UNITED NATIONS
ECONOMIC AND SOCIAL COUNCIL

Distr.
GENERAL

E/CN.3/492
29 March 1976

ORIGINAL: ENGLISH

STATISTICAL COMMISSION
Nineteenth session
New Delhi, 8-19 November 1976
Item 7 of the provisional agenda

ENVIRONMENT STATISTICS

Draft guidelines for statistics on materials/energy balances

Report of the Secretary-General

SUMMARY

The Statistical Commission considered a draft system of environment statistics (E/CN.3/452) at its eighteenth session, and recommended that work in this area should continue. The present paper deals with one part of the over-all framework of environment statistics proposed there, namely, statistics on materials/energy balances, proposing draft guidelines for the compilation of such statistics. It is designed on the same principles as the System of National Accounts, and is entirely compatible with the national accounts. It is also entirely compatible with "Towards a System of Integrated Energy Statistics" (E/CN.3/476), also before the Commission. Unlike the latter, which is focused upon short-run possibilities and objectives, the present paper is concerned with a longer-run statistical programme, one which may be thought of as an objective towards which to aim, rather than a project for immediate implementation.

The paper discusses the uses of statistics of this type (chapter II), design criteria (chapter III) and the structure of the proposed framework (chapter IV). It then goes on to provide the necessary definitions (chapter V). Chapter VI contains a short note on the assessment of environmental damages and abatement costs, and chapter VII suggests possible ways to approach implementation in the shorter run.

76-06520

CONTENTS

INTRODUCTION

1. The present paper[1/] is a continuation of work on part of the programme outlined in "Statistics of the environment", (E/CN.3/452), considered by the Statistical Commission at its eighteenth session.[2/] It contains draft guidelines for statistics on materials/energy balances, as part of the over-all development of statistics on the environment. Those elements of these guidelines dealing with energy statistics are in harmony with the programme outlined in "Towards a System of Integrated Energy Statistics" (E/CN.3/476), also before the Commission. The framework proposed is intended to encompass a common core of statistics that would be suitable both for analysis of the energy economy *per se* and for energy statistics pertaining to the environment.

2. The general character, purposes and possible uses of a system of environmental statistics has been discussed extensively, both at meetings and seminars[3/] and in previous documents.[4/] Hence, only a brief re-capitulation is provided here. Statistics on materials/energy balances were proposed as part of a phased programme of work on environmental statistics to be undertaken over the next few years by the United Nations Statistical Office and the Conference of European Statisticians, with support from the United Nations Environment Programme. It is thus conceived as a "module" in a larger system of statistics. The structure and content of the complete system have not, as yet, been fully defined, pending more extensive interaction between the agencies that would ultimately be responsible for defining classifications and compiling statistics and potential users thereof, both national and international. In the case of the materials/energy module, it is felt that user needs are sufficiently well defined to permit a more detailed level of specification at this time.

3. Briefly, the primary purpose of a system of environmental statistics (and, hence, of any module thereof) is to facilitate environmental studies and analysis with policy implications, particularly by and for Governments and international agencies. Such studies will, typically, require forecasts of the environmental consequences of various economic, demographic or technological trends or policies or, conversely, of the economic and social implications of environmental changes.

4. Obviously, there is already a large amount of accumulated raw data relevant to some environmental topics but much more is needed in other areas. Raw data may be derived from many sources, such as scientific measurements, questionnaires and sample surveys, administrative records etc. Many of these data have been, or will be, processed, compiled and published as special-purpose statistical series.

1/ Prepared by R.U. Ayres, acting as consultant to the United Nations.

2/ *Official Records of the Economic and Social Council, Fifty-eighth Session, Supplement No. 2*, paras. 86-92.

3/ A meeting on Statistics for Environmental Studies and Policies was held by the Conference of European Statisticians, Geneva, 19-23 March 1973 ("Report of the meeting", CES/AC/40/5, 26 March 1973); a Seminar on Environmental Statistics was held jointly by the Conference of European Statisticians and the Senior Advisors to ECE Governments on Environmental Problems, Geneva, 15-19 October 1973 ("Conclusions of the Seminar", CES/Sem. 6/11-Env. Sem 1/11, 27 November 1973).

4/ Conference of European Statisticians, "Statistics for environmental studies and policies" (CES/AC-40/2) (Geneva, 13 February 1973) and "Steps towards a system of environmental statistics (CES/Sem 6/2-Env/Sem 1/2) (Geneva, 4 September 1973).

5. There are also on-going programmes to develop internationally comparable statistics on population, urbanization, health, nutrition, education, social variables, weather and climate, resources, energy, agriculture, trade and so forth.

6. In the context of the existing United Nations programmes, the proposed system of environmental statistics has two important functions. First, it will provide a broad framework for co-ordinating and harmonizing a number of concurrent statistical activities. Secondly, it should provide guidance to both national and international statistical offices in terms of evolving future activities in such a way as to fit into a coherent over-all scheme.

7. It is natural to raise the question as to why a broadly conceived system of environmental statistical is really needed. Why not, in other words, build another set of special statistics encompassing purely environmental changes such as ambient pollution levels and discharges? This question is all the more important, inasmuch as many statisticians have evidently assumed that environmental statistics, would, indeed, be limited to this kind of data. The materials/energy balance module, on the other hand, does not include statistics about the ambient state of the environment but does, very clearly, overlap other existing types of special statistics such as energy and industrial statistics.

8. The answer to this question can be found in the nature of the environment itself--it is all-encompassing by definition--and the requirements imposed by this attribute of comprehensiveness on the analytical tools needed to study or do research on environmental issues. It is not enough to consider biological or ecological effects in isolation. For purposes of environmental policy evaluation and assessment, changes in the biosphere or the climate of the earth must be traced back to social and economic activities of man which, in turn, depend upon resource constraints and technology. It is the causal connexions between these diverse phenomena that matter and for which an international system of statistics is needed. A set of statistics that simply describes the ultimate physical or biological consequences of the causal chain, without incorporating data on the critical dynamic mechanisms, would have a very limited value to policy makers. Its value would not be consonant with the enormous cost of acquiring and processing the necessary data on a worldwide basis.5/

9. In short, special-purpose statistics are a valuable resource in the context of short-range environmental problem-solving, but they are seldom adequate for longer-range analytical studies--a purpose they were after all not designed to serve. For the latter, it is essential to distinguish observed symptoms or effects (which are by far the easiest to measure, and, hence, dominate the existing data), from more

---

5/ The possible scientific value of such data is another question. It must be pointed out, however, that the kind of data most valuable to scientists is often of little or no use to statisticians. For instance, marine biologists interested in the movement of toxic substances (say, mercury) through a "food chain" of biological organisms would like to gather very complete data, covering a large number of organisms, for a specific lake or bay for which mercury inputs could be monitored exactly. On the other hand, environmental policy makers would prefer to collect time-series or cross-sectional data on the mercury content of all fish sold for human consumption. The design of a suitable monitoring system will be completely different in the two cases, and the data gathered for one purpose would generally be of negligible value for the other. It remains to be seen, however, whether data gathering projects can in principle be designed to serve scientific and environmental policy purposes simultaneously.

fundamental underlying variables or driving forces. While a thorough explanation of this distinction cannot be undertaken here, suffice it to say that the system of environmental statistics--and materials/energy balances, in particular--will be designed to satisfy the broader needs of governmental agencies for a systems approach to the analysis of policy choices with respect to environmental implications of major public projects, technological developments, material substitutions, fuel substitutions and so forth. These purposes require development of analytical tools and models utilizing extensive data on environmental media, resources, processes, and stocks and flows of materials and energy.

10. An important distinction can be made between statistics that are derived entirely from direct measurements (or survey responses) and statistics that are, in part, synthesized from a combination of direct measurements and physical, biological or economic models. The importance of the distinction can best be explained by an example. Let us suppose that it is deemed important to develop uniform statistics on the discharge of pollutants into the atmosphere by region. The most straightforward approach is to sample the atmosphere in a large number of locations, utilizing spectrophotometres, lasers and all other available instruments, and compile the resulting measurements. Of course, the practical difficulty and expense of the method dictates that the number of sampling locations and times will be limited, it being assumed that measurements taken at random times and locations will be typical.6/ An alternative approach would rely on in-depth engineering studies, including detailed measurements where necessary, of each industry, starting with the biggest and most obviously polluting ones, to develop a set of characteristic coefficients relating material and energy inputs, production of useful products and production of waste products. The coefficients can also be statistically related to scale of production, age of facility and other variables. (In short, a model is built for each industry). Estimates of production of pollutants for a region, then, can be generated from a combination of engineering process data and economic statistics on industrial production by commodity, process and location. This alternate strategy is particularly vital in the environmental area and will be a key factor in making basic decisions in the design of the system of environmental statistics, and especially materials/energy balances.

11. The use of partly synthetic statistics and other innovations can help to keep the difficulty and cost of developing the module within reasonable limits, but, - as will be seen, - its ultimate scope is nevertheless quite large. This naturally raises three related questions. First, is it a practical goal to implement such a large system? Secondly, are there ways of implementing it in stages, starting with comparatively small parts of the full system, so as to establish procedures and work out difficulties before a full-scale commitment is made? Thirdly, would a modest part of the complete system have significant value in itself, independent of the rest?

12. It is clear that if the answer to even one of these questions were negative, the probability of success would be slight. Chapter VII argues for affirmative answers to all three questions, however, and proposes a specific strategy for implementation in stages.

6/ This assumption is very likely to be faulty. For obvious reasons, teams of technicians carrying out sample surveys are quite likely to prefer working during ordinary (daylight) business hours. Polluters know this. It is widely rumoured, therefore, that major polluters save their worst pollutants for discharge at night, when visibility is bad.

I. ACTION BY THE COMMISSION

13. The Statistical Commission may wish to comment upon the scope, feasibility and desirability of the framework described herein, as a basis for organizing statistics on materials and energy balances, in the light of the relationship of that framework to the wider body of environmental statistics, on the one hand, and to the national accounts and balances, on the other hand.

II. USE OF MATERIALS/ENERGY BALANCES IN SIMULATION AND OPTIMIZATION MODELS

14. Probably the major application of statistics on materials/energy balances will be as a basis for constructing large-scale models for environmental forecasting and management purposes, just as there is a natural application of national accounting data to the development of input-output economic models. Indeed, the module will facilitate the natural extension of input-output models to incorporate resource requirements and waste residual outputs and to reflect the fact that the material/energy inputs and outputs for the economy must always balance.

