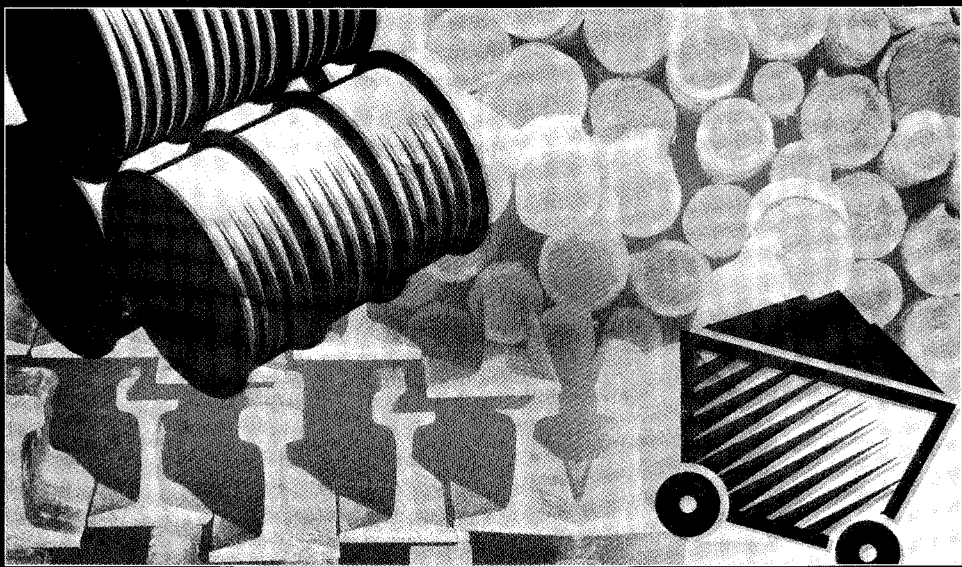
RESOURCE FLOWS:

THE MATERIAL BASIS OF INDUSTRIAL ECONOMIES



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NATIONAL INSTITUTE FOR ENVIRONMENTAL STUDIES

RESOURCE FLOWS: THE MATERIAL BASIS OF INDUSTRIAL ECONOMIES

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PREFACE

To begin industrial processes, people withdraw natural resources from the environment. The industrial system transforms these natural resources into nearly all of the products and services that we use—the food we eat, the clothes we wear, the cars we drive, the electricity we use to light our homes and power our computers. Virtually all of the natural resources that support this activity ultimately return to the environment, often in an altered form. This flow of materials from nature to the economy and back—the materials cycle—is fundamental to industrial economies.

The sheer scale of the process is remarkable and surprising, even in the most modern and efficient industrial economies. As this report documents, such economies require 45,000 to 85,000 kilograms of natural resources per person per year—the weekly per person equivalent of 300 shopping bags filled with materials, together weighing as much as a large luxury car.

The 1992 United Nations Earth Summit conference in Rio de Janeiro reached a broad consensus that the environmental resources of our planet are limited. Human activities, such as withdrawing natural resources, disposing of wastes, and modifying the landscape, can interfere with the planet's ability to support life. So sustaining a larger and more prosperous human society and providing for future generations requires decreasing the impact of economic activity on the environment. Natural resource use must be made more efficient and the growth of industrial economies decoupled from physical growth. Eventually, industrial societies' dependence on natural resources must be reduced and our economies "dematerialized" to some degree.

Yet, our ability to track such trends and to calculate the costs and benefits of industrial activity isn't up to the task. Conventional national economic accounts simply do not provide the information needed, nor do the prices of natural resources give accurate signals of the long term costs to society of their use.

This report proposes a way to enlarge our understanding of what sustainable economies require. It constructs a parallel set of national accounts in physical terms using material flow analysis and proposes new summary measures or indicators that can be used with economic indicators to give a far more accurate sense of the scale and consequences of industrial activity.

This analysis is particularly relevant in considering the expected global expansion of industrial activity. As human populations increase and industrial activity expands, pressures on the environment are intensifying. A four-or-five-fold expansion—the magnitude of expected growth in economic activity over the next half century—will present very serious environmental difficulties if the human use of natural resources and disposal of wastes grows apace. Yet, as this report shows, meaningful dematerialization—that is, an absolute reduction in per capita use of natural resources—is not yet occurring, even though over the past 20 years natural resource use has not risen as fast as economic activity. The world still has much to do to put itself on track toward a sustainable future.

This report results from a unique and productive international collaboration among our institutions. In such joint work may lie the best hope for finding broadly acceptable new approaches and powerful new insights that can stimulate the global transformation our societies need.

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EXECUTIVE SUMMARY

There is a price to be paid for modifying our environment, extracting resources, and emitting pollutants and wastes. But conventional national economic accounts do not spell out that price. They do not make explicit many activities that entail environmental modifications or uses of natural resources with potential environmental impact. For example, measures such as the Gross Domestic Product (GDP) do not include the movement or processing of large quantities of materials that have no (or even negative) economic value. Concepts such as full-cost accounting attempt to deal with such shortcomings, but trigger contentious debates about how to price the so-called externalities involved.

This study suggests an alternative or supplementary approach. It develops a parallel set of physical accounts to describe economic activity—accounts that can be related to national economic accounts—and proposes a new summary measure, the Total Material Requirement (TMR) of an industrial economy. The TMR measures the total use of natural resources that national economic activity requires.

National economic accounts fail to capture many activities of environmental consequence in part because the natural resources involved do not become commodities that are bought and sold. These hidden flows, which are associated with extractive activities, harvesting of crops, and infrastructure development, are immense. In the four countries studied, this report finds 55 to 75 percent of the TMR arises from hidden flows. National accounts in physical terms, such as those proposed here, are required to routinely document such uses of natural resources and their potential environmental effects.

In an ever more global economy, natural resources are frequently extracted in one country, transformed into products in another, and consumed in a third. The result is that a significant portion of the natural resource use that supports national economic activity often takes place outside national borders. Except in the United States, which is largely self-sufficient in natural resources, this report finds that the foreign proportion of TMR ranges from 35 to 70 percent in the countries studied, with the larger percentages in smaller countries. These high-income countries gain the benefits of consuming imported resources, but the environmental cost of producing them falls on others, often developing countries, that supply them. This disparity may not receive adequate consideration, because national economic accounts do not adequately measure the true extent of natural resource use and potential environmental harm. While this report covers only high-income countries, the methodology developed here could be applied to document international imbalances in the physical flows required to satisfy global economic demand.

The TMR takes into account both hidden flows and foreign components of natural resource use, as well as direct inputs of natural resources into the economy. The TMRs of even very modern industrial economies are enormous. This report documents that such countries now require an annual TMR of 45 to 85 metric tons of natural resources per person—and Direct Material Inputs (DMI) of 17 to 38 metric tons per person—to produce their flow of goods and services. This total does not include use of air and water.

This report also analyzes TMR figures over 20 years and finds both a general convergence among the countries studied and, in most, a gradual rise in per capita natural resources use. The implication is that meaningful dematerialization, in the sense of an absolute reduction in natural resources use, is not yet taking place.

