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A SYSTEM OF NATURAL RESOURCE ACCOUNTS

EIT REKNESKAPSSYSTEM FOR NATURRESSURSAR

BY
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STATISTISK SENTRALBYRÅ
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PREFACE

The Central Bureau of Statistics is developing a system of natural resource accounts. This report gives a survey of the system of accounts, primarily on the material resources e.g. resources which provide either materials or energy for the production of goods and services. Parts of the material presented here, is also being published in Norwegian in a larger publication in the series Statistical Analyses (SA).

Central Bureau of Statistics, 25 May 1981

Odd Aukrust

FORORD

Statistisk Sentralbyrå er i ferd med å utvikle eit rekneskapssystem for naturressursane. Denne rapporten gir ei oversikt over rekneskapssystemet, med vekt på materialressursane, dvs. dei ressursane som gir anten materialar eller energi til produksjonen av varer og tenester. Delar av det materialet som blir lagt fram her, blir også publisert på norsk i ein større samlepublikasjon i serien Statistiske analysar (SA).

Statistisk Sentralbyrå, 25. mai 1981

Odd Aukrust

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1. A REVIEW OF THE ACCOUNTS

1.1. Introduction

In 1974, the Norwegian Ministry of Environment was given the responsibility of preparing an annual report to Stortinget (Parliament) reviewing the stocks of natural resources and their present use (resource accounts), as well as proposals regarding their future use (resource budgets). The methodological work started in 1975. The results of a preliminary study was presented to the Ministry and Stortinget in 1977.

As the next step, the Central Bureau of Statistics was asked to undertake pilot studies on selected resource categories: Energy, fish and land (space). Later on, timber (forests) and some selected metals have been included. Pilot accounts for these resource categories have been presented, except for land resources, the pilot account for which will come early in 1981.

1.2. Resource policy

The exploitation of natural resources is extensively regulated, especially through legal restrictions. There is political consent on the principle that the use of natural resources in some way must be regulated by public authorities. There might, however, be some disagreement on the extent of the regulation.

Resource accounts will present the facts that must be the basis for any form of regulations. Such accounts will, as well, be a basis on which the goals of resource policy can be formulated. Resource budgets will present such goals in a quantitative form along with the program for use of policy instruments which is necessary in order to reach the goals.

The goals of resource policy are as a rule vaguely formulated and for the long run; as for example:

- to maximise the economic result ("social profit") of the use of natural resources
- to prevent unnecessary depletion and degradation of natural resource stocks.

The implementation of a resource policy has to work in the short run and has a need for specific goals and good data. Resource accounts and budgets are intended to fill the gap between long term, general goals and the formulation and implementation of the short term policy.

Most decisions in economic policy has resource consequenses, and, vice versa; most decisions in resource policy has economic consequenses. There is therefore a need for coordination between policy and resource policy.

Another problem is the lack of coordination between local and regional physical planning on the one hand and national land use policy, resource policy and economic policy on the other.

1.3. Classification of natural resources

The system of resource accounts must take into account both the physical properties of the natural resources and the way they are used. Different physical properties will lead to different ways of using the resources.

The natural resources provide materials and energy for the production processes as well as the environment for humans, animals and plants. Economic activities occupy space and affect the environment in different ways. For accounting purposes, we have set the main division between the resources which go directly into the production process (material resources) and the resources which are a more indirect need for the production processes and for human and animal life (environmental resources).

Figure 1 shows the connection between a well known physical classification and the economic classification used for accounting purposes. There is no sharp distinction between the material resources and the environmental resources; there is for instance a close connection between the inflowing resources (e.g. wind) and status resources (air).

Figure 1. Classification of natural resources

Economic classification	Physical classification	Physical properties
material resources	mineral resources: - elements - minerals - hydro carbons - stone, gravel and sand	non-renewable
	biologial resources (life) - in the air - in the water on land and in the ground	conditionally renewable
	inflowing resources - solar radiation - the hydrological cycle - wind - ocean currents and waves	renewable
environmental resources	status resources - air - water - soil - space	conditionally renewable

The environmental resources are as a rule not consumed by the production process. The most important aspect is that the quality of the resource is changed, and that this alters the suitability for other uses.

The material resources usually prevail in consentrations, and the most important aspect of such resources are the quantities which have an exploitable concentration. The resources can, after extraction, be transported, and the exploititation of material resources is most often organized as separate extraction activities (mining, fishing, hunting etc.).

1.4. The accounting system

In most countries the core of economic policy is based on national accounts, giving coherent data for the economic activities of the country. Thus, in order to solve the coordination problem between economic policy and resource policy, the system of resource accounts must be closely connected to the national accounts.

In a simplified description of the economy, the national accounts divide society into two parts: establishments and households. The establichments produce and the households consume.

Figure 2. Simplified flow diagram of a two-sector economy

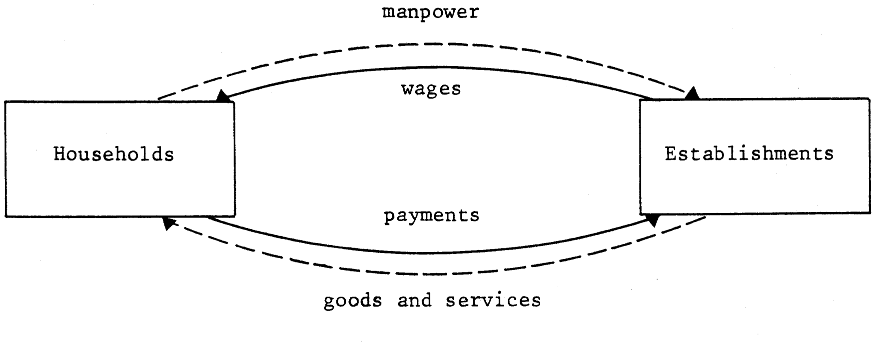
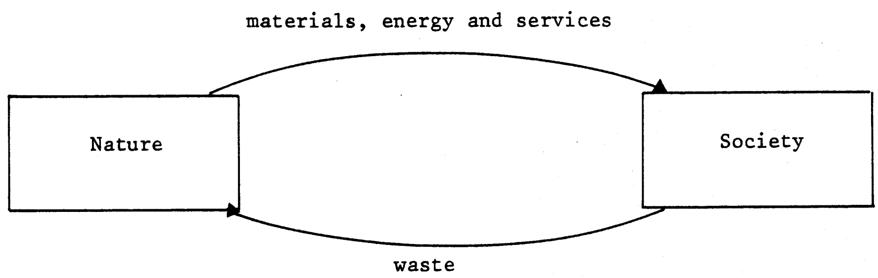


Figure 2 shows the circulation of goods, services and money between the two sectors: The households (workers) deliver manpower services to the establishments. They are paid with money, which is returned to the establishments in exchange for goods and services. In addition to the flows, the national accounts include stocks, for instance stocks of production capital, buildings machines etc. The stocks of natural resources, for instance oil reserves, are however not included.

