hagerstrand (1993), provides an alternative perspective for the analysis of flows. It is based on the time-geographical perspective and intended as an integrative framework for a more contextual analysis in the study of society-environment interaction. Its objective is to develop a dynamic view on how different processes occur and interact in the environment and to catch the forces (physical, biological, social or political) that form and change these processes.

The starting-point is the entirety that is made up of a part of landscape. This entirety provides an overview and a framework that can be used for more detailed studies. An important aspect of this approach is that attention is focused on the way things in the process landscape coexist in and compete for a limited area of time, space and energy. The challenge is to observe the relationships in time and in space between different processes in the environment. When elements are placed in their natural context, analysis can focus on how the processes are linked to, interact with and are limited by other processes and phenomena. In this analysis it is necessary to clarify the restrictions on different processes. Hagerstrand uses primarily the time-geographical concepts for the analysis of the process landscape. He distinguishes between individual corpuscles (which include living creatures, objects of nature like stones and cultural artifacts), which move in trajectories, and amounts (such as gases, water and grain), which move in flows. In a time-space perspective everything is always moving. If an object is immobile in space it is still moving in time. The trajectories are not divisible, an organism or an object cannot be in more than one place at the same time, but the flows are as divisible as their content allows. It should be emphasized that the process landscape is not connected to a certain scale of time and space and the level of detail and aggregation can be flexible, even if Hagerstrand aims at avoiding conventional simplifications. The approach strives to see phenomena in a concrete setting so as make generalizations at high geographical levels. The objective is to be able to make a detailed analysis in the context of a comprehensive perspective, making it possible to maintain an overview and to systematically connect different geographical scales. Hagerstrand connects also the process landscape to an analysis of management. This analysis starts off from the micro-level and focuses on how the actors and action at this level are contained in a hierarchical net of domains. The goal is to identify the restrictions for different actors. Administrative influence is dominantly exerted through definition of the boundaries for action. This view of the trajectories and flows of the process landscape as a web, caught in a network of domains, provides a framework to connect the actors and institutions in society, their technical equipment and the environmental setting, where both the natural processes and human activities take place.

One should observe that the flow perspective is not incompatible with the process landscape; the former is rather incorporated into the latter. But the view of the flows differs from the conventional flow perspective. Time and space are the basis for the analytical framework, and this definitely gives a different perspective on the flows, which is important for seeing them not only as isolated flows, but as related to other processes, elements and structures of society. The conventional flow model is based on similarity; the emphasis is put on adding similar activities without taking into account their diverging contexts. The spatial dimension brings in the nearness aspect and spatial arrangement of activities, while the temporal dimension emphasizes the different time scales of various processes in the landscape. The treatment of the region is also quite different; instead of being a limited summation unit, it is an arena for the study of interaction. The management structure of the process landscape is important to consider from the beginning. This structure makes it possible to introduce a power perspective (who can do what and when can they do it?). The objective is to make a detailed analysis of the local context at different steps in a material flow, while maintaining the larger context. It is necessary to know the actors, situations and arrangements involved to be able to identify the constraints (physical, economic, social or legal) for different actions. This is also important to be able to connect flow analysis to human behavior and decision-making processes.

The Process Landscape might inspire a way out of some of the major shortcomings of conventional flow studies. There are, however, still very few studies that have been based on this analytical framework. Lenntorp's (1993) analysis of flows connected to construction of four small houses in the Nordic countries is one of these few studies. An example from this study is given in figure 4, that shows the flows in time and space in connection to the central vacuum cleaner in the Norwegian house. This study can be described as a geographical life-cycle analysis. It shows clearly the necessity to put flows and life-cycles of products in a time-space context. When only summarized flows in a limited region or in connection to life-cycles are analyzed, the spatial arrangement of the flows, which is a very important trait, is absent in the analysis. The goal of getting closer to human actions cannot be noticed in this example, but the starting point in a specific house increases the possibilities to connect this analysis to a study of human actions and the frames of these.

To meet the challenges of the modern situation such as improving analysis of consumption and trade and to be able to get closer to human behavior and decision-making, it is definitely necessary to have a broader perspective where not the least temporal and spatial aspects are emphasized. Hagerstrand's "Process Landscape" might provide some inspiration and guidance to such efforts.