15. Table 2 of the framework displays the origins and destinations of each individual commodity (material or energy). But this information can also be expressed in the form of a commodity input-output table showing the relationships between all materials and forms of energy simultaneously.

16. A table of this kind can be used as an adjunct to a conventional (monetary) input-output table, or it can be used independently in an exactly analogous manner. (Indeed, the basic equations are identical). Thus, if a certain set of "final" material commodities is required, the matrix will immediately tell us the corresponding total quantity of each material or form of energy - including all raw materials and intermediates - that must be produced, based on current technology production. When the matrix is inverted, we can also discover the amount of each material or form of energy that is embodied both directly and indirectly in a unit quantity of any specified final material.

17. Thus, the inverse commodity matrix will tell us exactly how much energy, by type, is consumed both directly and indirectly in producing a given final product commodity - whether it be a loaf of bread or an automobile. Hence, the materials/energy input-output matrix will greatly facilitate answering questions that have sometimes proved vexatious in the past. For example, there has been controversy as to whether or not a hypothetical new technology such as solar cells for direct conversion of solar energy into electricity or direct microbiological conversion of petroleum into protein (by-passing conventional agriculture) would actually conserve more energy than it consumes. These questions can easily be settled by computing the direct and indirect energy required to produce the solar cells and supporting equipment, or the synthetic protein, respectively. These figures can be compared to the expected lifetime electricity output of the solar cells, on the one hand, or direct and indirect energy input to animal protein produced by conventional agriculture, on the other hand.

18. Optimization models may be expected to come into increasing use for purposes of environmental management. Selections must be made among alternative investment and abatement strategies, processes and/or manufacturing technologies, sources of

raw materials, locations of productive facilities, planting patterns for crops, product mix patterns for refineries and so forth. Models used for dealing with questions of this sort are typically of the "activity analysis" type, with optimization algorithms based on linear programming. Non-linear programming, rank-order enumeration and other methods can also be applied.

19. The formal uses of materials/energy balances in constructing and implementing environmental assessment and/or forecasting models of various types will be discussed below. However, it may be useful to review a typical situation where statistics on materials/energy balances or their equivalent would be helpful to policy-level planners. There have been a number of instances in recent decades where a particular pollutant was suddenly discovered to be potentially dangerous for some reason. Examples include the following:

(a) In 1959 mercury poisoning was tentatively identified as the cause of "Minimata disease", so-called because of a large-scale outbreak near the village of Minimata, Japan, beginning in 1953. Research in the last decade has shown that matallic mercury discharged in industrial wastes is converted by bacterial action to organic methyl mercury which is water soluble and is incorporated into the marine food chain, where it is gradually accumulated and concentrated in the bodies of fish or other higher organisms that are eventually consumed by humans. When this phenomenon was discovered it became apparent that mercury, in any form whatever, is environmentally dangerous.

(b) Also in Japan, a new disease called "Itai-Itai" (the aching disease) appeared starting about 1910 in the villages of the Jinzu River basin down-stream from a copper mine. The cause of the disease was traced eventually to cadmium, discharged with the mine waste. Like mercury, it is apparent that cadmium in the environment is exceedingly toxic and dangerous, regardless of circumstances.

(c) Rachel Carson's landmark book, Silent Spring 7/ identified DDT (endrin, dieldrin and some other chlorinated hydrocarbons) as environmentally hazardous due to its long residence time in soil and natural organisms. Like methyl mercury, DDT passes through the food chain and is concentrated by organisms at the higher trophic levels, such as fish-eating birds and insectivores. It can also cause harm directly to humans. For these and other reasons DDT, endrin and dieldrin have been banned in the United States of America. The long-term prognosis is not clear at this point.

(d) Evidence has been found that chlorinated biphenyls--another type of persistent chlorinated hydrocarbon were building up in the oceans of the world. It was suggested that this might interfere with the growth of phytoplankton, the primary photosynthetic organisms upon which the entire marine food chain depends--and which also constitutes an important link in the oxygen cycle of the world.

(e) Some evidence has come to light that inert and long-lived chlorine-bearing fluorocarbons, used as propellants for aerosol products may be accumulating in the stratosphere where the chlorine may combine with ozone, thus depleting the "ozone layer". This would allow more intense ultra-violet radiation to reach the surface of the earth, thus potentially increasing the incidence of skin cancer.

7/ New York, Fawcett World, 1962.

(f) Another organic chlorine chemical, vinyl chloride, has been found to be highly carcinogenic. This chemical is exclusively used to manufacture the ubiquitous plastic polyvinyl chloride (which is perfectly safe). However, during the manufacturing process some of the vinyl chloride monomer may escape into the environment. Workers, in particular, have some chance of exposure to it. Also, there is a possibility that a small quantity of unreacted vinyl chloride may be incorporated in the finished plastic product where users might be exposed to it.

(g) Carbon dioxide in the earth's atmosphere tends to absorb infra-red radiation from the earth and re-radiate it isotropically, thus acting as a reflector. This is called the "greenhouse effect", since it tends to warm the surface of the earth by preventing heat from escaping. Combustion of fossil fuels produces carbon dioxide and may increase the average concentration in the atmosphere, thus tending to raise the average temperature of the surface of the earth. On the other hand, combustion produces small particles, especially in the range of diameters less than one micron (10^{6} metre or 10^{3} mm), which reflect visible light very effectively. An accumulation of particulates in the stratosphere could, thus, lead to a cooling trend. It is not yet known which of these phenomena is likely to be predominant, and the over-all climatic consequences of simultaneously injecting both carbon dioxide and small particulates into the atmosphere via combustion and other processes is a matter of fierce dispute among the experts.

20. It is evident that, in all such cases, discovery of a potential problem associated with a particular waste residual naturally leads to questions about the over-all quantity of the residual, its geographical distribution, and the processes or industries with which it is associated. This type of information is far from easy to find, in general. One can say that carbon dioxide results from combustion of fossil fuels and estimate that approximately all fossil fuels produced in a year are also consumed in combustion processes. Similarly, all DDT that is produced is presumably dispersed into the environment in one way or another, though the geographical pattern of use is not so easy to fix. But what about the other cases?

21. Mercury is used in a variety of products, including fungicides, pharmaceuticals, thermometers, mirrors, mercury vapour lamps and dental alloys. It is also used as a catalyst in a process for the manufacture of chlorine and acetic anhydride - probably the major source of leakage into the environment. Cadmium is a by-product of zinc and is often found in zinc or copper mine or smelter wastes. It is also used as a plating material, in batteries, as a pigment and as a plasticizer - among other uses. Some of these uses may lead to environmental problems while others will not. How can we estimate the current quantities and locations, and the likely future changes in use and waste-flows?

22. Polychlorinated biphenyls are mainly used as high-temperature coolants for electrical transformers and similar devices. Chlorinated fluorocarbons are used as inert aerosol propellants as already noted--and also as refrigerants for household refrigerators and air-conditioners. Again, how can we estimate present production and usage patterns and project future changes?

23. Statistics on materials/energy balances are specifically designed to deal with questions like these.

III. DESIGN CRITERIA AND PROBLEMS

24. The importance of designing the system of environmental statistics and its various parts, such as materials/energy balances, to be compatible with the existing System of National Accounts (SNA) has been repeatedly stressed. Clearly, the same underlying structure and definitions should be used. Even if one system requires more disaggregation than the other, categories should be consistent with each other as far as possible. Thus SNA definitions and categories will be used unless there is a specific reason not to do so. Any deviation must be explained and justified. Similarly, the framework should be designed to co-ordinate a wide range of existing types of special statistics on energy, resources, industrial production etc.

25. The primary purpose of materials/energy balances is to trace the extractions and transformations of materials and energy from natural resources through various successive stages of processing to final use, and thence back to the environment as waste (or to secondary uses). The statistics must, therefore, deal explicitly with transformations from one form (or category) to another. This introduces a number of difficulties and creates risks of undercounting or overcounting. For instance, coal is used to generate electricity, another form of energy. Clearly, electricity generated from coal-fired boilers cannot be treated as an item in the accounts equivalent to coal itself, even though some users might consider them mutually substitutable. From the statistical viewpoint, processed forms of materials or energy should be kept separate from raw forms. Moreover, each stage of processing must be conceptually distinguished.

26. Another difficulty is posed by the interconvertibility of fuels and materials for other purposes. Natural gas, oil, coal and wood can be burned for heat. Or coal can be converted to coke which is used to reduce iron ore. The chemical energy value contained in the coke is partly wasted in the form of heat and by-products such as carbon dioxide and partly embodied in the product (pig iron). If the pure iron were oxidized (i.e., burned), it would revert to the chemical form of the ore (Fe_2O_3 or Fe_3O_4). Thus reduction is, energetically, the reverse of oxidation.

27. An example which is currently quantitatively insignificant but may be important in the future is the use of refined metals such as lead, zinc and nickel as battery anodes. (In the future lithium, sodium or magnesium may be widely used in this application). As the battery is discharged, the metal in the anode reacts with oxygen or some other element, resulting in a lower available energy content. The process may be reversed by recharging the battery using an external electrical supply. A satisfactory statistical system must be capable of disentangling these energy conversion processes.

28. Another troublesome case arises when natural gas, together with atmospheric air, are converted into ammonia. The hydrogen in the ammonia comes originally from the methane in the gas. Thus, the gas is, in effect, a feedstock for a non-fuel chemical product. (Of course, the ammonia has energy content and could actually be used as a fuel). Natural gas is also the main source of ethane and propane, which are in turn converted to ethylene and propylene, basic building blocks of organic chemistry leading to synthetic fibres, plastics and so forth. In the same way butane, benzene, toluene and xylene are generally obtained from cracking crude oil or, less frequently, from coal tar. These are used, in turn, to manufacture butylene, butadiene, styrene and a host of other synthetic elastomers and polymers.

29. Obviously, some materials that are manufactured from potential primary fuels later become available again as secondary fuels. This applies especially to organic materials such as paper and paperboard. Similarly, secondary flows of non-fuel materials must be considered. A satisfactory statistical system should explicitly reflect these factors.