Quite a few economists concerned with the resource situation, think that the GNP shound be corrected for the depletion of natural resources, in Norway e.g. by the in-situ value of the oil reserves that has been extracted. In this way, the GNP would give a more correct picture of what is the result of production, not including such liquidation of assets. Correction of the economic measures is not the purpose of the resource accounts, although the data of the resource accounts can be used as a basis for such calculations.

In the resource accounts, the system is expanded to include nature. This sector has stocks of natural resources, deliver goods and services to the society, and receives waste from the society. Figure 3 shows the flows.

Figure 3. A simple flow diagram of the resource accounts



The sector "nature" is highly complicated and the understanding of its functioning is often limited. It is, as well, difficult to find a simple and aggregated description of such complex phenomena. Building a system of resource accounts is therefore a difficult and time-consuming task, and the system will be built piece by piece. Priority has been given to pieces which will be useful, even when they are isolated from the rest of the system.

Corresponding to the classification of the natural resources, distinguishing between material resources and environmental resources, there is a main division in the accounting system, between the material accounts, and the environmental accounts.

1.5. Accounting units

The national accounts are kept in monetary units, e.g. current or fixed kroner. In the resource accounts, physical units are used, thus avoiding pricing of the stocks of natural resources. In an ordinary system of accounts, there should be one accounting unit. In the resource accounts this has proved impossible, or at least very difficult. Therefore, a number of different units are in use, both original physical units (tons, etc.) and derived units suited for aggregation witin groups of commodities: i.e. calorific value (in the energy accounts) and tonnes of pure iron (in the iron accounts).

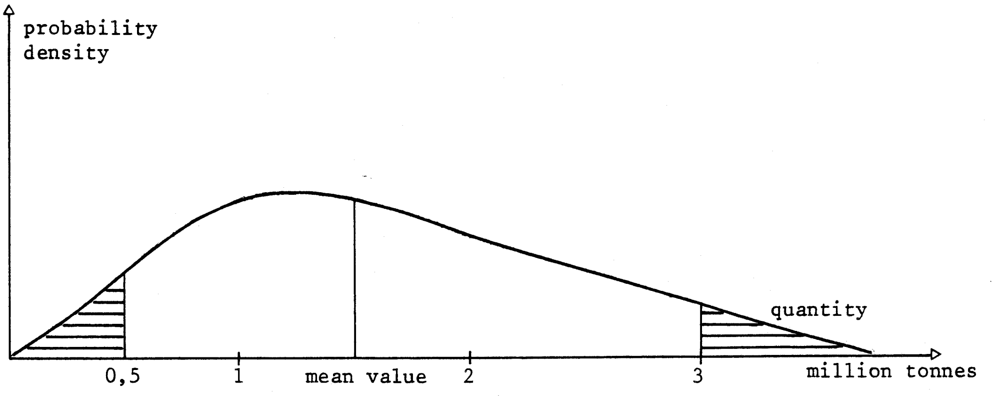
The main advantage of physical units as compared to monetary units, is that it is easier to make time series as inflation does not affect the accounts. The main disadvantage is that aggregating and comparison in cross-sections is difficult or impossible - it does not make much sense to add one ton of oil and one ton of iron.

1.6. Data quality

All data in the resource accounts will be uncertain. The degree of uncertanty will vary widely. Data on the resource stocks will generally be much weaker than data on resource flows. It has been decided that whenever possible, some statistical measure should be used to characterize the degree of certainty of the resource stock data.

Figure 4 shows a probability density curve for a mineral reserve. Such curves can be produced for a number of other resource stocks, as well. As will be shown below, it is the mean value that is used in the accounts. Confidence intervals are often used to characterize data. A 90 per cent confidence interval covers the true value with a probability of 90 per cent.

Figure 4. The probability density of a reserve estimate



The figure shows that the reserve is 1,5 million tonnes with a 90 per cent confidence interval going from 0,5 to 3 million tonnes.

Such a probability density curve has nothing to do with the resource itself. Given a specific definition, the reserve quantity is a given number, and is thus not stochastic. The curve characterizes the quality of the reserve estimate, i.e. how much we know about the reserve. Such curves can be used for any kind of technical definitions. Well known reserves will have peaked curves and narrow confidence intervals, whereas less known reserves will have flat curves and wide confidence intervals.

2. MATERIAL ACCOUNTS

2.1. Stocks of material resources

The most important new thing about the resource accounts, is the attempt to include stocks of natural resources into the accounting system. We have not been able to find any previous attempts to do this, and the full development of the accounting system will therefore take time.

Stocks of material resources appear in different cost classes, in the way that the production cost of the different resource based commodities wary, due to:

- extraction cost (open-pit or underground mining, steepness of a forest, etc.)
- consentration cost (e.g. ore grade)
- transportation cost

The best qualities are as a rule taken first. Later on, the poorer qualities will be exploitable, due to higher prices or lower cost (improved technology), usually a combination of the two.

Information about natural resources, especially the poorer cost classes, is scarce, and it has therefore been impossible to include all the different cost classes into the accounting system so far. Only the exploitable resources, e.g. those which are being exploited at the moment or will be exploited in the near future will be included, and thus called reserves of natural resources.