A critical question is whether, in modern industrial countries, economic activity is becoming decoupled from natural resource use. Historically, economists have discussed materials intensity as the ratio of natural resource inputs to GDP. This report proposes a more comprehensive measure of materials intensity based on the ratio of TMR to GDP. The result shows a clearly declining pattern of materials intensity, supporting the conclusion that economic activity is growing somewhat more rapidly than natural resource use. However, materials intensity as traditionally measured (based on direct material inputs or DMI to GDP ratio) has leveled off over the past decade, implying that use of natural resource commodities may now be growing in parallel with economic growth. And examination of detailed material flows in each of the countries studied makes it clear that most natural resources are still being used in an environmentally disruptive once-through manner.

Ultimately, sustainable development will require a closer understanding of how the economic and environmental aspects of human activity interact, as well as actions based on such understanding. Conventional economic information, while useful, provides very little insight into these interactions. But the parallel set of physical accounts illustrated in this report allows comparison of economic and physical factors, which can add significantly to the information and tools for decision-making. Indicators of these physical flows, such as the TMR, can guide progress toward more efficient use of natural resources. For example, the OECD recently adopted as a long range goal that industrial countries should decrease their material intensities by a factor of 10—a profound change that is not likely to occur unless the the target and progress toward it can be explicitly measured. Using the methodology of this report, that target can be expressed as 30 kilograms per $100 of GDP, compared to the present value of approximately 300 kilograms per $100 of GDP.

Comprehensive physical accounts are also necessary to develop policies that support more sustainable industrial economies. Many environmental policies have focused on wastes and pollution—on the back end of the materials cycle—even though more than half, and as much as three-fourths, of the natural resource use occurs at the front end of the process, before natural resource commodities enter the economy. Since what leaves the industrial system as wastes is closely related to the volume of material inputs, policies that reduce the use of primary natural resources not only diminish extraction pressures, but also wastes and pollution. Similarly, policies that make natural resource use more efficient or increase recycling lower requirements and environmental impacts over the entire materials cycle.

To gain the full insights from the national materials flow accounts proposed in this report will require additional work and expanded international collaboration. This report suggests specific actions that governments and international organizations can take in the near future.

1

INTRODUCTION

The analysis presented in this report derives from a study of the physical basis of four high-income industrial economies—Germany, Japan, the Netherlands, and the United States—which together constitute a broad cross-section of the OECD countries. Working together, researchers at four institutions* applied a common methodology to the diverse circumstances of each country.

The study seeks to provide a quantitative physical description of all the natural resources directly and indirectly used by the economic activity of these industrial countries, even when portions of that use occur outside a country's borders. The material flows documented here encompass both the commodities that enter into commerce and all the flows associated with making a commodity available for human use. In addition, the study also accounts for direct and indirect uses of natural resources in construction, deliberate alterations of the landscape, and such side effects of human economic activity as soil erosion from cultivated fields. The study focuses on broad categories of materials, not sectors of the economy. It traces the material flows for these categories over the 20-year period from 1975 to 1994 to show how these flows are changing as population and economic activity increase. More broadly, this study creates an analytical framework for examining the physical basis of industrial economies—the beginning of a more complete understanding of their environmental impacts. By illustrating how physical accounts of material flows can be created, in a manner similar to accounting methods for economic flows, the study shows how national accounts can be constructed using physical measures. The study proposes new indicators that summarize trends in natural resource use, that compare material and economic flows, and that allow analysts and decision-makers to examine and track trends in dematerialization. Thus this study seeks to add to the information and tools available for decision-making.

This report presents the methodology developed and the preliminary results of the study, including the major trends evident in the data, a discussion of their implications, and summaries of the physical accounts. (To facilitate and stimulate further analysis, the Appendix includes disaggregated data sets, along with data sources and estimation techniques, for each country.)

This work stands on the shoulders of many other researchers, including early theoretical studies of the importance of material and energy "throughputs" in

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industrial economies by Kenneth Boulding and Herman Daly;[1] studies of commodity consumption by Donald Rogich and others at the U.S. Bureau of Mines;[2] analyses of trends in material usage by Alan Kneese,[3] Alvin Weinberg,[4] Jesse Ausubel,[5] Iddo Wernick,[6] and Martin Janicke;[7] and work on materials flow analysis by Frederick Schmidt-Bleek, Stefan Bringezu, and colleagues at the Wuppertal Institute[8] and by Marina Fischer-Kowalski.[9] This study is also related to extensive work by many authors on life cycle analysis and industrial ecology,[10] which charts detailed materials flows for specific industrial processes or within specific sectors of industrial economies, and to efforts to develop highly aggregated environmental indicators.[11] The present study goes beyond these earlier efforts by constructing a comprehensive (although still preliminary) set of physical accounts, assessing the related material flows at the national level for a number of countries, refining the methodology of materials flow analysis, and proposing new summary indicators.

2

ACCOUNTING FOR MATERIAL FLOWS

Material flow accounting can systematically track the physical flows of natural resources through extraction, production, fabrication, use and recycling, and final disposal, accounting for all losses along the way. This technique is motivated by the desire to relate the use of natural resources to the capacity of the environment to provide the materials and absorb the wastes.

The method is used here to provide a comprehensive overview of the physical basis of industrial economies and to derive indicators for sustainability. Although water is an important, and in some countries a limiting, natural resource, water flows are excluded from the analysis here, as is air, because its use varies widely among regions. All other natural resources removed from the environment to support economic activities are accounted for, as are materials moved or processed.

On the input side of the economy, agriculture, forestry, fisheries, mining, and oil or gas wells extract or harvest primary materials. Industrial processes then transform these inputs to produce products and services. Materials can be tracked through the chain of industrial processes to their use by consumers and to their ultimate fate, whether recycling and reuse (as with many metals), deposition as waste, or dispersion into the environment (as with fertilizers and pesticides or the combustion gases released in fuel burning). In this analysis, the boundary between nature and the economy is defined at the point when humans first extract or move materials from natural sites.

Extracting or harvesting primary natural resources often requires moving or processing large quantities of materials that can modify or damage the environment even though they have no economic value. For example, to get access to metal deposits, mineral ores, or seams of coal, for example, often requires moving huge amounts of covering materials or overburden. Often crude ores must be processed or concentrated before they become commercial commodities, leaving large amounts of process wastes to be disposed. The cultivation and harvest of crops often causes soil erosion by wind and water, potentially transporting large amounts of material and reducing the soil's fertility. Constructing dams, highways, and buildings often requires the excavating or shifting large amounts of earth and stone. All such flows are part of a country's economic activity, but most never enter the monetary economy as commodities.* In this report, the flows of materials that do not enter the

* Because practices differ among different countries, especially in metals refining, so does the dividing line between what is a commodity and what is not. In Europe, for example, many ore concentrates enter commerce; in the United States, many unified refining operations process ores completely, shipping pure metal as the commodity.

BOX 1 | QUALITATIVE CHARACTERISTICS OF MATERIALS FLOWS

The material excavated or moved in the preparation of a construction site has a qualitatively different impact on the environment than the release of heavy metals or organic chemicals. One way to take account of such differences is to segregate material flows by their long term impact on the environment, ranking all flows as either major or minor on both the degree of mobilization of the material and its potential for causing environmental harm.