30. It is important to note, also, that many processed materials can be derived from alternative - sometimes very diverse - sources. Acetic acid and methyl alcohol can be obtained commercially from destructive distillation (pyrolysis) of wood or from fossil hydrocarbons. Ethyl alcohol for human consumption is derived from distillation of fermented carbohydrates (grain, potatoes, fruit etc.), whereas industrial alcohol is produced - much more cheaply - from natural gas liquids. Benzene and toluene are industrially produced from coal tar or from petroleum. Sodium carbonate (soda ash) is currently obtained mainly from natural deposits (trona), whereas it was formerly synthesized by the Solvay process from sodium chloride (rock salt) and limestone. The reverse is true of aluminium fluoride (cryolite), used in large quantities in the aluminium industry, which was formerly obtained from a natural deposit in Greenland but will, in the future, be manufactured synthetically (unless its use is obviated by a process change).

31. Many industrial chemicals which are now produced directly from raw materials will be derived largely or entirely from waste products in the future. The most obvious example is sulphuric acid, which is currently manufactured from elemental sulphur but will eventually be a by-product of coal or oil desulphurization or stock-gas treatment. Examples are not confined to the chemical and metallurgical industries. For instance, plaster of Paris - used in the building industry - is currently manufactured from the natural mineral gypsum, but will probably be available as a by-product of future stack-gas treatment processes. Future insulation, paving materials and other construction materials will undoubtedly be derived increasingly from recycled wastes. And already many food products and additives are being derived from non-agricultural sources. This is notably true of synthetic beverages and sweeteners, but animal feedstuffs and even synthetic proteins may be manufactured from fossil hydrocarbons in significant quantities before the end of this century.

32. An important consequence of the foregoing, from the standpoint of designing a set of tables, is that groupings that might seem "natural" today may not be so a few years hence. In particular, it cannot be assumed that a given processed material always comes from the same raw material or that a given raw material or ore will always be refined into the same final product. Thus, while it is sometimes useful to distinguish raw (unprocessed) materials from processed materials, this cannot be done meaningfully within a more narrowly defined category such as "agricultural products", "fuels", or "chemical products".

33. The interconversion of materials and forms of energy raises a potentially troublesome set of problems pertaining to units of account. Various inputs to a physical or chemical conversion process may be traditionally measured in different units; similarly, inputs and outputs may be measured in different units. For instance, coal entering a generating plant is normally measured in mass (tonnage) units while electricity output is measured in kwh. The equivalence factor between tons of coal and kwh of electricity is not a natural constant: it depends on the quality of the coal and the efficiency of the generating plant and varies over time. (The "energy balance" between outputs also involves different units--BTU and kwh).

34. Another example arises in the case of petroleum refineries where simultaneous materials and energy balances are needed. The input crude oil is measured in physical volume (usually in barrels) which is characterized by a certain average heat energy content (BTU/bbl). The outputs are also measured in volume terms, but the energy per unit volume of various refinery fractions (gasoline, naphtha, fuel oil, residual oil) varies quite considerably due to differences in specific gravity. Thus, the total volume of outputs need not be exactly equal to the volume of inputs, but the sum of weights and energies should, of course, balance when losses are considered. The specific gravity of input crude oil will vary from one country to another;[8] similarly, the specifications (including specific gravity) of outputs will also vary. Thus a set of supplementary weight/volume/energy equivalences must be supplied for each conversion process and for each country. Many of the indicated equivalence tables will, of course, be required for international energy statistics.

35. It is important to bear in mind that materials/energy balances will not be useful for cataloguing all actual or potential pollutants. They are necessarily concerned with volume pollutants, such as organic wastes or combustion products, plus specific major chemicals and metals. However, some pollutants are not subject to conservation rules. These include noise - (a non-conserved form of waste energy), - visual pollution and litter, carcinogenic, mutagenic, teratogenic or toxic organic chemicals and radio-active wastes. These can only be dealt with by linking the materials/energy balances to supplementary tabulations, such as the proposed International Registry of Toxic Chemicals.[9]

36. Logically, materials/energy balances could include the "stocks and flows" of some elements such as carbon, nitrogen, phosphorous (and energy) in major environmental reservoirs, such as the atmosphere, soil, forests, surface waters and oceans. At present, this must be regarded as an objective for the distant future, since it is not practically feasible to quantify most of the flows at present. From an environmental point of view, this gap is a major challenge that must be filled, in the first instance, by design of appropriate environmental monitoring systems, such as the Global Environmental Monitoring System (GEMS) currently being developed by the United Nations Environment Programme.

37. Similarly, ecological and health effects associated with pollution cannot now be incorporated into materials/energy balances. Such statistics are currently compiled to a minor extent by national agencies, Food and Agriculture Organization and World Health Organization. Similarly existing industrial and resource statistics must also be co-ordinated. Links can be provided by developing supplementary tables to reconcile relevant definitions and categories. At some future time, it would be desirable for the system of environmental statistics to incorporate these external data on a uniform and consistent basis.

8/ In tropical countries, crude is often "spiked" by addition of naphtha to increase the output of light fractions, since heavy fuel fractions (used for heating) are less required.

9/ See "The International Register of Potentially Toxic Chemicals - components and network", Report of the United Nations Environment Programme Workshop, 20 January 1975, UNEP/WG.1/4/Rev.1. The linkage would be essentially automatic as long as both systems use the same or related classifications.

IV. STRUCTURE OF STATISTICS ON MATERIALS/ENERGY BALANCES

38. The underlying design principle for the proposed statistics on materials/energy balances is conservation of materials and energy: all material and energy inputs to the world economic system, as well as to individual countries, must be accounted for either as final outputs or as changes in accumulated stocks, including durable goods in service as well as inventories. Two "balance" concepts are used: a gross (volume) balance is applied in the case of production, consumption and trade of major resources and commodities. A more refined materials and energy balance, by process, is also applied to elucidate the relation between resource/commodity production and consumption and the generation of waste flows.

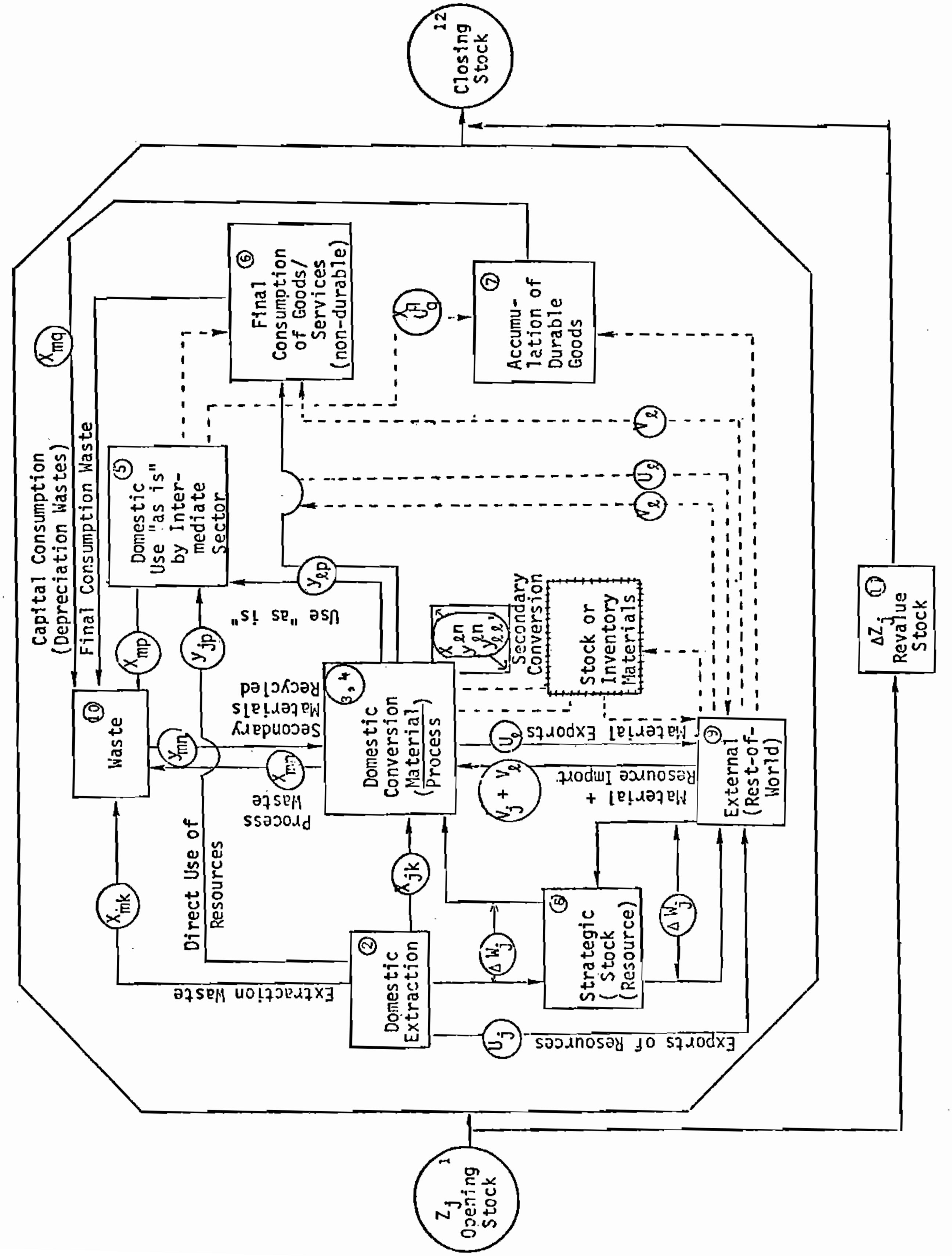
39. Some of the categories used are standard ones from national accounts statistics, namely, domestic output, imports, exports, domestic consumption and sectoral classifications of economic activity. There are two significant additions: (a) physical stocks and flows, including commodities and wastes; and (b) explicit materials/energy transformations, that is, processes.

40. The terms "stock" and "flow" are used above in a general and somewhat undefined sense. Definitions of these terms, as specifically used in the present document, will be given below. Distinctions must be made between stocks that are physically distinguishable natural reservoirs, such as ground water or oceans, and stocks that are essentially accounting categories, differentiated by ownership, production process etc. Similarly, flows may be additions to or subtractions from the quantity of a physical resource contained in a given natural reservoir; they may be transformations from one physical form to another; or they may represent shifts from one accounting category to another.

41. All changes of stocks are equivalent to flows, and this accounting identity is essential in constructing a statistical system. It follows, too, that changes in a stock can either be determined by direct enumeration and/or direct measurement, or they can be inferred by measuring and summing the corresponding input and output flows. Where both possibilities are feasible, one provides a useful check on the other. Sometimes only one of the two approaches is feasible, however, and it is not necessary to specify which approach is to be used in any given case.