The definition of the reserves of natural resources as based on three main principles. Reserves are supposed to be:

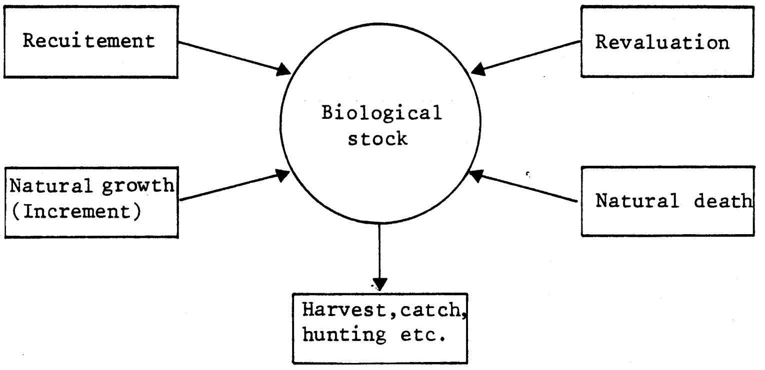
- economically exploitable, e.g. extraction must be profitable.
- measured as net numbers; reserves should only include the part of the in-situ resources which is recoverable.
- given as unbiased numbers. The reserve assessment should give the mean of what one expects to find.

These main principles has to be adapted to each resource category.

2.1.1. Biological stock accounts

The biological resources comprise all living organisms in the air, in water and in the soil, as well as on the ground. The main problem in assessing the size of a biological stock, is that such stocks change fairly rapidly because new individuals come into the stock (recruitment), individual growth and natural death. This comes in addition to the catches (harvest etc.) done by humans.

Figure 5. Biological stock accounts



Analytically, the accounting system for biological reserves can be given in the following form, by a vector equation:

$$Z_1^t + \Gamma + O_3 \;=\; N + U_1 J + Z_1^{t+1} \qquad (2.1)$$

The dimension of the equations is the total number of biological resource categories

Z_1^t represents total reserves on time t

R is the recuitment of new individuals to the stock in period form t to t+1

r is natural growth (increment) of each individual in the period from t to t+1

Γ_3 is revaluation of reserves in the period t to t+1

N is natural death in the period

U_1 is catch/harvest in the period specified by categories of biological resources and production sectors

J is a vector of ones of suitable dimension used to aggregate the extraction along the sector dimension.

2.1.2. Mineral reserve accounts

As it is used in the resource accounts, the consept of "minerals" comprise all kinds of substances of economic interest occurring naturally in the crust of the earth, including carbon and hydrocarbons (coal, oil, gas etc.).

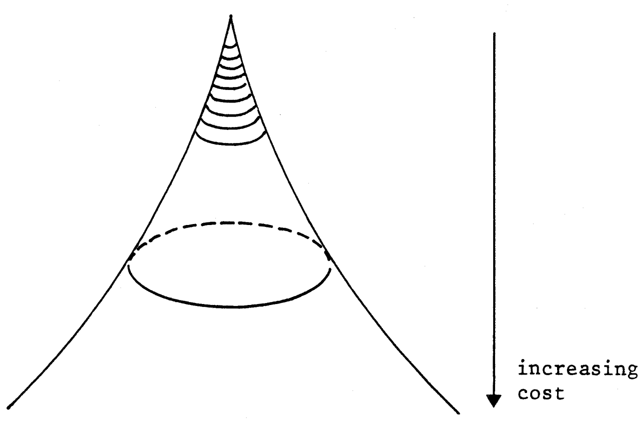
There is a number of different classification systems for mineral reserves. In most systems, the reserves are classified according to quality (economy) and according to how well the reserve is known. As a rule, the reserves have been classified as proven, probable, possible, speculative and hypothetical. Those are economic reserves with a falling degree of knowledge according to the exploration methods used. The definitions of such estimates are rather vague, and it is difficult to obtain the precise meaning of them.

The mineral reserves are frequently classified as depletable. This has created the widespread misunderstanding that the minerals will be completely "exhausted" in the long run. Fortunately, this is not so. In the absence of technical progress, the cost of extraction on the marginal mines increases with time, which results, correspondingly, in an increasing amount of energy, capital and manpower to be applied during the process of extraction.

At any moment, the economic reserves are given, whereas technical progress and price alterations will cause changes in the reserves. This dynamic feature of the accounts will play an important part in the system.

On a global scale there is a connection between quantities and required extraction costs, which can be described as a resource cone (figure 6).

Figure 6. The resource cone



Quantity is represented by the volume of the cone, and cost increases downwards along the axis. The black top of the cone has been "cut off" by extraction until now. The remaining global economic reserves are represented by the rest of the volume above the indicated cut-off, which is determined by the market prices of the resource.

Energy can be used as an indicator of cost. In the case of energy minerals (coal or oil), the ultimate limit of useful extraction will be given by the point on the cone where the cost of extraction exceeds output, measured in energy. In this case output of energy will equal input of energy, and the mine/field will not give net production. This sets a final limit to extraction of energy minerals.