CONCLUSIONS

There are many challenges for modern social research connected to environmental problems and development. Flow perspective is a useful and perhaps indispensable tool in this context. It may improve the overview of different parts of society's use of natural resources and improve the analysis of emissions and other environmental impacts. Since flow perspective has a long tradition in scientific environmental research, it

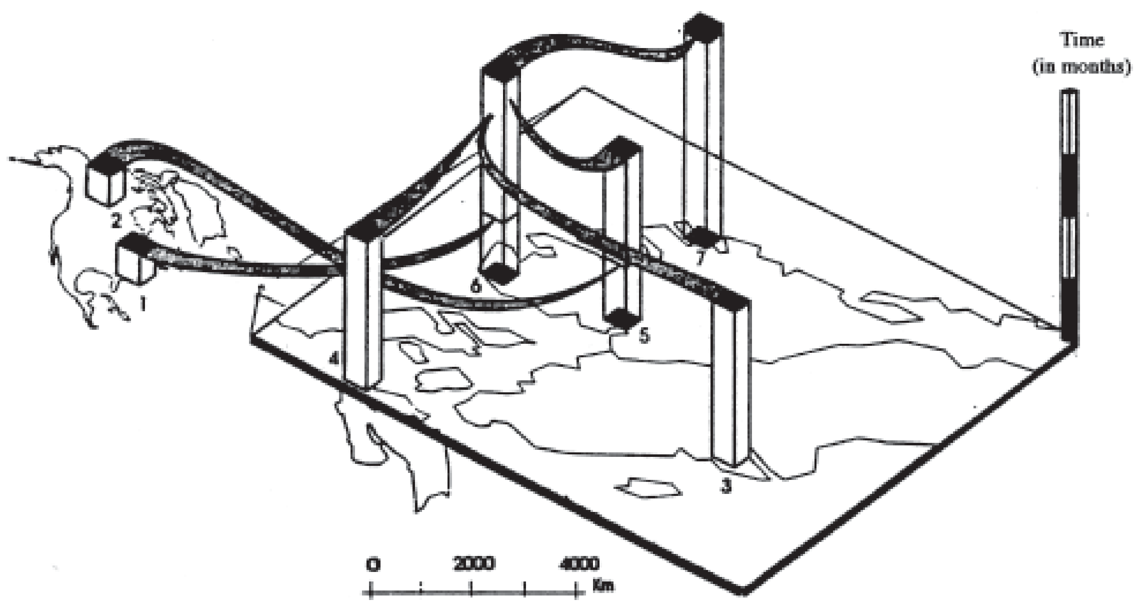


Fig. 4

can easily be combined with an assessment of environmental consequences. Related ideal models such as closed material cycles may also provide new ideas in connection with societal planning and environmental policy and strategy. Even if statistics generally do not adapt very well to this type of study and information on different types of emissions is limited, relatively uncertain and hard to generalize, conventional flow studies can help to improve the overview of resource flows in various scales of analysis.

But for really contributing to improved understanding of resource flows and their change it is necessary to develop studies and to keep limitations of flow perspective in mind. The conventional flow model, which is based on similarity criteria, focuses particularly on the flows as linkages. This type of model seeks to establish consistency along these linkages, and the contextual analysis of different parts of the flows is not emphasized. In theory, flow perspective is fairly comprehensive; however, the model is often used in a fairly abstract and narrow way. The focal point is only on single elements in a region and not on the wide context of the flows: the activities that drive them; their technological aspects; or how they are shaped and limited by their physical, economic, social and institutional frames. It is, therefore, difficult to connect flow analysis of single elements, such as heavy metals, to wider issues that have a far-reaching effect on the environment: spatial and temporal aspects, economic and technological change, and decision making in politics, administration and industry.

Flow analysis communicates well with environmental impact analysis, but its linkage to a wider analysis of society is more problematic. To address this limitation it is not sufficient to focus flows of single elements and to total them at a certain level of aggregation. It is necessary to analyze their context, especially the physical, economic, technological, and societal structures that influence, form and limit the flows. To increase the relevance of material flow studies as a tool for analysis, it is necessary to increasingly focus on the geographical context of the flows. Analysis should incorporate the temporal and spatial aspects of the flows, the infrastructures, patterns of industry and settlement and the linkages to the institutional framework. To develop and to improve understanding of the context of flows, material flow studies such as the Rhine Study need a clear objective and more flexibility to deal with the flows, the scales and the level of detail. To contribute to the understanding of social change and its relation to environmental impacts, analysis must be broadened. Material flows must be more explicitly intended for improving the general understanding and knowledge about the flows of materials in society and their change. Flows must not be cut off from their social context and other flows and processes. To understand the development of products, industries, and transports, analysis must take place at different levels, for example, the region in its context, industrial branches, enterprises, factories and households. The importance of industrial production and trade enterprises and households should be emphasized in such an analysis. Variations in approach, methods and detail are necessary, but it is important that analysis at different levels is concerned with the frames of the flows and with questions of power (what and who can influence?). The ultimate challenge is to connect the international, even global, level to the local level where the real actions take place.

To summarize, flow-based perspectives can be used to improve communication and integration between studies with different emphases that increase our knowledge and understanding of relationships between society and nature in a changing world. But this potential can hardly be realized with only a conventional flow perspective, which often becomes too abstract and narrow and cannot easily be connected to the wider context of the flows. Therefore, additional perspectives must be used to handle the temporal and spatial aspects of the flows and their physical, economic and social frameworks. By placing emphasis on analysis of flows in their context in time and space as well as on the constraints of the flows and their institutional context the time-geographical process landscape may offer guidance for addressing the limitations of material flow studies to evaluate social development and for creating a basis for analyzing development strategies.

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