42. Because of the interconnectedness of materials/energy stocks and flows, it is natural to employ a schematic matrix form of presentation. This format emphasizes the structural linkages with SNA; it also facilitates understanding of the differences between the two systems. The structure of the proposed framework is displayed graphically in figure I and in matrix form in the Annex. (Explanatory notes and a list of symbols and accounting identities in the system are also included in the Annex). It will be noted that balances can be defined at two different levels of aggregation. In the first place, all material and energy input and output flows to a given category or interaction box in figure I must exactly be accounted for by depletion or accumulation of some stock. This must hold not only for gross quantities (measured in mass or weight, for instance) but also for specific chemical elements. For instance, all phosphorus consumed by a sector must be compensated for exactly by the phosphorus content of production or of accumulation. By extension, of course, the same kinds of balances must also hold for groups of sectors, or for the economy as a whole. Thus, all sulphur that is extracted from the earth each year, either directly as sulphur or as a contaminant of petroleum or coal, must either accumulate in some reservoir or stock of durables, or it must become a corresponding flow of waste residuals.

Figure I. Diagrammatic presentation of materials/energy balances



43. The stock/flow data required to complete the scheme outlined above can be displayed conveniently in four major tabulations. Table 1 displays aggregated data on production, consumption and stocks of resources at all stages of processing, beginning with natural resources and unprocessed commodities and proceeding through all intermediate forms to finished materials and classifiable products. Fuels and forms of energy are also included.

44. It is certainly possible, in principle, to subdivide table 1 into several parts, as has been advocated. For instance, natural resources (not extracted), raw materials, and fuel (as extracted), and processed materials and processed forms of energy could be separated into separate tables for convenience. Similarly, natural resources could be subdivided into renewable and non-renewable categories with separate tables for each. These subdivisions may ultimately be done for convenience, since the combined table will obviously be very large. However, any separations also necessarily introduce some degree of arbitrariness. Is forage or pasture harvested by animals to be regarded as "extracted" or not? Are ground water or top soil "renewable" or not? To avoid fruitless controversy over such questions, it seems advisable to avoid unnecessary boundaries.

45. The purpose of table 1 is to display gross accounting balances for each major natural resource or commodity in large-scale production. In the case of renewable natural resources, such tables would provide a basic management tool, e.g., for adjusting extraction rates to maximize output without depleting the resource. In the case of non-renewable resources, the current extraction rate would typically be measured against the rate of upward revaluation of stocks due to exploratory activity or improvements of extraction technology. Limitations on current production of resources and on its rate of expansion constitute an important input to resource/environmental management and economic forecasting models.

46. Commodity data are included in the same basic tabulation because they provide the necessary link between final demand for goods and services and calls on basic resources. Again, these data would primarily be utilized in resource/environmental management and forecasting models.

47. The resource/commodity balance data in table 1 will generally be derived annually from current government statistics on agriculture, fisheries, forestry, mining, manufacturing and trade. Departments of parks, tourism and urban affairs will also provide some data. While these standard statistical sources are not necessarily of high quality, the over-all figures thus derived will nevertheless constitute a useful means of updating and projecting the more detailed materials/energy balance-by-process data in table 2, discussed below. Table 1 would include production, consumption, import, and export figures for such materials as DDT, chlorinated biphenyls, fluorocarbons, polyvinyl chloride, mercury and cadmium, thus providing basic data to deal with questions of the type discussed above.

48. Table 2 is an elaboration of table 1, providing breakdowns on material/energy source by extraction or production process, subsequent conversion (if any) by process, utilization as such, by sector and incorporation into various durable goods, by category.

Table 1. Resource/commodity accounts

Country/year

Account	Resource/ commodity name	Resource No. 1	Resource No. 2	Resource No. 3
		Hectares x 10^3	M^3	Bbl
Opening stock not yet extracted				
Stockpile held for strategic reserve				
Withdrawals from (additions to) strategic reserve				
Domestic production (total)				
Exports				
Imports				
Domestic consumption (total)				
Domestic use for conversion to other commodities				
Domestic utilization in unconverted form				
Additions to, or revaluations of opening stock				
Closing stock				

Table 2. Conversion/disposition accounts

Accounts	Resource/ commodity (name, unit)	Resource No. 1 (units)					
Sources, by major production process	Production process name	Process 1	Process 2	Process 3	Process 4	Process 5	Other process n.e.c.
	Process type, code						
	Quantity produced						
Disposition by major conversion processes	Conversion process name	Process 1	Process 2	Process 3	Process 4	Process 5	Other process n.e.c.
	Process type, code						
	Quantity converted						
Disposition by incorporation in major commodities	Commodity name	Commodity 1	Commodity 2	Commodity 3	Commodity 4	Commodity 5	Other commodity
	Commodity code						
	Quantity accounted for						
Utilization by sector (final form)	Sector	Agri-culture	Manu-facturing	Construc-tion	Transport	Govern-ment and services	Household
	Quantity						
Utilization by category of durables (final form)	Category	Machinery and equipment	Producer struc-tures	Residen-tial housing	Personal vehicles	Household appliance	Other private
	Quantity						

49. The purpose of table 2 is to display moderately detailed relationships between inputs and outputs of materials and energy, including wastes, at the successive stages of production and transformation of natural resources into commodities and subsequently into final goods and services. The data will ultimately provide a basis for projecting detailed resource and energy requirements and gross residuals generation prior to abatement processes, consequent to changes in the technological level of industry or the pattern of government regulation. It also permits, in principle, the development of linear-programming or related models to facilitate the optimal choice of industrial development strategy and pollution abatement strategy in terms of resource and conservation and environmental protection criteria.

50. Statistical data for table 2 are not completely available currently in most countries, and would have to be gathered especially, through such sources as a census of manufactures. This is unlikely to be carried out on an annual basis in the foreseeable future and would, in any case, involve significant delays for data processing and checking. Thus, table 2 will normally be compiled several years later than table 1; it will be several years out of data when published - and will be prepared at less frequent intervals. It will constitute a "benchmark" in the same sense as the input-output tables now prepared at intervals by several Governments. Table 2 would include information on key industrial processes. For example, it would show the amount of chlorine that is produced by means of the so-called "mercury-cell" method of electrolysis (as opposed to the "diaphragm cell"). It is only the former which leads to loss of mercury to the environment. It would also show the amount of cadmium that is used for plasticizers, which might ultimately escape to the environment via incineration of combustible solid wastes.

51. The connexion between tables 1 and 2 is not completely defined without a set of supplementary tables displaying the equivalences between weight, volume, heat and electrical energy units for inputs and outputs of each conversion process. Typical equivalence relationships that must be specified include: density (mass/volume), energy content (BTU/kg or BTU/litre) and generating efficiency (kwh/BTU). As noted previously, these equivalences vary from year to year and from country to country.

52. Table 3 is concerned with production, consumption (depreciation) and stocks of durable goods, by category. A supplementary table must also be developed, indicating typical or average materials content of the various categories of durables.

53. The purpose of table 3 is mainly to develop a record of stocks of durables in use, from which inferences can be drawn with regard to future wastes to be disposed of and materials potentially available for recycling, particularly metals. A gross accounting type of balance is likely to be adequate. Most of the data, except on depreciation and scrappage, are already available from conventional sources. Data on depreciation and scrappage of durables will require some extension of currently available data from such sources as census of households and of manufactures.

54. The table would also be useful in the event that some material already in widespread use was found to be potentially harmful (as, for instance, lead pipe or lead-based paint). Many household appliances or machines contain component elements that may cause environmental hazards when the equipment is eventually discarded, especially if it is incinerated. Examples include fluorocarbon refrigerants, high-temperature coolants, mercury-vapour lamps and mercury-switches. The rapidly

Table 3. Accumulation accounts

Accounts	Measure	Type of durable					
		Machinery and equipment	Producer structures	Residential housing	Personal vehicles	Household appliances	Other
Opening stock	Value ($)						
	Units						
Domestic production	Value						
	Units						
Exports	Value						
	Units						
Imports	Value						
	Units						
Domestic consumption (addition to stock)	Value						
	Units						
Domestic scrappage (depreciation of stock)	Value						
	Units						
Revaluation of opening stock	Value						
	Units						
Closing stock	Value						
	Units						

spreading use of synthetic fabrics and plastics for household furnishings and even structural components, combined with an enormous number of different plasticizers, stabilizers, fire retardants, colouring agents, water repellants and so forth, raises strong possibilities that currently unsuspected risks will come to light from time to time. When this occurs, statistical data on the distribution and use of the dangerous substances will obviously be needed.

55. Table 4 is concerned with generation and disposition of waste materials and forms of energy, by type. It lists categories of waste and tabulates sources by production process, by type of end-use, by sector etc. Wastes generated by depreciation of durable goods are also tabulated by category of durable.

56. Table 4 is, in certain respects, the heart of the materials/energy balances, since it is the link between economic activity and the production and disposition of waste residuals which pollute the environment. The statistics will be used, primarily, in forecasting the environmental consequences of economic growth and development, in designing governmental programmes to improve the state of the environment or to minimize the adverse environmental impact of development projects. Explicit links are thus provided to specific resource extraction and commodity manufacturing processes and to various types of consumption. Waste residuals are also linked to aggregate sectors. Waste flows are identified as to environmental media.

57. The basic source of these statistics will be some combination of engineering studies (e.g., of a "typical" plant exemplifying a given extraction or production process) and of survey or monitoring data compiled by responsible monitoring and regulatory agencies. These data are not currently available in adequate detail in most countries, and much attention will have to be given to the problem of designing appropriate methods of measurement and aggregation.

58. Table 4 could include such data as the rate of loss of mercury to the environment from the mercury-cell chlorine manufacturing process, or the cadmium content of wastes from zinc mining and/or smelting. It would also, in principle, show mercury and cadmium residuals resulting from the incineration of paper impregnated with mercury-based fungicides or plastic products containing cadmium-based plasticizer. For DDT, polychlorinated biphenyls and fluorocarbons, it would show waste flows resulting directly from "final" use of these materials.

59. It is important to point out that, while the data in table 4 should be fully consistent in a materials/energy balance sense with data in tables 1, 2 and 3, as a general rule they would be derived independently from measurements of discharges or ambient environmental pollutant concentrations. Discrepancies would normally occur in the process of constructing the tables - as now happens in building input-output tables - and their resolution should help to strengthen the data base as compared to what it would be if based only on production and/or consumption data.