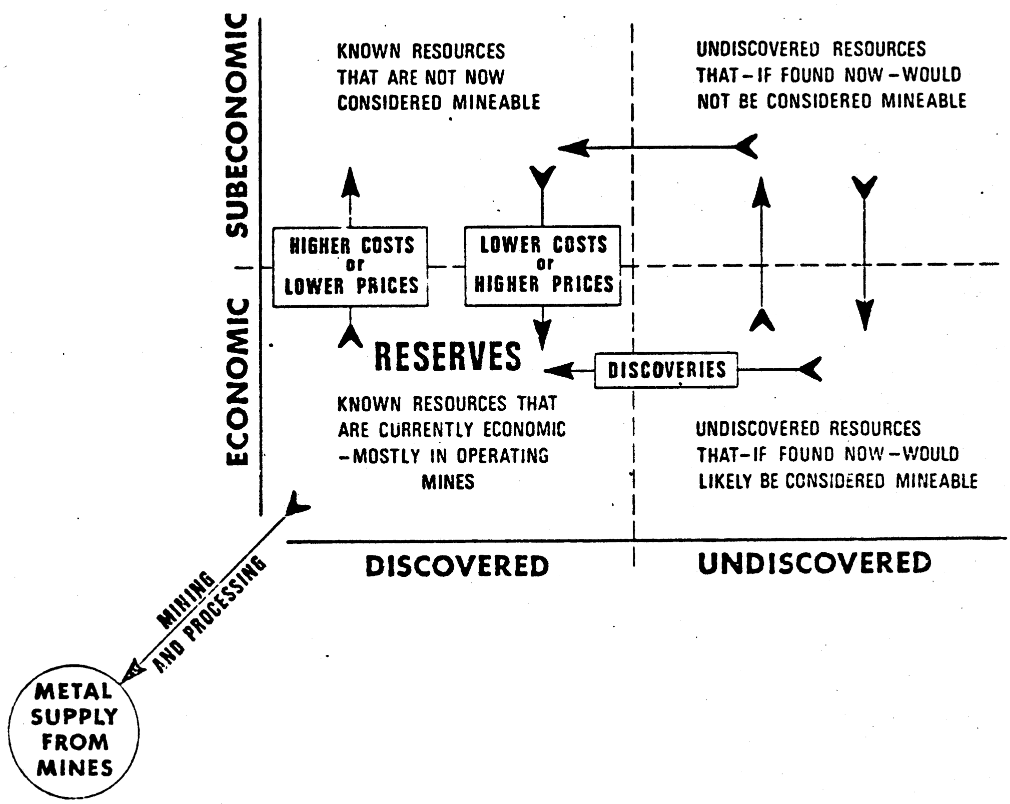
Figure 7 shows an accounting scheme proposed by Department of Energy, Mines and Resources in Canada[1]. Here the classification is simplified, distinguishing between discovered and undiscovered and between economic and subeconomic. Reserves are those quantities which are discovered (known) and economic.

1) EMR: Uranium resource evaluation. Report ER 77-1.

New discoveries which increase the reserves occur constantly. Changes in prices, costs and technology will influence the reserve quantities by changing the economic portion of the changes in prices are rapid and strong.

Corresponding changes in the reserves quantities would be impractical and would, as well, give an unrealistic picture of reality and a basis for decisions which changes too rapidly. To avoid this, we have decided to consider as reserves all quantities which one has planned to take out of existing or planned mines, whether or not this would give a profit just now.

Figure 7. The flow of resources over time



In order to be able to compare reserve quantities and extracted quantities, the reserve quantities are given as net numbers, e.g. leaving out quantities which in themselves are of reserve quality, but which for some technical or economical reason are left in the mine (or reservoir). The in-situ reserve number is therefore multiplied with a recovery factor.

The accounting scheme in figure 8 has been altered slightly, by dividing the reserves in two parts:

- undeveloped reserves
- developed reserves

The reserves are considered developed when most of the basic investments have been made and ordinary production has started.

This division is very important in connection with extraction policy: When an oil well or a mine is in production and the investments have been made, one can in principle choose whether or not to extract anything next year. The choice is, however, restricted by the amount of invested money which has to give some kind of profit. Reserves which are undeveloped, need a planning and construction period before production can be started, but the choice itself is less restricted.

Figure 8. Mineral reserve accounts

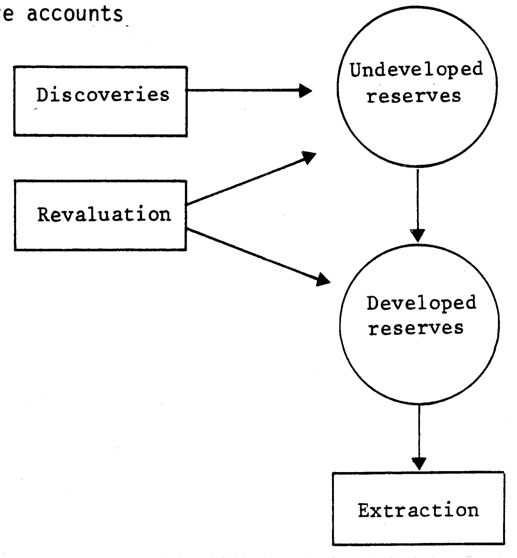


Figure 8 shows the structure of the mineral reserve accounts. The account for revaluations include changes caused by new prices and technologies as well as changes due to new information about the reserves.

In connection with the mineral reserve accounts, information about the resources which are not included in the accounts will be given as well. Supplementary tables will, when possible give assessments on:

- cost classes of known, uneconomical resources
- resources which are not known well enough to be included in the accounts.

Analythically, the accounting system for mineral reserves can be presented in the following forms; by two vector equations.

$$V^t + O_1 + \Delta_1 = \Delta_2 + V^{t+1} \qquad (2.2)$$

$$Z_2^t + O_2 + \Delta_2 = U_2 J + Z_2^{t+1} \qquad (2.3)$$

The dimension of the equations is the number of mineral resources categories.

V^T represents indeveloped reserves at time t

Z^T is a matrix of developed reserves at time t

O_1 and O_2 are revaluations in period t to t+1 for undeveloped and developed reserves respectively

Δ_1 represents discoveries in the period

Δ_2 is development of mines in the period

U_2 is extraction on the period, specified by categories of mineral resources and production sectors

J is a vactor of ones, used to aggregate the extraction matrix along the sector dimension.

2.1.3. Estimation of mineral reserves

The resource cone in figure 6 of Ch. 2.1.2. gives some information about the general availability of different mineral resources on the world scale. Such information is, however, of little interest for a mining engineer whose task is to determine the available quantity at different cost levels in a single mine. His sources of information will be general experience about geological formations combined with data from the prospecting which is being carried out in the mine.

One way of conceptualizing the problem is to represent the grade of the ore by a function

$$Z = Z\,(x,y,z),$$

where x,y,z are the geographical coordinates of the point. Simplifying, the main task of the engineer is to estimate the quantity of ore being richer than a certain cut-off grade, the grade which has the minimum richness acceptable for the mining company. If the engineer has full information of the Z, his estimates will be:

i) total volume:

$$V = \iiint_{\omega} dxdydz$$

ii) total quantity of (for instance) metal:

$$M = \iiint_{\omega} Z(x,y,z)\; dxdydz$$

where ω is the body in which $Z(x,y,x) \leq Z^{o}$, the cut-off grade.