Mobilization, the spatial domain affected by a flow, reflects the ability to reverse impacts caused by the flow; materials released to the atmosphere or dissipated to land and water systems affect larger areas than controlled landfills or tailings ponds. Materials that are biodegradable or have been moved or physically transformed generally have less potential to harm the environment than materials that have been chemically transformed.

Applying these criteria subjectively to the 21 billion tons of material flows for the United States in 1991 and calculating the percentage of the total flow in each category gives the following result:

high mobilization, high potential for harm	12 %
high mobilization, low potential for harm	29%
low mobilization, high potential for harm	5 %
low mobilization, low potential for harm	54 %

Flows in the first category may be most important from a long term national sustainability perspective. Locally, however, the third category of flows may be of greatest concern. This example illustrates that aggregate material flows can be disaggregated to give measures of their qualitative characteristics.

monetary economy are separated from those that do. The former flows are described as the hidden flows[12] associated with the extracted primary natural resource commodities.[13] The pressure on the environment exerted by hidden flows is often different from that due to materials that directly enter the industrial system and are transformed to goods and services. A million tons of earth moved in construction is not the same as a million tons of toxic wastes. But all uses of natural resources cause potentially important environmental alterations. To provide insight into measures of quality as well as quantity, materials can be classified in many ways. One is to distinguish those materials associated with construction and infrastructure from those associated with production processes (such as soil erosion, removal of mining overburden, and ore processing) and those that become commodities. Another possible categorization distinguishes inert materials that have little capacity to interact or combine chemically from those that are chemically reactive. Materials can also be classified by their degree of mobilization and whether they pose major environmental hazards. *(See Box 1.)* Such qualitative distinctions provide insight into how materials are used and into the nature of the environmental pressures that their use generates. So far, however, no standard method exists for measuring this environmental pressure.

This analysis asserts that it is not possible to know in advance what flows will be environmentally damaging. Determinants include both the perspective of the observer and the characteristics of the local environment: Filling in a wetland with earth to construct a highway is not a tragedy from a global or even a national perspective, but from a local perspective, it may be. Accordingly, in this study, flows of materials are recorded in the quantity as they occur, without additional weighting, even though there are clearly substantial differences in their character and potential environmental impact. Using the disaggregated accounts in the Appendix, however, researchers could combine data on the magnitude of different flows with additional weighting factors, should a scientific or political consensus emerge on the relative hazards or risks associated with any particular type of material or natural resource use.[14]

Because the market does not place a price on the hidden material flows, economic accounts do not usually include them. The resulting statistics understate the natural resource dependence of an industrial economy, giving decision-makers a distorted image of the physical scale and consequences of economic decisions. Under such circumstances, it is easy for economic planners or decision-makers to fail to adequately anticipate environmental effects.

For a given product or service, the primary natural resources and the associated hidden flows required to produce it comprise the total material requirements associated with that product or service. This quantity is also a measure of the potential environmental pressures attributable to that product or service. In the same way, the total material flows associated with a national economy can be calculated. These flows represent the total use of natural resources required to generate a national economy's goods and services.

Materials transported in international trade require additional discussion. In today's global economy, materials may originate in one country (raw material), be processed to some point (semi-manufactures) in another, created into final products in a third country, and ultimately consumed by yet a fourth nation. In principle, the hidden flows associated with exported materials could be assigned to the exporting country on the grounds that each country should be responsible for the environmental burden that its exports create. In practice, however, that approach overlooks the severe asymmetry between industrial economies—all of which import significant quantities of primary natural resources—and developing economies, many of which depend heavily on the export of such resources and, therefore, suffer from the environmental costs of resource extraction. Such a convention would also understate the actual physical basis of most industrial economies and the importance, from a global environmental perspective, of using natural resources more efficiently in these economies. In this analysis, an estimate of the hidden flows associated with imported primary natural resources and semi-manufactures (such as cast iron) is included in each national account. Separately, a preliminary account of the exports of each country is also presented.

Exactly how are the hidden material flows associated with imported materials calculated? They include estimates of the overburden removed in mining as well as materials that are processed but not sold. Where accurate numbers from the country of origin are not available, domestic numbers for comparable processes are used. Erosion of agricultural and forestry lands in the country of origin is used to estimate the hidden flows of imported renewable raw materials. The hidden flows of imported semi-manufactures are also estimated from calculations for domestic production. Provisionally, imported final products, such as manufactured goods, are accounted for directly, without hidden flows. Further work on measuring the hidden flows associated with internationally traded products is needed to establish consistent conventions for regular reporting. Nonetheless, the approximate numbers that this methodology yields provide a reliable basis for making preliminary international comparisons.

BOX 2 SOME USEFUL DEFINITIONS

Hidden material flow: This is the portion of the total material requirement that never enters the economy. It is the natural resource use that occurs when providing those commodities that do enter the economy. The hidden material flow comprises two components, ancillary flows and excavated or disturbed flows.

Ancillary material flow: This is the material that must be removed from the natural environment, along with the desired material, to obtain the desired material. Some examples are the portion of an ore that is processed and discarded to concentrate the ore and the plant and forest biomass that is removed from the land along with the logs and grain, but is later separated from the desired material before further processing.

Excavated and/or disturbed material flow: This is material moved or disturbed to obtain a natural resource, or to create and maintain infrastructure. Included in this category is the overburden that must be removed to permit access to an ore body, the soil erosion from agriculture, and the material moved in the construction of infrastructure, such as a highway or a building, or in the dredging of harbors and canals.

For simplicity, both ancillary and excavated or disturbed material have been combined into the single category of hidden material, even though they can have markedly different environmental impacts. Hidden flows have been calculated for six categories of material flows: fossil fuels, metals and industrial minerals, construction materials, renewable natural resources, infrastructure creation and maintenance, and soil erosion.

Direct Material Input (DMI): This is the flow of natural resource commodities that enter the industrial economy for further processing. Included in this category are grains used by a food processor, petroleum sent to a refinery, metals used by a manufacturer, and logs taken to a mill.

Total Material Requirement (TMR): This is the sum of the total material input and the hidden or indirect material flows, including deliberate landscape alterations. It is the total material requirement for a national economy, including all domestic and imported natural resources. The TMR gives the best overall estimate for the potential environmental impact associated with natural resource extraction and use.

The total physical requirements of a national economy—the sum of domestic and imported primary natural resources, together with their associated hidden flows—are called the Total Materials Requirement (TMR). This number is a measure of the physical flows, or the magnitude of economic activity measured in physical terms, that underpin an industrial economy. The TMR complements monetary measures of a nation's economic activity such as the GDP. Together, physical and monetary measures provide a more complete view of the size and scope of an industrial economy. The TMR can also be considered an approximate measure of the potential pressure exerted by an economy on the global environment, though precise measures will depend on the disaggregated components of the TMR and their environmental impacts. For purposes of international comparison, the material flow accounts of the four countries considered in this report are presented on a per capita basis, TMR per capita. An economy's use of natural resource commodities, the Direct Materials Input (or DMI) per capita, is also calculated; this quantity is the TMR less the domestic and imported hidden flows.