Table 4. Waste residual accounts

Accounts	Type of waste (name, units)		Waste No. 1 (units)					
Waste source by major materials production/ conversion process[a]	Production process name		Process 1	Process 2	Process 3	Process 4	Process 5	Other process n.e.c.
	Process type, code							
	Waste quantity generated	Soil						
		Air						
		Water						
		Ocean						
Waste generated by disposition services and consumption[b]	Sector		Commer-cial transport	Utility services	Other commerce	Govern-ment	Personal transport	Other house-hold
	Quantity by medium	Soil						
		Air						
		Water						
		Ocean						
Waste generated by sector (total)	Sector		Agri-culture	Manu-facturing	Construc-tion	Transport	Govern-ment and services	House-hold
	Quantity by medium	Soil						
		Air						
		Water						
		Ocean						
Waste generated by depreciation of durables	Type		Machinery and equipment	Producer struc-tures	Residen-tial housing	Personal vehicles	Household appliance	Other private
	Quantity by medium	Soil						
		Air						
		Water						
		Ocean						

a/ Including airborne wastes from incineration of municipal or industrial solid wastes.

b/ Not including solid wastes that are subsequently incinerated (to avoid double counting).

V. DEFINITIONS OF NATURAL RESOURCES, COMMODITIES AND WASTES

60. The distinction often made between renewable and non-renewable resources has already been mentioned. In brief, the renewable resources are primarily sunlight, air, water and chemical substances, such as carbohydrates and proteins, which are major constituents of biological systems. These are extensively transported and converted from one form to another via natural, meteorological, biological and geological processes or are extracted by man from natural cyclic systems. Hydrogen/water, oxygen, carbon/carbon dioxide,[10/] alkali metals (sodium, potassium and calcium) and nitrogen are chief constituents of such materials.[11/] Because of the existence of natural cycles, supplies of all of these elements are essentially infinitely renewable. Elements such as silicon, sulphur and chlorine are also present in such large amounts in the earth's crust, relative to their incorporation in living systems, that their possible natural cycles are of somewhat less interest. Land is often regarded as a renewable resource because it too is, in theory, indefinitely reusable, i.e., it is not "used up" by conservative cultivation practices. Obviously, this statement does not apply to specific nutrients in soil, which can be and are used up by some types of agriculture and must be separately replaced. Also, it is evident that some agricultural practices result in irreversible erosion losses of the top soil itself; this should be dealt with by means of supplementary tables.

61. Some elements of the major natural cycles (land, air, water, living systems) are accounted for and distinguished. Thus, if ground water is one source of water for irrigation in a country, the table should include an estimate of the current stock of the underground reservoir available for pumping. It is not necessary to try to estimate the total quantity of ground water available in the country. In the case of tree crops, such as citrus fruits, apples, plums, peaches, nuts, olives, coconuts, coffee, cocoa, natural rubber, and in the case of other perennial producers, such as grape vines or alfalfa, the stock in question may be measured by the number of producing trees or the area of land planted. In the case of dairy products, the stock (number) of producing cows is of considerable interest, especially when significant expansion in the producing stock takes several years. One important use of the statistical system should be to record significant trends, such as the substitution of annual crops, for example, soybeans, for perennial crops in certain countries.

62. The total stock of any renewable resource is fixed by nature, but the amount in any given form or location can vary from time to time and may be affected by the actions of man. The "flows" are transfers from one form, location or category to another. In most instances, the total stock of a renewable resource in its natural state is actually irrelevant (and may be unknown, except to a crude first approximation), because what counts is the amount available in certain forms, locations or times. This is generally a function of the rate of flow rather than the size of the total reservoir.

10/ Hydrogen is biologically derived from water and vice versa; similarly carbon and oxygen are biologically interconvertible. Oxygen is, of course, involved in both cases.

11/ Phosphorus, the other essential ingredient of biological materials, is not cycled except on a geological time-scale. This gives rise to special interest in phosphorus as a potential bottleneck of life on earth.

63. It is clear, for example, that most of the water on earth is in the deep oceans, but equally clear that what really counts for human purposes is the amount of surface run-off and the stored surface fresh water which can be diverted to agricultural, industrial or municipal use before being returned. Most of the earth's carbon is in carbon dioxide dissolved in the ocean or in carbonaceous rocks, such as limestone, whereas only the free carbon dioxide in the atmosphere is available to plants. Similarly, most of the earth's oxygen is tied up with hydrogen in water or as oxides, but only the free oxygen in the atmosphere is available to animals. Finally, the free atmospheric nitrogen is not available to plants or animals; not until it is "fixed" as water soluble nitrates (by specialized bacteria) can it be taken up and utilized by biological organisms.

64. Renewable resources to be accounted for specifically in tables 1 and 2 include the following:

Water (volume)

Fresh, surface; underground; ice/snow (water equivalent); saline (land-locked).

Land (area)

Cultivated; fallow, grazed; grazing only; forest, harvested; forest, unharvested; desert; tundra; urbanized; parks, urban; parks, natural area; transition zone, salt marsh; transition zone, dune; transition zone, up-stream valley; transition zone, alpine meadow; ocean beach, protected; lake/riverside, protected.

Fisheries (annual production, by weight)

Salmon; tuna; sardines; cod; flounder; sole; oysters; clams.

Orchards and plantations (annual production, volume or weight)

Grape vines (volume); tree fruit, by type (weight); nuts, by type (weight); olives, coffee, cacao etc.; pulpwood (weight); softwood (volume); hardwood (volume).

Livestock by type (producing units)

Cattle; sheep; goats; hogs; horses, mules; water buffalo; oxen.

Assimilative capacity of water (for organic waste)

Assimilative capacity of air for particulates and gaseous wastes

Oxides of sulphur; oxides of nitrogen; carbon monoxide.

Assimilative capacity of soil for organic wastes (such as sewage sludge)

Sunlight, incident on land per sq km per year

65. Non-renewable resources are extracted from the earth's crust and not replaced by natural cyclic processes, except, perhaps, over geological time-scales. Non-renewable resources to be accounted for specifically in tables 1 and 2 would include at least the following:

Fossil fuels

Coal; lignite; natural gas; petroleum; other.

Metals and minerals

Alumium; antimony; arsenic; asbestos; barite; bauxite; beryllium; bismuth; bitumen; borax; brines(B, Li, K, Cl, Br, I); cadmium; chromium; clay/kaolin; coal; cobalt; construction stone; copper; diatomite; dolomite; evaporites; feldspar; fluorine; fluorite; gallium; gemstones; gold; granite, building stones; graphite; gypsum; helium; iron; kyanite; lead; limestone and dolomite; lithium, cesium and rubidium; magnesium; manganese; marble; mercury; mica; molybdenum; nickel; niobium; oil shale; phosphate rock; platinum; potash; quartzite; rare-earth elements; rhenium; salt; sand/gravel; scandium; selenium; silica sand; silver; slate; sulphur; talc; tantalum; thallium; thorium; tin; titanium; trona; tungsten; uranium; vanadium; zeolite; zinc; zirconium and hafnium.

66. Commodities, in this context, are simply processed materials, forms of energy or products. Any consistent international classification, such as the International Standard Classification of All Goods and Services (ICGS) can be used as a basis for tables 1 and 2, although some elaboration will be needed. A full list of commodities, cannot be reproduced here, but lists are available in the ICGS, which is before the Commission (E/CN.3/493).

67. The main difficulty with most existing international commodity classifications arises from their use of "basket" categories for chemicals. For the purpose of establishing balances, it is essential to avoid lumping together different chemicals (or other major materials) in groups under general headings such as "cyclic intermediates". Rather, the major tonnage chemicals must be tabulated individually, lumping all others in a not-elsewhere-classified (n.e.c.) category.

68. Categories of waste residuals have not yet been internationally specified, but the following should probably be included, as a minimum:

Waterborne wastes

BOD;[12/] COD;[13/] dissolved solids (salts); suspended solids.

Airborne wastes

Particulates; carbon monoxide; carbon dioxide; hydrocarbons; oxides of nitrogen; oxides of sulphur.

12/ Biological Oxygen Demand in water measured at the end of 5 days. This is a measure of the quantity of biodegradable organic material in the waste water.

13/ Chemical Oxygen Demand.

Solid wastes

Combustible solids; non-combustible solids.

Heavy metals

Lead; mercury; cadmium; arsenic; other (chromium, selenium, bismuth, thallium etc.).

Chlorinated hydrocarbons

DDT; fluorocarbons (chlorinated); chlorinated biphenyls.

Thermal waste

Heated waste water > 5^{o} above ambient; water vapour (steam).

Nuclear waste

Plutonium (curies); other high level (curies); other low level (curies).

69. As commented earlier, the System of National Accounts definitions are to be adhered to as closely as possible. There is no difficulty with using SNA definitions for domestic production, exports, imports and domestic consumption.

70. The terms requiring more careful definition (stock not yet extracted, stock in strategic reserve, conversion/utilization as such, conversion process, durable goods, depreciation, waste) are dealt with below.

71. Stock not yet extracted. This term applies most obviously to a non-renewable natural resource such as petroleum or iron ore. However, for consistency, one can also apply the term to natural accumulations of renewable resources such as uncut forests, potentially cultivable farm land or stored fresh water (underground or surface). It does not apply to natural resources that cannot be stored at all, such as sunlight impinging on the surface of the earth or atmospheric water vapour.

72. In the case of non-renewable resources (e.g., minerals or fossil fuels), the obvious definition of "stock" would be the concentrations which can, in principle, be extracted from the earth's crust. However, this is generally not a fixed quantity; it depends on the state of technology and the effort expended on extraction. Moreover, the over-all distribution of mineral concentrations is not known. Much of the partial knowledge that does exist is not available to the public (or Governments). Hence, more limited concepts, such as "proved" reserves and "inferred" reserves have come into use.

73. The proven reserves of minerals or fossil fuels available at a given time depend directly on the rate of discovery, the rate of extraction and the assumed market price of the commodity. The same can also be said for inferred or estimated reserves. A rise in commodity prices will automatically increase the expected economic recovery from existing mines or wells and vice versa. This change can

realistically be reflected in annual statistical series provided some reasonable price convention is specified. Since mineral commodity prices are notoriously unstable, and true world market prices are not even defined for a number of commodities,14/ it could be highly misleading to use spot prices on a given date each year or in a single location for purposes of estimating recoverable resources. It might, however, be reasonable to use something like an extrapolation of a five-year rolling average of historical prices taken from a number of locations as a basis for estimation. Another possibility is to use the prices on the futures market (appropriately averaged, of course) where such a market exists.