The statistical inference problem of mineral reserve estimation is a quite difficult one, both because the sampling procedures are expensive and because of the mathematical complexity of the problem[1].

As a starting point, we will use a stylized example, and at first assume that:

- The 'population' is a regular body of bedrock (Ω).
- The surveyor has no prior knowledge of the morpholgy of the ore.
- The sampling method is to drill vertical holes in the body.
- The task is to estimate the volume of ore richer than the cut-off grade (i.e. the volume of ω) inside Ω.

We divide the body into N vertical square strings, the side of the square being Δ. The total length of string i is ℓ_i. The total volume of the string is thus $L_i = \ell_i\Delta^2$.

A sample of n strings is selected at random, and the length of the string where the average grade exceeds the cut-off grade, is g_i. The volume of ore in each string is $G_i = g_i\Delta^2$. As estimatior of ω would be

$$\hat{\omega} = \Omega\,\frac{\Sigma g_i}{\Sigma l_i}$$

$\hat{\omega}$ is a ratio estimator which is unbiased if l_i is unstochastic and approximately unbiased of the variance of l_i is 'small'. Assuming independence between the g_1, standard textbooks give a variance formula for ratio estimators. For some minerals, which show rapid changes in concentration in the bedrock, reasonable estimates of the variance could be obtained using such formulas, provided that the holes are rather evenly distributed. In this case, the g_i will be approximately independent.

1) Matheron: "The Theory of regionalized variables and its Applications". Ecole Nationale Superieure des Mines de Paris (1971).

Other minerals show slower changes in concentration, and the g_i will be correlated, especially within clusters of holes. For an even spread of holes, the standard variance formula for ratio estimators will generally overestimate the variance.

In a practical case, some prior knowledge will always be available, based on experience concerning morphology, on seismic or magnetic surveys etc. Such knowledge can be used in stratification or in building models to predict the variation in the grade of the ore. In addition, the sample can be used to estimate the correlation structure of the sample. Matheron (op.cit.) sees the function Z as a random function, and he uses the statistical properties of Z to make statistical inference, given som information (estimates) of particular realizations of Z. His main tool to describe the statistical properties, is the semi-variogram.

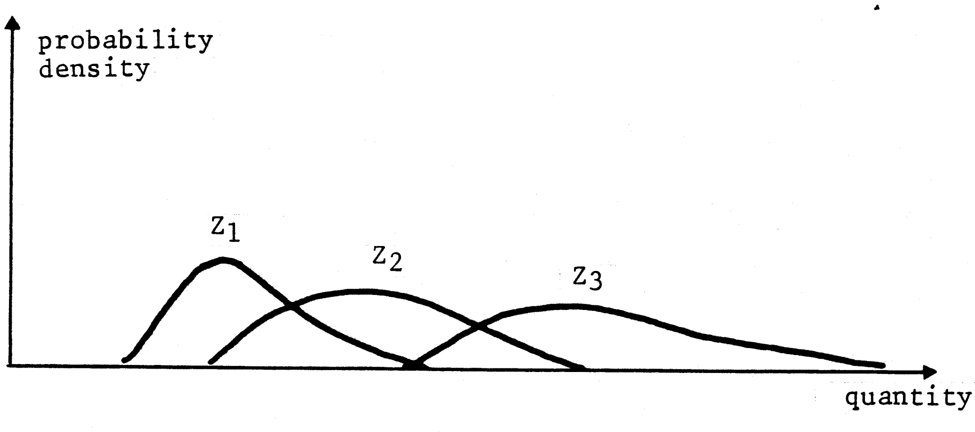
Given some regularity conditions, for instance that the difference $Z(x_1,x_2,x_3,)$ - $Z(x_1 + h_1, x_2 + h_2, x_3 + h_3)$ is stationary in x[1], the semi-variogram is defined by the equation:

$$\gamma\ (h_1, h_2, h_3) = \tfrac{1}{2}\ E\ \{Z(x_1,x_2,x_3) - Z\ (x_1 + h_1, x_2 + h_2, x_3 + h_3)\}^2$$

The semi-variogram can be used to obtain variance estimates of the $\tilde{\omega}$. Matheron gives both the theoretical formulas and several approximation formulas.

In general, the above procedure provides a 'family' of distributions corresponding to different cut-off grades, demonstrated in figure 1.

Figure 9. The probability density function of reserve estimates with different cut-off grades. $Z_1 > Z_2 > Z_3$



The probability density functions above can be interpreted as marginal densities with different truncation related to one simultaneous distribution of grade and quantity.

The management of the mining company has an economic objective for their activities: For instance maximal discounted profits. Such an objective function can be used to transform the technical estimates above to resulting optimal quantities. Such optimalizations will, somewhat simplified, correspond to different optimal cut-off grades, and members of the 'family' can be selected. Optimalization based on alternative price assumptions will result in different choices of cut-off grade and thus in different distributions.

Figure 9 can then be interpreted as an example of distributions of quantities in different cost classes, Z_1 being the cut-off grade of the reserves (currently economically recoverable). Z_2 and Z_3 can be interpreted as estimates of successive cost classes.

1) Weaker assumptions can be used as well.

2.2. Material flow accounts

The purpose of the material flow accounts is to follow the materials and the energy from the natural state and to the different sectors of the economy. The accounts are designed to help answering questions like:

- how much oil was consumed in Norway in 1977, and for what purpose?
- are any conservation measures required conserning the fish stocks?
- shoult the government initiate prospecting for mineral ores?