Discussion

As defined here, the TMR is concerned with the input end of the materials cycle, the total physical requirements and throughputs of materials on which a nation's economic activity depend. Accordingly, the material flows associated with exports—raw materials, semi-manufactures, or finished goods and their associated hidden flows—have not been deducted from TMR. The measure is adjusted, however, to take into account materials transfered across a country without being altered or stored there. This presents an accurate picture for countries such as the Netherlands, the entry port for many materials intended for other European countries.

Exports for each country are reported separately. In this preliminary stage of analysis, fully consistent export figures in physical terms for the four countries are not yet available. Nonetheless, the export figures provided illustrate that comprehensive materials flow accounts, which compare or "balance" imports and domestic extraction against exports and outputs to nature, can be constructed.

These national material flow accounts, analogous to national economic accounts, include the extraction and harvest of materials from the domestic environment. Imported materials, with their associated hidden flows, are added. Analysis of hidden flows for imports into Japan, Germany, and the Netherlands confirm that they are at least as large as the hidden flows associated with domestic extraction of primary natural resources; thus these flows cannot be neglected when considering how a nation's economic activity exerts pressure on the environment. These inputs can be compared with the outputs to the domestic environment in the form of wastes, emissions, and dissipative use of products, as well as outputs in the form of exported products. The result is a set of national material flow accounts. *(See Appendix.)*

These accounts provide valuable information on the relationships among flows, such as the ratio between renewable and non-renewable inputs or the amount of food and fiber from agriculture compared to the erosion caused. The balance between inputs and outputs indicates the net accumulation of materials in the industrial system. Moreover, such accounts link economic activities to their physical implications, which may be particularly important in considering sustainable development.

If significant reductions in per capita natural resource use and in the materials intensity of industrial economies are necessary in the long run to make sure that the benefits of industrial systems are enjoyed by all the world's societies, for example, then such indicators as the TMR will be necessary to monitor progress toward that goal. Since such questions arise not from a fear of resource scarcity but rather from concern about the environmental consequences of resource extraction and use, the TMR is an appropriate indicator for these purposes. Planning and managing more efficient and sustainable industrial economies and developing policies to encourage such a transition will require both detailed knowledge of the underlying physical flows and such highly-aggregated indicators as the TMR and the DMI to track overall trends.

Materials intensity has often been discussed as the ratio of natural resource inputs, or of pollution outputs, to Gross Domestic Product (GDP). This analysis extends that concept by including the natural resource use that does not enter the monetary economy, but is nonetheless a direct consequence of economic activity, the hidden flows. Thus, this analysis makes it possible to more accurately characterize the overall material intensity of an economy, as defined by the ratio of the TMR to the GDP.

This analysis also makes it possible to report the percentage of TMR associated with imports, which indicates the amount of potential burden to the environment within other countries that is associated with domestic economic activities. In addition, the analysis yields other potentially useful measures, such as the savings in natural resource use obtained by recycling iron or other materials. (More detailed discussion of the methods used to measure or estimate material flows in each country are given in the Appendix.)

3

RESULTS, IMPLICATIONS, AND CONCLUSIONS

Trends in natural resource use for the four countries studied are presented in a series of graphs, beginning with trends in TMR. Per capita figures are used to allow comparisons among countries. Subsequent graphs illustrate the composition of the TMR by six broad categories of materials, decompose the TMR into direct inputs and associated hidden flows, and show the proportion of domestic and foreign components. Two views of the material intensity in these four industrial economies is presented, and the benefits of recycling materials illustrated.

The four countries analyzed here vary considerably in the size of their populations, economies, and land area; however, all are highly industrialized countries with high standards of living. Perhaps not surprisingly, they show very similar overall trends in natural resource use.

Figure 1 gives the TMR in per capita terms for each of the four countries. In the early portion of the period studied, per capita TMR varied considerably, but over time the trends converge. For Germany, the Netherlands, and the United States, per capita natural resource use as measured by the TMR appears to be leveling off at about 75 to 85 metric tons per year. The decline in U.S. TMR per capita in the early years of the period was due primarily to major reductions in soil erosion after the enactment of the Conservation Reserve Program—which paid farmers not to farm highly erodible lands—and the completion of much of the federal interstate highway system. Japan's TMR per capita has followed a gradually rising pattern similar to that of Germany and the Netherlands, but at significantly lower levels, about 45 metric tons per year. The sharp rise in German TMR in 1991 reflects the reunification with the former East Germany, altering what would otherwise have been a relatively constant trend.

Despite the current overall similarity in TMR per capita for three of the four countries studied, the pattern of natural resource use varies significantly, as does the composition of the TMR by major categories of materials. There is one common factor: fossil fuel use is overwhelmingly the largest contributor to TMR in the United States and Germany and is the second largest contribution in Japan and the Netherlands. *(See Figure 2.)* In all of these countries except Japan, high levels of energy consumption, primarily from fossil fuels, is a major reason for the high overall levels of TMR. By the same token, Japan's relatively small per capita use of energy is the primary reason that its TMR is significantly lower than in the other countries. In Germany,* heavy use of low-caloric content coal

* The German data in Figure 2 reflect the impact of the 1991 reunification, so that the figures reflect energy and other natural resource consumption for a number of facilities that have subsequently been closed.

FIGURE 1 **TOTAL MATERIAL REQUIREMENT ANNUAL FLOWS PER CAPITA**

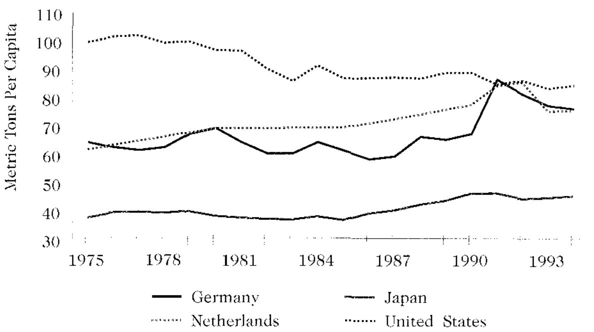
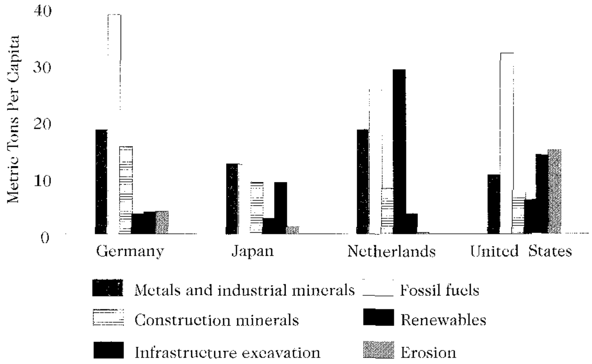


FIGURE 2 **PRIMARY CONTRIBUTIONS TO TMR, 1991**



(lignite) and the accompanying hidden flows stemming from the large overburden moved in mining coal dominates the fossil fuel contribution. Metals, reflecting strong automobile and steel sectors, and construction also contribute heavily to the country's total material requirements. In Japan the metals and industrial materials industry is the largest contributor. The contribution from domestic erosion is relatively low, reflecting the dominance of paddy rice cultivation.