74. Unfortunately, one must recognize a fundamental difficulty in assigning any consistent interpretation to estimates of proven and/or inferred reserves. The problem is that transfers of known deposits from the latter to the former category occur at the time specific mine investments are being planned in detail. This, in turn, occurs as new sources are needed to replace depleted ores. Mining or petroleum companies have no incentive to carry out detailed surveys of known deposits prior to such time. Hence, in many cases there is a marked tendency for proven reserves to hover around the level of 20 years supply at current or extrapolated output, simply because this is the economic lifetime of a typical mine or oil field.

75. An alternative theoretical possibility might be to use inferred reserves. This figure is less sensitive to the economic parameters of the mining or drilling business but, on the other hand, it is intrinsically much more uncertain for two reasons. First, by definition, the ore bodies or deposits counted in this category have not been surveyed in detail; hence, magnitude of yield probably can only be determined on the basis of previous experience in the same region or in similar geological strata. Secondly, much of the underlying data is currently not in the public domain, being proprietary to the various mining and oil drilling concerns. In the near future, at least, publicly available figures are likely to be significantly incomplete and, therefore, highly unreliable. To be sure, it is widely recognized that more and better information in this area is needed and must ultimately be provided under census-type legislation15/ as a matter of necessity for rational public policy making.

76. Stock in strategic reserve. For purposes of these guidelines the "strategic" stockpile is conceptually distinguished from normal commercial inventories of materials. It can be assumed that commercial users of raw and processed materials keep the smallest quantities on hand that are consistent with risks of supply interruption and market fluctuation. These risks do not generally change dramatically from year to year; hence, commercial inventories remain relatively constant.

14/ This may be due to the prevalence of either long-term bilateral contracts between producers and consumers or localized sources incapable of supplying markets located far away. The latter may, in turn, be a consequence of lack of facilities for storage and preservation (e.g., for food products) or intrinsically high transport costs (e.g., sand and gravel).

15/ Legitimate proprietary interests can be preserved (as in the census of manufactures for most industrialized countries) by not publishing data for individual producers or narrowly specified locations. However, useful national aggregates could be prepared from individual producers' data.

77. Strategic stocks, however, are maintained by Governments for both national security and political reasons. These stocks can and do change dramatically from one year to the next depending on government policy. Some stockpiles of critical materials (such as tungsten, chrome and manganese) have amounted to as much as several years of normal consumption. If this material is sold off quickly - as has happened - it may have a sharp effect on current production and cause large discrepancies between current production and current consumption.

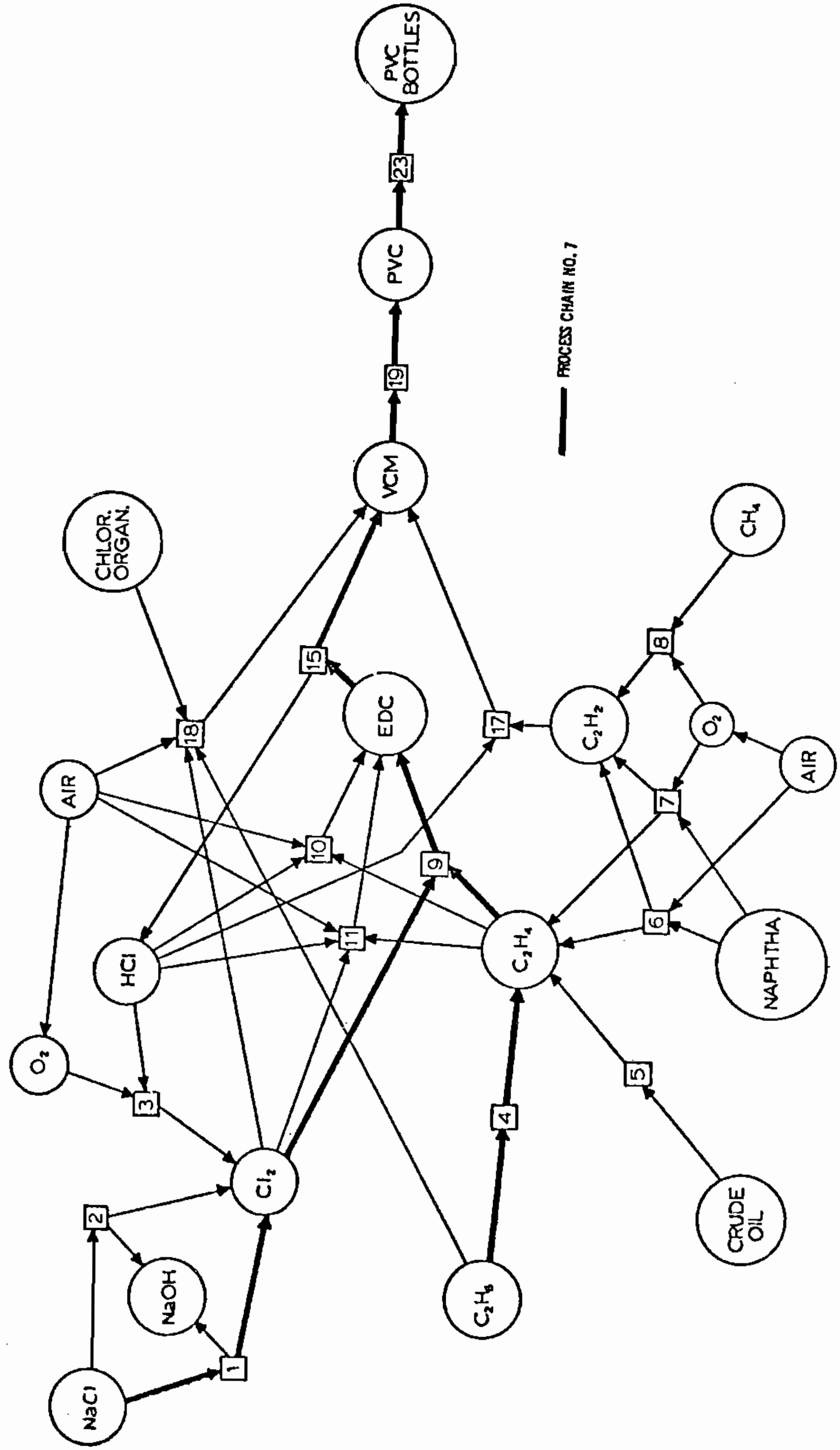
78. Conversion versus utilization. The distinction here is critical. A resource or commodity is "converted" if, and only if, it is physically or chemically incorporated into another commodity or product. Thus, chemical feedstocks are incorporated into synthetic rubber, plastics or fibres. Fibres (synthetic or natural) are incorporated into woven or knitted fabrics, which are in turn converted into textile products. Similarly pulpwood is converted into pulp, thence to paper and finally to paper products. Metal ores are converted to concentrates, then to crude pigs or ingots, then to more refined alloys in castings, bars, sheet, foil, wire, tube and finally (after cutting, shaping, machining, welding etc.) to metal products, structures etc. The chemical energy of coal or residual oil is also "incorporated" into a successor product by electrical generating plants.

79. It is important to note, however, that many important materials and energy fuels are not physically or chemically incorporated into successor products. On the contrary, they are used up, and discarded as wastes, at intermediate processing or manufacturing stages. This applies for example, to cleaning agents, lubricants, coolants, dispersants, bleaches, anti-freezes, fluxes, solvents and numerous other items. It is notably true of fuels and electricity used in industry and commerce (except as noted above, where the fuel energy is simply converted to electricity). It also applies to many products such as maintenance items and capital goods that are not sold to final demand but used as intermediate inputs in industry. All of these may be said to be used "as such", in that they are not physically or chemically incorporated into successor products.

80. Conversion process. In view of the foregoing definition, the meaning of "conversion" is probably sufficiently clear. In general, there are a number of different, accepted methods of producing a given commodity or product. These may start from different input materials or they may proceed by different routes. For example, ethane can be produced either from petroleum by fractional distillation or from natural gas by separation. Similarly, ethylene can be produced from naphtha, ethane, propane or from other hydrocarbons by thermal cracking. Again, ethylene dichloride (EDC) can be manufactured from ethylene by direct chlorination or by oxychlorination. Similarly, vinyl chloride monomer can be produced either by pyrolysis of EDC or by direct chlorination of ethane (see figure II). All of the above constitute distinct processes.

81. On the other hand, differences in scale or in detailed plant design do not constitute different processes - only variations on a basic theme. In the basic materials industries (e.g., chemicals, metals) the number of different conversion processes in use is small enough so that there is wide agreement among engineers as to their specific identities and characterization in terms of inputs, outputs, capital equipment and labour requirements. Obviously, there is some room for disagreement

Figure II. Process network leading to PVC bottles



Notes to figure II

Processes 12, 13, 14 and 16 are pictorially identical to processes 9, 10, 11 and 15, respectively, except that processes 13 and 14 use oxygen instead of air.

Unit processes participating in bottle manufacture are:

1. Chlorine via salt electrolysis - mercury cell
2. Chlorine via salt electrolysis - diaphragm cell
*3. Chlorine via HCl oxidation using HNO_3 (Kel-Chlor)
4. Ethylene from ethane pyrolysis
*5. Ethylene via autothermic cracking
6. Acetylene/ethylene via Wulff process (naphtha feed)
*7. Acetylene/ethylene from naphtha by partial oxidation
8. Acetylene from methane by partial oxidation
9. EDC via ethylene chlorination (vapour)
*10. EDC via ethylene oxychlorination (vapour)
11. EDC via ethylene chlorination/oxychlorination (vapour)
*12. EDC via ethylene chlorination (liquid)
*13. EDC via ethylene oxychlorination (liquid)
*14. EDC via ethylene chlorination/oxychlorination (liquid)
15. VCM from EDC pyrolysis
16. VCM from EDC pyrolysis with waste treatment
17. VCM from concentrated acetylene
*18. VCM from ethane oxychlorination (Transcat) - part waste feed
19. PVC from VCM - bulk process
23. PVC bottle manufacture

*Processes not presently in domestic production.

as to exact definitions, but an international group of experts should be able to arrive at a satisfactory resolution of most difficulties. More serious problems arise in the industries which fabricate products or structures from finished materials. Here the processes are not well-defined because the number and range of final products is extremely large and processes can only be defined functionally (e.g., cutting, drilling, weaving, assembly, painting) rather than in terms of specific input/output combinations. Thus, in practice, a high degree of aggregation of processes must be accepted in these industries.