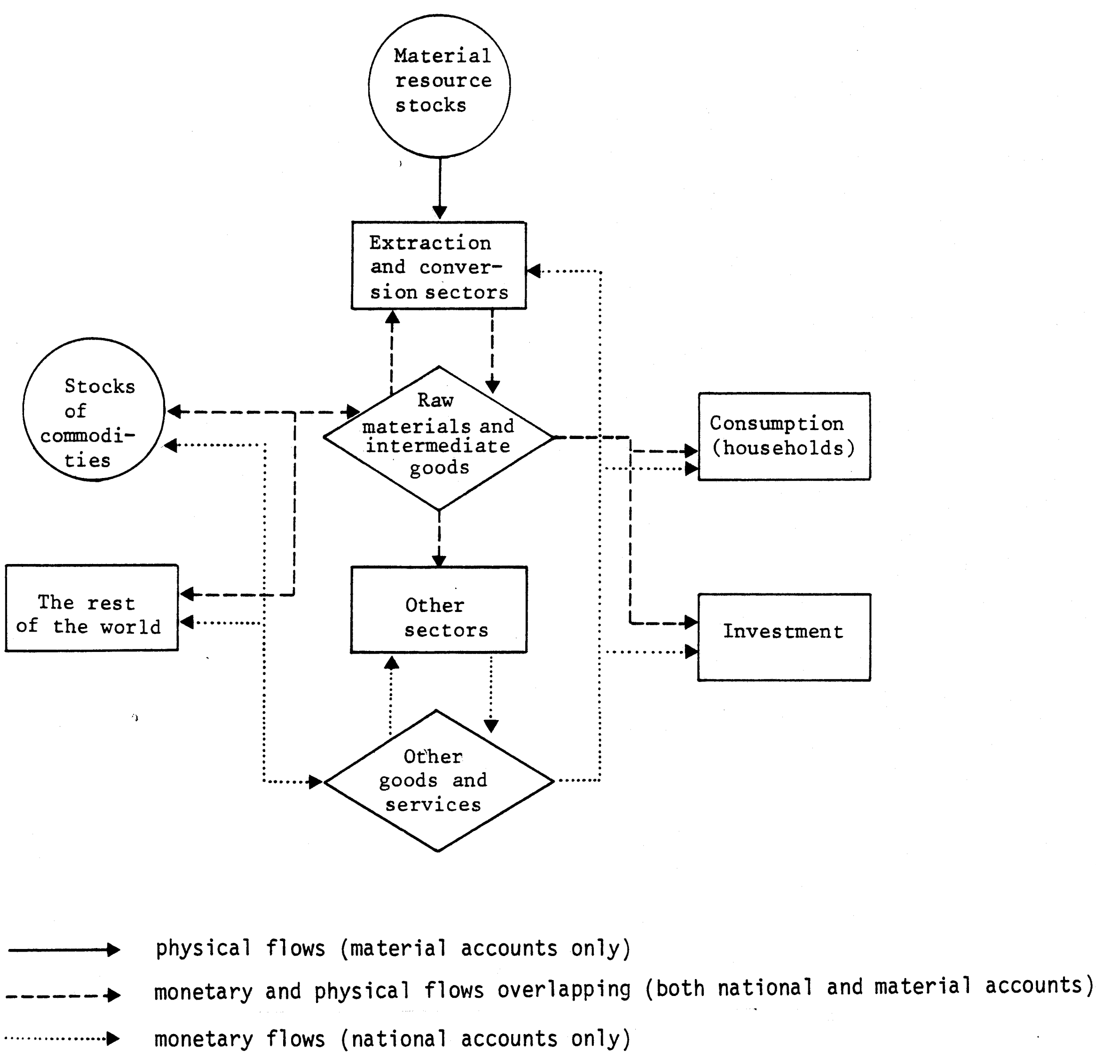
The geographic dimension (space) plays a minor role compared to the economic dimensions (sectors, commodities etc.).

As shown in figure 10 the material flow accounts can be regarded as a modified version of the input-output table of national accounts.

The modifications are:

1) The resource accounts are kept in physical units
2) Stocks of natural resources are included
3) Commodities other than "resource commodities" are excluded.

Figure 10. The main structure of the material flow accounts



For various reasons, the material accounts and the national accounts overlap. The overlapping parts are called the material flow accounts.

The material flow is followed from extraction, through conversion to the use in production sectors and household. The material flow accounts follow, with few exceptions, the definitions of sectors and commodities in the national accounts; the only major difference is the accounting unit.

At the outset, the production sectors of the national accounts can be divided into three groups:

- extraction sectors
- conversion sector
- other sectors

As a rule, the commodities can be classified in a corresponding way:

- raw materials
- intermediate goods
- services and other goods

Such a partition has to be done for each resource category for which material flow accounts are to be set up. In the following, the system is described as it is for a single resource category. In this connection the distinction between extraction and conversion sectors is not particularly important, and they are combined to the figure.

The general description can be formalized as an equation system, closely linked with the equation system of the National Accounts. In the Resource Accounts, the transactions between commodities and sectors of the NA is extended to cover extraction. Formally, this can be done by expanding the commodity list to include the resource categories. The sector list is not expanded; extraction sectors are already included in the ordinary production sectors.

In monetary terms the balance of the commodities can be presented as an equation which is rather familiar to economists:

$$DJ = C + I + G + A - B + L \tag{2.4}$$

D is the input-output matrix of the economy, specified in terms of commodities by production sector. The sum of the elements of D is the GNP of the nation. For our purposes, it is rather convenient to have it on commodity form, e.g. it is added up only in terms of sectors. The addition is performed by a vector of ones, $J = [1,1,\dots,1]^T$ of suitable dimension. The equation(s) can be interpreted as commodity balances in which net delivery of each commodity from the production sector (DJ) equals total domestic final delivery (C+I+G), plus export surplus (A-B), and net increase in stocks (L).

Similar commodity balances can be produced in physical units (mass or energy) for specific commodities which have been measured in such units.

The balances can be presented as:

$$D^mJ = C^m + I^m + G^m + L^m + A^m - B^m, \tag{2.5}$$

where m gives the change of unit. (Other commodities are annihilated, but the dimensions are kept for convenience of notation.) In themselves, the balances (2.5) do not provide much extra information compared to equation system (2.4), except in some cases, where price discrimination has distorted the monetary balance[1].