In the Netherlands, renewable materials are the largest contributor to the country's TMR. Imports of feed for its large livestock operations, such as tapioca from Thailand and grain from Canada, account for most of the renewable flows. Fossil fuels, primarily natural gas, and metals are also major contributors. Domestic erosion is negligible, but some foreign erosion is included as a hidden flow with the imported livestock feeds. In the United States, in addition to the contribution of fossil fuels, continuing high levels of road building and other infrastructure development are major contributors to TMR, as well as erosion from agricultural operations.

Hidden material flows dominate the TMR, accounting for between 55 and 75 percent of the total in 1991. *(See Figure 3.)* The Netherlands and Japan are at the low end of this range and the United States and Germany are at the high end. The enormous size of the hidden flows underscore the importance of taking their environmental impacts into account.

An examination of trends over the past 20 years in the United States shows that hidden flows have decreased slightly and direct inputs have increased slightly as a proportion of the TMR. Thus, in some sense, the overall efficiency of natural resource use has improved. That improvement has come largely from the Conservation Reserve Program, evidence that appropriate policies can reduce hidden flows and thus diminish their environmental impacts.

FIGURE 3

DIRECT INPUTS AND HIDDEN FLOWS (AS A PROPORTION OF TMR), 1991

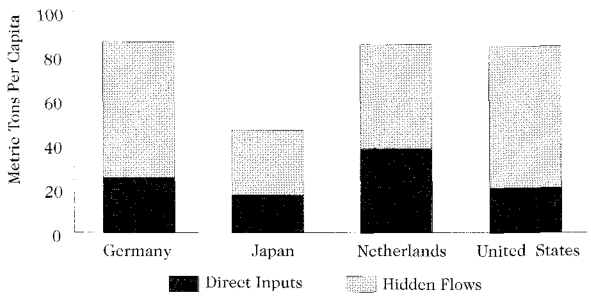
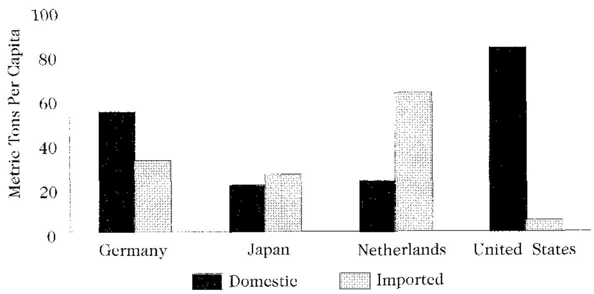


FIGURE 4

DOMESTIC AND FOREIGN COMPONENTS OF TMR, 1991



The TMR can also be split into domestic and foreign components. As Figure 4 illustrates, the proportion of natural resources from domestic sources varies considerably among the countries, despite the overall convergence of TMR per capita. Since the United States is largely self-sufficient in natural resources, except for oil, bauxite (the ore from which aluminum is made), and a few other industrial minerals, its material flows are almost entirely internal. In smaller industrial countries, a significant proportion of the total material flow that supports their economies takes place outside their borders: about 35 percent for Germany, more than 50 percent for Japan, and more than 70 percent for the Netherlands. These large proportions signify that the environmental impacts of these country's natural resource use are only partly borne by, and visible to, the residents of these countries. Indeed, Figure 4 suggests a generalization: the smaller an industrial country, the larger in proportion its transboundary materials flows and the greater the separation of the environmental effects of its natural resource use from their consumption benefits.

A critical question is whether modern industrial economies are becoming less material intensive as they shift, for example, from producing goods to producing services: Is economic activity becoming decoupled from natural resource use? Figure 5 summarizes trends in overall materials intensity, as measured by the TMR/GDP ratio. To prevent distortions caused by currency fluctuations, the intensity is based on a constant monetary unit in each country and indexed to a 1975 reference year. The curves are presented as moving five-year averages to smooth fluctuations in the business cycle. The analysis shows a declining pattern of materials intensity in all countries, supporting the conclusion that a modest decoupling is taking place. The decoupling trend would be even stronger if the effects of Germany's reunification were removed.

FIGURE 5 **OVERALL MATERIAL INTENSITY (TMR/GDP) INDEX**

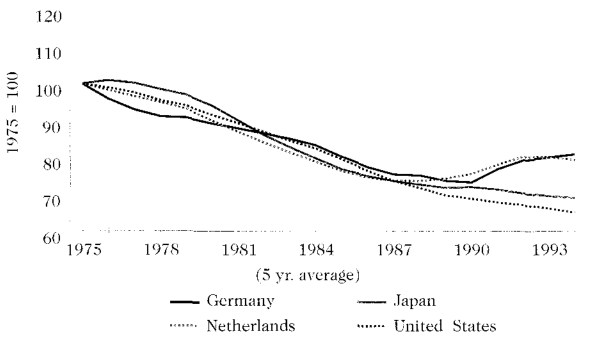


FIGURE 6 **DIRECT INPUT MATERIALS INTENSITY (DMI/GDP) INDEX**

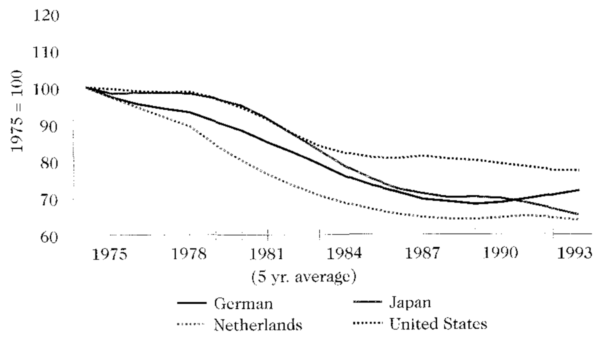


Figure 6, a comparable analysis, includes only the direct material inputs (natural resource commodities). It gives the DMI to GDP ratio, a measure of the direct input intensity. As above, this intensity is indexed to a reference year and fluctuations have been smoothed. The resulting pattern shows a modest decline in intensity, followed by a leveling off over the past decade, which implies that direct inputs of natural resources are now growing in parallel with economic growth. Improvements in technology and industrial practice or structural shifts to a more service-intensive economy, which might be expected to reduce this measure of material intensity, do not seem to be continuous.

This analysis makes it possible to characterize the relationship between natural resource use and economic activity more comprehensively, using both an overall materials intensity and a direct input intensity. However, the TMR/GDP ratio provides the best measure of a country's materials intensity or overall eco-efficiency, because it includes extractive activities and other hidden flows. This indicator is a useful tool to track progress toward decoupling natural resource use from economic activity. At the same time, the DMI/GDP ratio can signal the presence or absence of technology-related changes or industrial practices that increase the efficiency of materials use.