82. This would be a serious drawback but for the fact that fabrication and assembly operations do not generate large waste flows (except for cumbustion products and scrap, which is largely recycled) and thus do not have significant adverse environmental effects. Combustion of fuel in heating plants or stationary engines can be regarded as distinct and reasonably well-defined processes.

83. Durable goods. The term "durable" is used here in essentially the same way as it is used in national accounts. The distinction between durable and non-durable goods is based on average lifetime in service. A one-year criterion is normally

assumed. Most producer goods (machines, tools, structures) are durable by this standard. Consumer goods are more divided. Houses, cars, household appliances, recreational goods, furnishings and most clothing are durables. Food, beverages, cleaning supplies, cosmetics, pharmaceuticals, newspapers, magazines and sundries are clearly consumables, along with some items of clothing.

84. The distinction is useful because consumables are converted immediately to waste (in varying forms), whereas durables only contribute to waste-streams as they are discarded. Regrettably, direct data on scrappage of durables is almost non-existent. In some cases, e.g., automobiles, annual scrappage may be inferred for many countries by comparing new registrations of vehicles with changes in total registrations, although this procedure is far from foolproof. In some countries, registration fees are so large in comparison with the value of the vehicle that old vehicles are never scrapped, but perpetually rebuilt. This is, to some extent, tantamount to piece-meal scrappage spread over a long period of time. But reliable data are unavailable as to the details of this process.

85. For other durable goods, even less information on scrappage is typically available. Consequently, it is necessary to estimate scrappage by assuming that it occurs when goods have depreciated to negligible economic value. Thus, depreciation data are needed.

86. Waste versus recycling. In most cases, the term "waste" is not ambiguous in practice. The only source of ambiguity arises in connexion with recycling. Specifically, any by-product of an industrial process is a waste product if there is no immediate market for it and if it must be stored indefinitely or disposed of through an environmental medium (atmosphere, surface water, soil etc.). All consumables become wastes at the point where they are discarded by their users and collected for disposal.

87. By this definition, primary scrap material - metal, paper or plastic - that is generated in a factory, and collected and sold commercially to a specialist processor is not classified as a waste stream, because this material was never actually discarded or disposed of through an environmental medium. On the other hand, so-called secondary scrap material that is separated from mixed municipal or other refuse (after collection from the original users) is counted initially as part of a waste stream, notwithstanding later re-use. In the present context, the term "recycling" refers only to the recovery and re-use of secondary scrap.

88. A possible ambiguity arises in connexion with material that is discarded as waste, which accumulates in one spot, and which is subsequently found to have commercial value for some purpose. This has recently happened, for instance, in the case of some nineteenth-century mine tailings, which constitute viable ore based on present-day technology. Such an eventuality can de dealt with by appropriate revaluation of the stock of the resource in question.

VI. ENVIRONMENTAL DAMAGES AND ABATEMENT COSTS[16/]

89. One of the types of information most frequently needed by policy analysts concerned with environmental problems is data on costs, both paid and unpaid. In the category of paid costs one would include expenditures - either by producers or by consumers - directly or indirectly attributable to pollution abatement and/or environmental management activities. The actual expenditures by affected parties may often not be directly known, since they are not part of a government budget.

90. It is clear that information on actual expenditures on pollution control and abatement should, in principle, be derivable from the national accounts. Expenditures by Governments attributable to environmental management could be explicitly separated. On the production side, a separate industry to produce pollution abatement or environmental management goods and services would also need to be distinguished from the other sectors. Purchases of such services by Governments, or by other production sectors, would constitute revenues to that sector.

91. The practical difficulty in compiling this information arises from the fact that it is very difficult to distinguish between goods and services purchased for various purposes by firms. Even the standard distinction between capital and operating costs is an essentially artificial one, though sanctified through long recognition by the tax regulations of most countries and familiarity on the part of accountants and auditors. But to distinguish between different kinds of capital and different kinds of operating costs would be very troublesome. Most firms would have difficulty documenting the internal allocation of expenditures in this manner, and outsiders still more so.

92. The most plausible way out of this difficulty would be for certain categories of capital and operating expenditures to be explicitly designated as for environmental purposes by the tax authorities. (For example, purchases of electrostatic precipitators, complete water treatment plants, complete desulphurization plants, catalytic convertors for automobiles etc.). An accelerated depreciation schedule or some other form of tax concession could be made available on condition that the expenditures were properly documented. The information thus accumulated would constitute a potential data base for statistics on the paid costs of environmental control.

93. The problem of determining unpaid environmental damage costs is even more difficult, since most of these costs are unpaid, at least in part, precisely because there is no impersonal market mechanism for fixing their appropriate prices. A number of economists have attempted to develop cost-benefit methodologies for estimating real or potential damages.[17/] Whatever their respective merits, all these methods have the common disadvantage (from a statistical point of view) of being indirect and theoretical. That is, there is no set of empirically derived damage costs that could be compared on an international basis at this time.

16/ The present chapter should be read in conjunction with chapter IV in "The feasibility of welfare-oriented measures to complement the national accounts and balances" (E/CN.3/477), also before the Statistical Commission.

17/ For a comprehensive summary of the relevant methods, see Government of the United States of America, Department of Transportation, Economic and Social Measures of Biologic and Climatic Change, edited by R.C. d'Arge, CIAP Monograph No. 6 (Washington, D.C., September 1975).

94. In the near future, unfortunately, it seems unlikely that any fully satisfactory resolution of these difficulties will be achieved. What can be done short of such an ideal solution? As regards paid costs, the only possibility that strongly suggests itself at this stage is the systematic use of engineering information to estimate costs, and of survey data to estimate the extent of pollution abatement activity. In water-pollution control, for instance, the following three-tiered classification of water-treatment processes has been established by wide usage:

(a) Primary treatment. Settling and filtration; removing most suspended solids and 30 per cent of BOD.18/

(b) Secondary treatment. Bacterial treatment of the output of the primary treatment process, leading to cumulative removal of 90 per cent of BOD, 50 per cent of nitrogen, 20 per cent of phosphorus and 5 per cent of dissolved salts.

(c) Tertiary treatment. Various additional steps leading to cumulative removal of 95 per cent of BOD, 98 per cent of nitrogen, 97 per cent of phosphorus and 50 per cent of dissolved salts.

95. It is feasible to classify all industrial or other waste-water discharges according to the highest level of treatment, for example, 10 per cent tertiary and 80 per cent secondary. Data of this sort could be broken down by region and source category (industry, agriculture, industry). Unfortunately, the classification into primary, secondary, tertiary levels of treatment is applicable mainly to municipal wastes or process industries utilizing organic materials (pulp and paper, food processing etc.). It is not very relevant for chemical or metallurgical wastes.

96. In a similar vein, it is feasible to classify levels of treatment of smoke for major industrial or municipal steam-electric power plants, incinerators, coke ovens, blast furnaces etc. Particulate removal by means of electrostatic precipitation can be estimated in percentage terms. Levels of treatment of motor vehicle exhaust can also be estimated by engineering analysis and dynamometer tests on a cross-sectional sample of each year's new vehicle output, combined with longitudinal surveys on a few vehicles over their lifetimes to determine the effect of aging. Fractional removal of sulphur and ash from coal and from fuel oil are fairly well-known and can be determined by comparing samples of raw and finished fuels. Fractional removal of sulphur dioxide from stack gases would be a known function of the efficiency of the treatment process (if any). Disposition of municipal solid wastes via land fill, incinerator or by other means is not as well documented as might be expected, but good estimates are available in many localities.

97. With regard to other pollutants, however, treatment or abatement methods are generally not yet standardized and levels and costs of treatment will prove more difficult to compile. This problem is particularly troublesome where trace contaminants or wastes from metallurgical or chemical processes are concerned. No immediate solution seems available.

18/ Biological Oxygen Demand - that is, the amount of oxygen that will be consumed by aerobic decay organisms in five days. It is a measure of the amount of biodegradable organic material in the waste mater.

VII. POSSIBILITIES FOR INITIAL IMPLEMENTATION

98. It is highly desirable to segment the framework proposed in these guidelines so as to permit gradual construction of the full system in smaller stages. Both horizontal and vertical cuts are possible. A horizontal cut would begin with one reasonably well-defined stage of materials flow (say, extraction of raw materials) and identify all the relevant flows into and out of box 2 in figure I. This would be a relatively simple extension of production and trade statistics already available in many countries. The two added features would be specification of waste flows from primary extraction processes (by process) and specification of subsequent utilization according to whether further conversion processes are involved or not. The system could not, of course, be "closed" in any sense and materials/energy balances could only be struck for the extractive activities per se.

99. In a similar manner, other sectors in figure I could be dealt with successively. Thus, all imports and exports of raw materials, commodities and finished goods could be compiled to obtain a balance for the rest-of-world sector. Balances for consumption of non-durables and accumulation of durables could be arrived at by a combination of direct survey data and indirect (synthetic) methods. The same is true for conversion industries and manufacturing industries. Here census-type data would have to be supplemented by engineering studies. The inputs and outputs to the waste sector (presumably left to the last) would then be completely specified.

100. The weaknesses of this approach are clear: first, the piecemeal approach does not yield a very useful result until it has been completed. Moreover, by far the largest and most difficult segments are perhaps still indigestibly massive projects.

101. The vertical approach offers more promise. Here one would identify a single element (or group of related materials) and follow it through the economy from raw material to final consumption, taking account of all waste flows. At a later time, one could aggregate the results to obtain a complete system. Meanwhile, the partial results are still potentially quite useful.

102. In fact, it would make sense to begin with a set of the most environmentally critical materials, such as toxic heavy metals (lead, cadmium, mercury etc.). Most of these metals have a fairly restricted set of uses. Experience acquired in compiling the process-waste-consumption flow data on these metals would be helpful in dealing with the more widely used and more complex flow patterns of the major metals. Moreover, the data sets for many metals overlap significantly. For instance, cadmium is a coproduct of zinc refining. In compiling necessary data on cadmium, one would necessarily obtain quite a lot of relevant data on zinc, thus simplifying the task for zinc. Similarly, zinc and lead often occur together, along with copper, silver, arsenic and other metals.