In order to make the accounting useful for practical useful for practical resource management, some aggregation has to be carried out. The physical units which have been used in the accounting

1) Longva (1977): Energibruk i Norge (Energy use in Norway).

are, however, not directly applicable in the aggregation. There is, however, a "natural" set of weights which can be called "resource concentration", for instance energy content in gasoline, crude oil, coal etc. and iron content in some mineral or in pig iron etc. Such natural weights could be used to reduce the number of commodities by making one aggregate for each "resource family", or rather group of natural resources and commodities. For convenience the groups of natural resources, are just called "resources" in this context.

We define F as the concentration of the different resources per physical unit of commodities, measured physically, specified in terms of resources and commodities (e.g. energy content in gasoline).

By premultiplying equation (2.5) the corresponding resource balance is obtained:

$$FD^mJ = F(C^m + I^m + G^m + L^m + A^m - B^m) \qquad (2.6)$$

Equation (2.6) equals the net delivery of the resources from the production sectors to the sum of:

i) resources delivered to domestic final demand $F(C^m+I^m+G^m)$
ii) resources delivered to increase in stocks FL^m
iii) resources in export surplus $F(A^m - B^m)$

By using analythic methods, it is possible to follow the resources further into the economy than is allowed by physical accounting. Such analyses are based on what we may call a "postulate of resource preservation". This means that resources which are put into a sector, are passed on in the products delivered from the sector. Thus, the resource are traced from the sectors which physically use it to the sectors which use the final products, for instance the household. The resource cost is imputed on the final products, and the results are called "resource cost" or "indirect resources". The technique is as follows:

S is defined as the resource cost in physical units per monetary unit of each commodity, specified in terms of resources and commodities. Commodities which are accounted for physically (having non-zero elements in D^m), will have a direct resource content F per physical unit in addition to the resource cost S per monetary unit.

The "postulate of resource preservation" can thus be represented by the matrix equation:

$$MU + FD^m + SD^m = 0 \qquad (2.7)$$

where M is the concentration of resources per unit of measured physically, specified in terms of resources. One element in the matrix might for instance be the iron content in mineral ore.

The matrix of natural resource extraction, U, is obtained by simply piling U_1 on top of U_2, obtaining a matrix of the dimension natural resource categories by producting sectors.

This matrix equation has the dimension resource by production sectors. For each resource and each production sector, the sum of extraction of resources (MU), net deliveries of physical resources from production sectors (FD^m), and net deliveries of resource cost from production sectors (SD), equal zero.

Rearranging (2.7)

$$SD = -(MU + FD^m)$$

In the classical Leontief model, resource costs would have been computed by inverting D, which gives:

$$S = -(MU + FD^m)D^{-1} \qquad (2.8)$$

In an activity analysis model, which is actually used, the input-output matrix is not square. The matrix is rectangular, which is due to the fact that the number of sectors is different from the number of commodities. The matrix D is therefore not directly invertible. By adding some extra restrictions to the system, it can be inverted. The matrix thus obtained is called D^{-1}, and has a function in the system analogous to an inverse. The formal solution will then be the same as for equation (2.8).

By aggregating equations (2.7) by sectors, one gets the equation

$$-MUJ = (SD + FD^m)J \tag{2.9}$$

which is a set of resource balances for the economy as a whole. By substituting (2.4) and (2.5) into (2.9), the overall resource balance can be represented as

$$\begin{aligned} -MUJ = {} & (SC + FC^m) + (SI + FI^m) \\ & + (SG + FG^m) + (SL + FL^m) + (S(A-B) + F(A^m-B^m)) \end{aligned} \tag{2.10}$$

This balance, which is the resource analogy equation (2.5), says that total domestic extraction of resources ($-MD^rJ$) equals the sum of the direct and indirect resource input (cost) in the production of the commodities that are delivered to:

- private consumption
- gross capital formation
- public consumption
- net increase in stocks
- export surplus

3. ENVIRONMENTAL ACCOUNTS

The development of a system of environmental accounts is as yet on a preliminary stage, and only a rough sketch of the system can be presented here.

The purpose of the environmental accounts is to show how the environment is used and how environmental qualities are changed as a result of emission of waste and other use. The environmental accounts consist of two parts:

a) The emission accounts, which deal with the emission of waste products into air, water and soil. Although the emission is a direct extension of the material flow described in the material accounts, it has been decided that the emission accounts should be considered a part of the environmental accounts.

b) The state accounts, which describes the state of the environment at different points in time and the changes of the environment in the periods between them.

The most important feature of the environmental accounts is that it is closely connected geographical dimension and describe a spatial structure.

Figure 11 shows the material flow of the emission accounts. The waste is producted in the households and in the production sectors. Some production sectors modify the waste into less harmful waste products or to commodities which can be returned to the economy. The net production of waste is returned to the environment (air, water or soil).