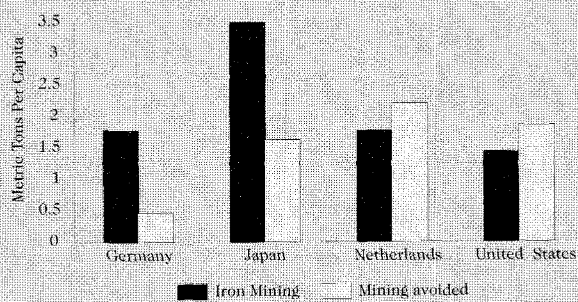
As an example of how such a tool might be used, the research team calculated the dollar value of the 1993 TMR/GDP ratio, using 1993 currency exchange rates. The results show that the U.S., German, and Dutch economies require, respectively, 3.4, 3.3, and 3.2 kilograms of physical inputs per dollar of GDP. Japan has a distinctly lower intensity of 1.4 kilograms per dollar. Because currencies fluctuate far more rapidly than do material flows, such figures should be used with caution; in 1985, for example, Japan's TMR/GDP ratio was 3.0 kilograms per dollar, with the difference almost entirely due to currency fluctuations. It is the overall trend, measured in a constant currency unit, that is significant. Nonetheless, such figures provide a

BOX 3 **SAVINGS FROM RECYCLING**

Not all materials that enter industrial economies are immediately returned to the environment as wastes or pollutants. Some have semi-permanent economic uses, such as buildings or highways. Others, such as iron and aluminum, are increasingly recycled and reused. Such reuse has significant economic and environmental effects.

To illustrate these effect, consider the recycling of iron. The hidden portion of the material flow associated with mining and processing of primary metals is particularly large. Every ton of iron recycled not only replaces a ton that would have been mined, but also avoids several tons of hidden material flows associated with iron mining and processing. (The amount differs in each country.) The figure below shows current material flows associated with iron mining in four countries and the material flow avoided by current recycling efforts. *(See Figure.)* For example, without recycling, the iron-related material flow and the associated environmental costs in both the United States and the Netherlands would be more than twice as large.

Savings from Recycling Materials (Iron)



convenient rule-of-thumb for the material-intensive nature of modern industrial economies: To generate $100 of income at present in Germany, the Netherlands, or the United States, requires about 300 kilograms of natural resources, including hidden flows.

Implications

The results from this study have far-reaching implications. Consider the sheer size of the natural resource requirements in the four countries studied. The 45 to 85 metric tons of natural resources per person per year required in these modern and advanced industrial economies translates into an enormous amount of extractive activity, landscape rearrangement, soil erosion, and direct consumption of natural resources to maintain current levels of industrial activity and lifestyles. For example, the food and fiber produced by the U.S. agricultural system causes about 15 metric tons of soil erosion annually for each U.S. resident; to build highways and other infrastructure requires excavating and moving about 14 metric tons of material per person every year. To support the Dutch livestock industry requires imported feeds and associated soil erosion corresponding to more than 29 metric tons for each resident, with most of the environmental impact falling on other countries. To produce the automobiles and other metal-intensive products for which Japan is well known demands the annual removal or processing of about 14 metric tons of metal ores and industrial minerals for each resident, again with much of the environmental impact occurring outside Japan. And to produce the energy used in a year in Germany requires, quite apart from the fuel itself or the pollution caused by its combustion, removing and replacing more than 29 metric tons of coal overburden for each German.

These are staggering volumes of material that create significant environmental impacts. Moreover, as the examples above suggest, the environmental costs are not borne entirely, in some cases even primarily, by these industrial countries. Is such a materials-intensive industrial model sustainable? Can it be replicated by many other countries without serious environmental harm? If much of the world were to extract and use natural resources at volumes and in patterns comparable to those in the countries studied in this report, where would resource withdrawals take place? And who would bear the environmental costs?

Even in the four countries studied here, aside from the erosion reductions in the United States, per capita natural resource requirements rose over the period analyzed, albeit slowly. The extractive pressures on domestic and foreign environments resulting from these industrial economies also rose. The most hopeful finding reported here is that natural resource requirements did not rise as rapidly as economic activity as measured by the GDP, but this analysis does not support the conclusion that direct input materials intensity, which most closely tracks industrial practices, is continuing to decline. For the past decade, at least, direct input materials intensity has been roughly constant.

Conclusions

These considerations highlight the need for more comprehensive materials accounts and for indicators, such as those proposed here, that can draw attention to overall use of natural resources. Indeed, to understand the links between economic activity and environmental degradation—and to integrate economic and environmental planning and policy-making—requires a more detailed understanding of the material basis of industrial economies. Such information is also necessary to formulate policies for improving the efficiency of natural resource use. What is needed are physical accounts, analogous to national economic accounts, that show the origin, use, and deposition of all materials associated with industrial economies. As established industrial economies continue to expand and as developing economies move rapidly toward industrialization, such information becomes ever more critical.

One example of how indicators based on physical accounts will be essential in decision-making comes from recent efforts to set social goals for decoupling natural resource use and economic growth, i.e., for dematerializing industrial economies.[15] The Carnoule Declaration proposes a 30- to 50-year goal of "cutting in half of present global non-renewable material flows" and argues that to accomplish this, given the needs of developing countries, requires industrial countries to decrease their material intensity by at least a factor of ten; the OECD Environmental Policy Committee also recently adopted this target as a long term goal.[16] In terms of the indicators proposed here, the Carnoule goal is equivalent to a tenfold reduction of the ratio TMR/GDP, through both decreases in absolute levels of material requirements and increases in economic activity. This translates to material intensities (as calculated in this report) of approximately 30 kilograms per $100 of GDP rather than the present 300 kilograms. Such profound changes are not likely to occur without an explicit way to formulate the goals and to measure progress toward such a goal, and without the detailed physical and economic accounts needed to understand how the industrial system must be transformed accordingly. The concept of TMR provides an important indicator for such purposes.

One more reason why both physical and economic accounts are needed is to improve economic decision-making. Because most material flows

BOX 4 IRREVERSIBLE NATURAL RESOURCE USE

Many current uses of natural resources are wasteful because the resources are used in a once through fashion. An industrial system may ignore potential efficiencies; for example, when a metal is mined, processed into a product, used, and discarded as waste, instead of being recycled and reused. More efficient industrial processes that reuse and recycle materials—metals, paper, plastics, even construction materials—thus point the way toward reducing the environmental effects of natural resource use and preserving them for future generations.

Not everything can be recycled, however. Some current uses of natural resources are inherently dissipative or irreversible. For example, when coal, petroleum, and natural gas are used as fuels, they can only be burnt once, and the resulting carbon dioxide is dispersed to the atmosphere. Similarly, soil eroded from fields and transported elsewhere by wind or water. Some toxic materials, such as those contained in pesticides, are deliberately dispersed in the course of use.

These examples are not trivial exceptions. Fossil fuels, including their hidden flows, represent between 26 and 46 percent of the TMR for the countries surveyed in this study. Erosion contributes 17 percent of the U.S. TMR. To reduce such irreversible uses will require policies that go beyond recycling to provide incentives to reduce the demand for fuels or encourage more sustainable methods of cultivation—policies that influence the front end of the materials cycle.

associated with industrial economies are not commodities and hence unaccounted for in economic terms, many strictly economic indicators give misleading signals. One widely-acknowledged example is the tendency to associate GDP growth unambiguously with economic progress, even when it reflects such activities as cutting forests, eroding soils, or other forms of natural resource degradation that may undercut future economic progress. Recent studies also show that productivity measures are similarly skewed because they fail to take into account the use of materials that are not sold but are disposed of in the environment.[17] The growing interest in alternative accounting practices at both the national level and at the level of the firm, the interest in industrial metabolism, product life-cycle analysis, and the development of measures of eco-efficiency all underscore the need for both physical and economic accounts.