103. The logic of a vertical approach beginning with the more toxic metals and then gradually extending to other materials can also be seen from the fact that some materials or elements are far more critical than others, both from conservationist and environmentalist standpoints. A disproportionate amount of environmental damage is caused by a small number of processes (e.g. combustion of fossil fuels) and by chemical compounds composed of a small number of especially potent elements.

104. In this context, it is noteworthy that the major elements of biological systems (hydrogen, carbon, oxygen) are relatively innocuous when combined with each other, but that four minor elements of living systems (nitrogen, sulphur, phosphorus and chlorine) combine with these three, singly or all together, to form a large variety of toxic or carcinogenic compounds from oxides of nitrogen and sulphur to cyanides, mercaptans, nitrosamines, nerve gases such as phosgene, peracyl acetic nitrate, bacteriocides, algicides, fungicides, herbicides, insecticides, food preservatives, vinyl chloride and polychlorinated biophenyls. Clearly, monitoring these four elements and their uses should take precedence over monitoring the other three.

105. Similarly, a group of minor metals, including lead, cadmium, mercury, arsenic and chromium, are far more dangerous to the environment than the more widely used elements such as compounds or alloys of aluminium, calcium, iron, silicon and sodium. Again, even though the latter are far more important economically, priority in monitoring should go to the former.

Annex

MATRIX REPRESENTATION OF STATISTICS ON MATERIALS/ENERGY BALANCES

	1	2	3	4	5	6	7	8	9	10	11	12
1. Opening stock	Z_j											
2. Domestic extraction		X_{jk}	y_{jn}	y_{jl}		-	-	ΔW_j	U_j	X_{mk}		
3. Domestic conversion (process)		NT	NT	y_{1n}	NT	NT	NT	-	NT	X_{nm}		
3'. Domestic conversion (material)		-	y_{1n}	$X_{11'}$	y_{1p}		y_{1q}	-	U_1	NT		
4. Intermediate production		-	-	-	-	NT	NT	-		X_{mp}		
5. Final consumption, non-durables		-	-	-	-	-	-	-	-			
6. Accumulation, durables		-	-	-	-	-	W_q	-	-	X_{mq}		
7. Strategic stock of resources		-	ΔW_j	NT	-	-	-	W_j	ΔW_j	-		
9. External sector		V_j	V_1	NT		NT	V_q	ΔW_j	-	-		
10. Waste		-	y_{mn}	-	-	-	-	-	-	W_m		
11. Revaluation											ΔZ_j	
12. Closing stock												Z_j

NT = Not tabulated

Notes to matrix display

1. The matrix display corresponds essentially to boxes 1 to 12 and connecting lines in figure I in chapter IV above (see notes below, however). Tabulations (or sub-matrices) are shown symbolically. An explanation of indices and nomenclature follows these notes.

2. In figure I, intermediate use (box 5) and final consumption of non-durable goods and services (box 6) are separated. However, these are combined in some tables, e.g., $y_{1p}(t)$, $X_{mp}(t)$.

3. Current production of durable goods $W_q(t)$ in material terms cannot be derived from the other elements of the matrix. This is, strictly speaking, a supplementary table. In principle, however, it must be the sum of material flows from finished materials y_{1p} and intermediate products (flows from box 5 to box 7 in figure I, not tabulated). Note that current depreciation of durable goods $y_q(t)$ in material terms corresponds to the consumption of such goods and their abandonment or demolition. This is, essentially, a waste stream and can be defined as such (hence $y_q = \sum_m X_{mq}$).

4. Some useful aggregate variables do not correspond directly with either stocks or flows in the diagrammatic presentation (figure I). Examples include:

   y_j (domestic supply of j^{th} resource);

   y_1 (domestic supply of 1^{th} material or commodity);

   X_m (total waste of m^{th} type).

5. Some flows (lines) in figure I have no corresponding tables (see note 3 above), either due to relative unimportance or lack of data. These are denoted NT (Not Tabulated) in the matrix, and are shown as lines of dashes in figure I.

6. The stockpile of finished or partly processed materials has been tentatively omitted. However, this omission should be considered for possible future inclusion. It is shown in figure I as a broken-line box (not numbered).

LIST OF SYMBOLS AND DEFINITIONS

Symbol	Definition	Range of Indices
(All letters j ... q, except o)		(All letters, J ... Q, except O)
j	Natural resource type	$j=1, \ldots J$
$k(j)$	Extraction process (mode) for j^{th} type of resource[(a)]	$k(j)=1, \ldots K(j)$
ℓ	Processed material or commodity	$\ell=1, \ldots L$
m	Waste residual type	$m=1, \ldots M$
n	Conversion process type	$n=1, \ldots N$
p	Production or consumption sector	$p=1, \ldots P$
q	Type of tangible capital asset	$q=1, \ldots Q$

Symbol	Definition (Stock)	Maximum Number of Quantities
Z_j	Stock of j^{th} resource not yet extracted	J
W_j	Stock of j^{th} resource held for strategic reserves	$<< J$
W_m	Stock of m^{th} type of waste available for possible recovery	$<< M$
W_q	Stock of q^{th} type of tangible capital asset "in use"	Q

Symbol	Definition (Flow)	Maximum Number of Quantities
T_j	Domestic consumption of j^{th} resource	J
X_{jk}	Domestic output of resource j by k^{th} process	$\sum_j K(j)$
U_j	Exports of j^{th} resource (unprocessed)	J
V_j	Imports of j^{th} resource (unprocessed)	J
ΔW_j	Stockpile withdrawals[(c)], j^{th} resource	J
ΔZ_j	Stock additions[(b)] or revaluations, j^{th} resource	J
Y_ℓ	Domestic supply of ℓ^{th} material/commodity	L
$X_{\ell n}$	Output of ℓ^{th} material/commodity by n^{th} process	$<< L \times N$
U_ℓ	Exports of ℓ^{th} material/commodity	L
V_ℓ	Imports of ℓ^{th} material/commodity	L
$Y_{j\ell}$	Input of j^{th} resource to ℓ^{th} material/commodity	$J \times L$
Y_{jn}	Input of j^{th} resource to n^{th} process	$J \times N$
Y_{jp}	Utilization of j^{th} resource *as such* by p^{th} sector	$J \times P$
$Y_{\ell\ell'}$	Conversion of ℓ^{th} material to ℓ'^{th} material ($Y_{\ell\ell} = 0$)	$L \times L$
$Y_{\ell n}$	Input of ℓ^{th} material/commodity to n^{th} process	$L \times N$
$Y_{\ell,p}$	Utilization of material/commodity ℓ *as such* in sector p	$L \times P$
$Y_{\ell,q}$	Utilization of material/commodity ℓ *as such* in capital q	$L \times Q$
X_q	Current production of capital of type q	Q
T_q	Current depreciation (consumption) of stock of type q	Q
X_m	Total waste generated of type m	M
X_{mk}	Waste of type m produced by $k(j)^{th}$ resource extraction process	$\sum_j k(j) \times M$
X_{mn}	Waste of type m produced by n^{th} conversion or consumption process	$N \times M$
X_{mp}	Waste of type m produced by *consumption* use (as such) in p^{th} sector. (d)	$P \times M$
X_{mq}	Waste of type m produced by *depreciation* (consumption) of capital goods (e) of type q	$Q \times M$
Y_{mn}	Input of m^{th} waste type to n^{th} process (recycling)	$M \times N$
U_q	Export of q^m capital	
V_q	Import of q^m capital	

LIST OF SYMBOLS AND DEFINITIONS (Continued)

Accounting Identities	Interpretation
$Y_j = \sum_{k(j)} X_{jk} - U_j + V_j + \Delta W_j$	Domestic supply equals production less exports plus imports plus stockpile withdrawals.
$Y_\ell = \sum_n X_{\ell n} - U_\ell V_\ell$	Same as above.
$Y_j = \sum_\ell Y_{j\ell} + \sum_p Y_{jp} = \sum_n Y_{jn} + \sum_p Y_{jp}$	Consumption of j^{th} resource equals the amount of that resource converted to all other forms plus the amount of the resource used as such (without further conversion). By definition resource supply equals current consumption.
$\left[\sum_\ell Y_{j\ell} = \sum_n Y_{jn}\right]$	Resources allocated among all conversion processes (n) must equal resources converted to processed materials (ℓ), by definition.
$Y_\ell = \sum_{\ell'\neq\ell} Y_{\ell\ell'} + \sum_p Y_{\ell p} + \sum_q Y_{\ell q} = \sum_n Y_{\ell n} + \sum_p Y_{\ell p} + \sum_q Y_{\ell q}$ $\left[\sum_{\ell'\neq\ell} Y_{\ell\ell'} = \sum_n Y_{\ell n}\right]$	Consumption of ℓ^{th} material or commodity equals the amount of the material converted to other materials, plus the amount utilized as such (without further conversion) for intermediate production (e.g. of services), final consumption goods and durable (capital) goods. The quantity of material/commodity allocated among all (other) conversion *processes* must equal the quantity converted to other materials and processes.
$X_m = \sum_m X_{mk} + \sum_n X_{mn} + \sum_p X_{mp} + \sum_q X_{mq}$	Total waste generated of type m must equal waste produced by extraction, conversion, consumption and depreciation, respectively.
	MATERIALS BALANCE BY PROCESS
$\sum_j Y_{jn} + \sum_\ell Y_{\ell n} + \sum_m Y_{mn} = \sum_\ell X_{\ell n} + \sum_m X_{mn}$	The sum of all materials entering a process must equal the sum of all useful products plus wastes. Care must be exercised to include environmental resources (air, water) on both sides of the equation.

(a) It is convenient (and reasonable) to assume that each resource has a *unique* set of associated extraction processes and that each process results in only *one* product. If a given extraction process (say strip mining) is applicable to more than one resource, it is simply counted as a separate process in each case. This procedure is *not* followed for conversion processes because of the problem of joint products. That is, each process yields several products. Hence processes must be separately indexed.

(b) Additions to stock are defined as gross annual production in the case of renewable natural resources. In the case of non-renewable resources, effective additions to stock arise from revised estimates of recoverable fraction of existing ore-bodies due to price changes or technological improvements, discoveries of new sources of standard types of ores and development of practical methods of utilizing known but hitherto unutilizable ores such as oil shale, ocean nodules, etc.

(c) Stockpile accumulation is regarded as a *negative withdrawal.*

(d) Conversion wastes are excluded, being separately accounted for in the extraction and conversion stages.

(e) Capital goods in this context specifically include consumer durables (automobile, housing) as well as producer durables and structures.