Figure 11. The emission accounts

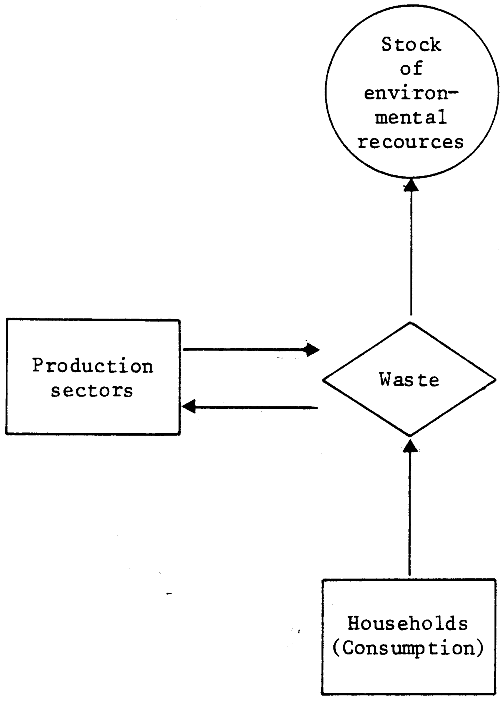
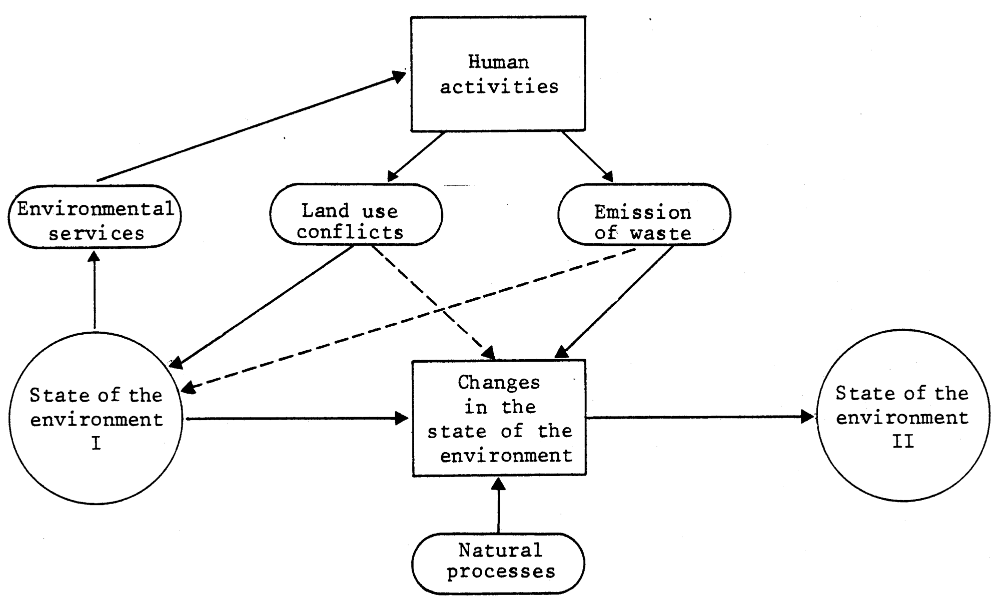


Figure 12 shows how the emission of waste, other human activities, and natural processes change the state of the environment.

The envirionment renders services to the humans: space, air to breathe, water to wash clothes in, air, water and soil for the use in production etc.

Figure 12. The environmental accounts



As the environment must be used on the spot, there will be conflicts between different users of the "same" environment: conflicts between polluters and inhabitants, land use conflicts, etc. Such conflicts will be both a limit to the use of the environment and a cause of changes in the state of the environment.

Equations in the resource accounts

Equation number	Equations	Interpretation	Dimension
		Reserved equation for biological resources	
(2.1)	$Z_1^t+R+\Gamma+O_3 =$ $N+U_1J+Z_1^{t+1}$	Reserves of biological resources at the end of period plus hunting/harvesting etc. in the period equals reserves at the beginning of the period regulated for natural growth, recuitment, natural death and revaluations.	Categories of biological resources
		Reserved equations for mineral resources	
(2.2)	$V^t+O_1+\Delta_1 =$ Δ_2+V^{t+1}	Undeveloped reserves at the end of the period t plus reserves developed during the period, equals undeveloped reserves at the beginning of the period, regulated for revaluation and new discoveries.	Categories of mineral resources
(2.3)	$Z_2^t +O_2+\Delta_2 =$ $U_2 \cdot J+Z_2^{t+1}$	Developed reserves at the end of period t plus extraction during the period, equals developed reserves at the beginning of the period, regulated for revaluation and development during the period.	Categories of mineral resources
		Equations for material flows	
(2.5)	$D^mJ =$ $C^m+I^m+G^m+$ $L^m+A^m-B^m$	Balance in physical units, which equals net domestic production of commodities total domestic final deliveries plus net exports.	Commodities
(2.7)	$MU+SD+FD^m = 0$	The equations defines S, resource cost of the commodities. Extraction of resources equals the sum of physical resources and resource costs from production sectors.	Resources x production sectors
(2.10)	$-MD^rJ =$ $(SC+FC^m) +$ $(SI+FI^m) +$ $(SG+FG^m) +$ $(SL+FL^m) +$ $(S(A-B) +$ $F(A^m-B^m)$	The overall resource balance of the economy: For each resource, total extraction equals the sum of direct and indirect resource costs to produce the commodities that are delivered to: - private consumption - gross capital formation - public consumption - net increase in stocks - export surplus	Resources

Appendix 2

Symbols and definitions

Symbol	Description	Unit of measurement	Dimension (formal dimension)
A	export	monetary	commodities
A^m	export	physical	commodities
B	import	monetary	commodities
B^m	import	physical	commodities
C	private consumption	monetary	commodities
C^m	private consumption	physical	commodities
D	input-output matrix	monetary	commodities x production sectors
D^m	input-output matrix	physical	commodities x production sectors
F	concentration of resources per unit of commodities	physical/ physical	resources x commodities
G	public consumption	monetary	commodities
G^m	public consumption	physical	commodities
I	gross capital formation	monetary	commodities
I^m	gross capital formation	physical	commodities
J	vector of ones		
L	net accumulation of stocks	monetary	commodities
L^m	net accumulation of stocks	physical	commodities
M	concentration of resources per unit of each natural resource category	physical/ physical	resources x natural resource categories
N	natural deaths of biological resources	physical	resources
O_1	revaluation of estimates undeveloped reserves of mineral resources	physical	mineral resource categories
O_2	revaluation of estimates, developed reserves of mineral resources	physical	mineral resource categories
O_3	revaluation of estimates, reserves of biological resource	physical	biological categories
R	recruitment to biological resources	physical	biological resource categories
S	resource cost per unit of commodities	physical/ monetary	resources x commodities
U_1	extraction (harvesting, hunting etc.) of biological resources	physical	biological resource categories
U_2	extraction of mineral resources	physical	mineral resource categories
U	extraction of resources (combination of U_1 and U_2)	physical	natural resource categories

Symbols and definitions (cont.)

Symbol	Description	Unit of measurement	Dimension (formal dimension)
V^t	estimates of undeveloped reserves of mineral resources at time t	physical	mineral resource categories
Z_1^t	estimates of developed mineral resources at time t	physical	mineral resource categories
Z_2	estimates of biological resource stocks at time t	physical	biological resource categories
Δ_1	discoveries of mineral reserves at time t	physical	mineral resource categories
Δ_2	development of mineral reserves at time t	physical	mineral resource categories
Γ	natural growth of biological stocks	physical	biological resource categories

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