A more fundamental rationale for physical accounts is a concern with the sustainability of industrial economies. Much of the policy attention to this issue has focused on wastes and pollution, on the back end of the materials cycle. Yet, if more than half (and as much as three-fourths) of the natural resources used occur at the front end of the cycle, as this report documents, then efforts to reduce environmental impacts must also focus there. Since what leaves the industrial system as wastes and pollution is closely linked to the volume of material inputs, policy incentives to reduce use of primary natural resources not only diminish extraction pressures but also waste and pollution. Similarly, policies that make natural resource use more efficient or increase recycling lower material requirements and environmental impacts throughout the materials cycle. Comprehensive physical accounts are needed to support such policies.

In an increasingly global economy that supports growing international trade, the pattern of economic activity is complex and involves numerous transborder flows of both money and materials. To the extent that the environmental costs of each stage in this process are not adequately captured in commodity prices, then an inherent inequity exists between who pays these environmental costs and who gains the benefits from using natural resources. As this study documents, large hidden portions of the materials flows associated with economic activity are not captured by economic accounts, making it probable that commodity prices do not adequately reflect environmental costs. Moreover, in all countries studied except the United States, very substantial portions of the materials flows, and hence the environmental costs, associated with national economic activity take place outside national borders. To understand this complex pattern of interlinkages, and perhaps eventually to equitably apportion costs and benefits, will require documenting materials flows, establishing national accounts of materials flows, and working out agreed international conventions on how to account for transboundary flows of materials. This report offers some preliminary attempts at such an accounting, but additional work is needed.

4

NEXT STEPS

The outcomes of this study suggest that a more detailed understanding of the material basis of industrial economies is needed to better understand the links between economic activity and environmental degradation. We suggest five next steps that would contribute:

1. The Development of Accounts

The present study introduced the concept of TMR as a means of summarizing the physical aspects of economic activity at the input or front end of the materials cycle. An obvious next step would be to develop a more complete accounting and some aggregated indicators to summarize the physical flows at the back end of the material cycle. Such an accounting would comprehensively measure all human-induced materials flows entering the environment and would supplement more specialized indicators of specific pollutants.

Systematic assessments at the front and the back end of the materials cycle would also make possible comprehensive national accounts that balance materials flows by comparing domestic inputs and imports with exports and outflows to the environment and additions to infrastructure and other stocks. Such accounts have already been established by the German Federal Statistical Office as part of its integrated environmental and economic accounting procedures.[18] Along with conventional economic accounts, they provide a more complete picture of economic activity and its environmental consequences and allow scrutiny of how outputs are related to inputs, showing where more efficient use of primary materials can reduce pollution.

2. Focusing on Economic Sectors

This study is materials oriented. It groups physical flows into six broad categories of materials. But decision-making processes at the sectoral level generally can not be based on national aggregate measures, such as the TMR, or on broad materials categories, because they are not specific enough for any sector considered. An obvious next step would be to further disaggregate and regroup the material flows by economic sectors, for at least the most important sectors. For example, it would be useful to generate separate numbers for the materials flows associated with the production and consumption sectors. This approach lends itself to developing sector-specific policies.

3. Taking Account of National Differences

The globalization of economic activity results in a more intense exchange of economic goods and services. Since the products generated, the industrial technologies applied, and operational practices differ from one nation to another, as do environmental conditions, accurate calculations of the hidden flows associated with economic activity must also take account of such differences. This will require further international collaboration. A related question is whether and how hidden flows should be attached to imports of manufactured products and other final goods.

4. Qualitative Aspects of Materials Flows

The present study gives some examples of categorizing materials flows by their potential to harm the environment. Further work in this direction would seem warranted, including an investigation of weighting schemes that allow a more quantitative assessment of environmental impacts arising from different materials flows.

5. International Coordination

This study is limited to the materials flows of four industrialized countries. Applying the methodology to a larger number of countries would expand the physical database, improve the methodology, and lay the basis for progress toward more sustainable economies. Adoption and application by such bodies as the OECD and by additional national governments would further this process. The World Trade Organization and U.N. agencies such as the U.N. Commission on Trade and Development could help coordinate and harmonize the methodology. Development banks could apply this methodology on behalf of their client countries, either directly or, where data are lacking, by deriving coefficients from comparison of physical and economic flows in this study to estimate the physical flows and potential environmental consequences of development plans.

NOTES

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11. A. Adriaanse, *Policy Performance Indicators* (SDU Publishers, The Hague, 1993); A. Hammond et al., *Environmental Indicators* (World Resources Institute, Washington, D.C., 1995).

12. Because practices differ among different countries, especially in metals refining, so does the dividing line between what is a commodity and what is not. In Europe, for example, many ore concentrates enter commerce; in the United States, many unified refining operations process ores completely, shipping pure metal as the commodity. .

13. In some of the literature, the term "ecological rucksacks," after the German word for backpacks, is used to describe hidden flows.

14. Just such weighting procedures are often used in applying the technique of Life Cycle Analysis to particular materials or industrial processes.

15. Organization for Economic Co-operation and Development (OECD) "Meeting of OECD Environment Policy Committee at Ministerial Level" (OECD, Paris, 1996).

16. Factor 10 Club, *Carnoules Declaration* (Wuppertal Institute, Wuppertal Germany, 1995) p.11; Organization for Economic Co-operation and Development (OECD), Meeting of the OECD Environmental Policy Committee at Ministerial Level, February, 1996.

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DATA SUMMARY

Based on this study, the material requirements of industrialized economies were seen to vary significantly in their six main underlying categories, although very similar in the aggregate. The data presented in this section, particularly in the Summary Table, provide a harmonized view of material requirements for the four countries in this study. This table was developed as an overview of the detailed time-series data in the attached Appendix. Data are presented on the relative importance and nature of exports from each of the four countries and illustrate the hidden flows attached to exports in one country, the United States. Additional data are provided in this section for Germany and the Netherlands to show how comprehensive physical accounts of an economy (combining material requirements and outputs, including exports and flows into the environment) can be constructed to more completely map the material flows through an economy.

TABLE 1 **SUMMARY TABLE OVERVIEW**

	U.S.A.	Japan	Germany	Netherlands
Total domestic commodities	4,581	1,424	1,367	271
Total foreign commodities	568	710	406	303
Grand total commodities	5,149	2,133	1,773	574
Grand total commodity per capita	20	17	22	38
Domestic hidden flows	15,494	1,143	2,961	69
Foreign hidden flows	594	2,439	2,030	632
Total hidden flows	16,088	3,583	4,991	701
Tot. hidden flows./tot. comm	3	2	3	1
TMR (commodities + hidden flows)	21,237	5,716	6,764	1,275
TMR/capita	84	46	86	84

TABLE 2 **SUMMARY TABLE**

	DOMESTIC							
	Commodity				Domestic Hidden Flows			
Material Category	U.S.A.	Japan	Germany	Nether-lands	U.S.A.	Japan	Germany	Nether-lands
Fossil fuels total	1,684	13	365	68	5,846	3	2,333	1
Commodity/capita (domestic and foreign)	8	3	6	15				
Total hidden flows/commodity (domestic)	3	0	6	0				
Metals total	185	1	0	0	1,750	6	0	0
Commodity/capita (domestic and foreign)	1	1	1	1				
Total hidden flows/commodity (domestic)	9	12	1	NA				
Industrial minerals total	105	194	53	7	312	21	35	1
Commodity/capita (domestic and foreign)	0	2	1	0				
Total hidden flows/commodity (domestic)	3	0	1	0				
Construction material total	1,730	1,103	749	59	159	0	164	15
Commodity/capita (domestic and foreign)	7	9	10	7				
Total hidden flows/commodity (domestic)	0	0	0	0				
Infrastructure total					3,473	1,105	300	51
Total/capita					14	9	4	3
Soil erosion total					3,710	8	129	2
Renewable total	878	113	199	137	244	NA	NA	NA
Commodity/capita (domestic and foreign)	4	2	3	12				
Total hidden flows/commodity (domestic)	0	0	0	0				
Semi-manufactures								
Total hidden flows/commodity (domestic)								
Finished goods								
Semi-manufactures + finished goods/capita								
Total commodities (domestic)	4,581	1,424	1,367	271				
Commodity per capita	18	11	17	18				
Total hidden flows (domestic)					15,494	1,143	2,961	69
Total hidden flows/commodity (domestic)	3	1	2	0				

Total Material Requirements

The Summary Table, which combines data from detailed country specific data sets into a common format and for a single year, 1991, illustrates the similarities and differences found in the four industrialized countries. Data are presented by flow type (direct or hidden flows), source (domestic or foreign), and material category (fossil fuels, metals, industrial minerals, construction material, infrastructure, erosion, renewables, and the imports of semi-manufactures and finished goods) for each of the four countries. The Summary Table Overview also contains the summary statistics for each country.

Some conclusions are straightforward. In all four countries, construction materials constitute a major

TABLE 2 **SUMMARY TABLE (continued)**

	FOREIGN							
	Commodity				**Foreign Hidden Flows**			
Material Category	U.S.A.	Japan	Germany	Netherlands	U.S.A.	Japan	Germany	Netherlands
Fossil fuels total	412	408	139	157	73	1,049	181	155
Commodity/capita (domestic and foreign)								
Total hidden flows/commodity (domestic)								
Metals total	30	142	49	10	42	662	228	61
Commodity/capita (domestic and foreign)								
Total hidden flows/commodity (domestic)								
Industrial minerals total	17	12	2	0	13	7	619	0
Commodity/capita (domestic and foreign)								
Total hidden flows/commodity (domestic)								
Construction material total	0	9	26	45	0	0	10	16
Commodity/capita (domestic and foreign)								
Total hidden flows/commodity (domestic)								
Infrastructure total								
Total/capita								
Soil erosion total								
Renewable total	9	76	23	46	120	190	179	263
Commodity/capita (domestic and foreign)								
Total hidden flows/commodity (domestic)								
Semi-manufactures	48	54	124	11	347	531	814	149
Total hidden flows/commodity (domestic)	7	10	7	13				
Finished goods	52	10	45	34				
Semi-manufactures + finished goods/capita	0	1	2	3				
Total commodities (domestic)	568	710	406	303				
Commodity per capita	2	6	5	20				
Total hidden flows (domestic)					594	2,439	2,030	632
Total hidden flows/commodity (domestic)								

portion of direct domestic flows of materials into the economy. But sand, gravel, and stone also have relatively small attached hidden flows and are usually produced locally with relatively small foreign sources.

The data for fossil fuels are slightly more complex. Fossil fuels make up a large component of total requirements in all four countries, but each country has a different mix of the relative importance of domestic and foreign sources and there is great variability in the relative size of hidden flows, depending largely on the amount of coal mined or imported and the mining method used to extract that coal. For example, the hidden flow (primarily coal overburden) from fossil fuel production in the United States is the single largest category of flow

TABLE 3 EXPORTS FROM FOUR INDUSTRIAL COUNTRIES

	Commodity Exports			
Material Flow Category	**U.S.A.**	**Japan**	**Germany**	**Netherlands**
Fossil fuels total	151.96	7.15	5.57	129.74
Commodity/capita	0.60	0.06	0.07	8.65
Metals total	10.87	0.00	0.35	3.27
Commodity/capita	0.04	0.00	0.00	0.22
Industrial minerals total	6.93	0.00	5.36	*
Commodity/capita	0.03	0.00	0.07	0.00
Construction material total	5.40	0.00	25.50	21.56
Commodity/capita	0.02	0.00	0.32	1.44
Renewable total	130.44	1.40	14.45	30.05
Commodity/capita	0.52	0.01	0.18	2.00
Semi-manufactures	94.95	35.98	47.64	41.20
Finished goods	30.96	31.27	112.39	11.14
Semi-manufactures + finished goods	125.90	67.25	160.03	52.34
Semi-manufactures + finished goods/capita	0.50	0.54	2.00	3.49
Total commodities	431.50	75.79	211.25	236.95
Commodity per capita	1.71	0.61	2.64	15.80

Notes: Totals are in millions of metric tonnes. Per capita estimates are in metric tonnes.
* Industrial minerals exported by the Netherlands are included in construction materials.

for the four countries. The same flow for Germany dominates its accounts.

Every country is different. The United States produces most of its metals while Japan, Germany, and the Netherlands import theirs. Excavation for infrastructure is very small in Germany and the Netherlands, and is large in Japan and the United States, which is partly due to the relative maturity of infrastructure in the two European countries. But it might also be because of differences in building methods and in the lifetimes of features of the built environment. Erosion varies widely among the countries, reflecting differences in soils, topography, and agricultural systems, but only the United States actually surveys erosion on a regular basis. Other than for erosion, there are no estimates of hidden flows for renewable resources.

The summary statistics are surprisingly similar. The United States, Japan, and Germany had almost identical direct input flows, DMI, per capita. Those

TABLE 4 **EXPORTS AND HIDDEN FLOWS: A UNITED STATES EXAMPLE**

Material Flow Category	Direct Commodity Exports	Associated Hidden Flows	Total Effective Exports
Fossil fuels total	151.96	624.81	776.76
Commodity/capita	0.60	2.47	3.07
Metals total	10.87	35.05	45.92
Commodity/capita	0.04	0.14	0.18
Industrial minerals total	6.93	27.72	34.66
Commodity/capita	0.03	0.11	0.14
Construction material total	5.40	0.11	5.51
Commodity/capita	0.02	0.00	0.02
Renewable total	130.44	868.48	998.92
Commodity/capita	0.52	3.44	3.95
Semi-manufactures	94.95	692.85	787.80
Finished goods	30.96		30.96
Semi-manufactures + finished goods	125.90	692.85	818.76
Semi-manufactures + finished goods/capita	0.50	2.74	3.24
Total commodities	431.50	2,249.02	2,680.52
Commodity per capita	1.71	8.90	10.61

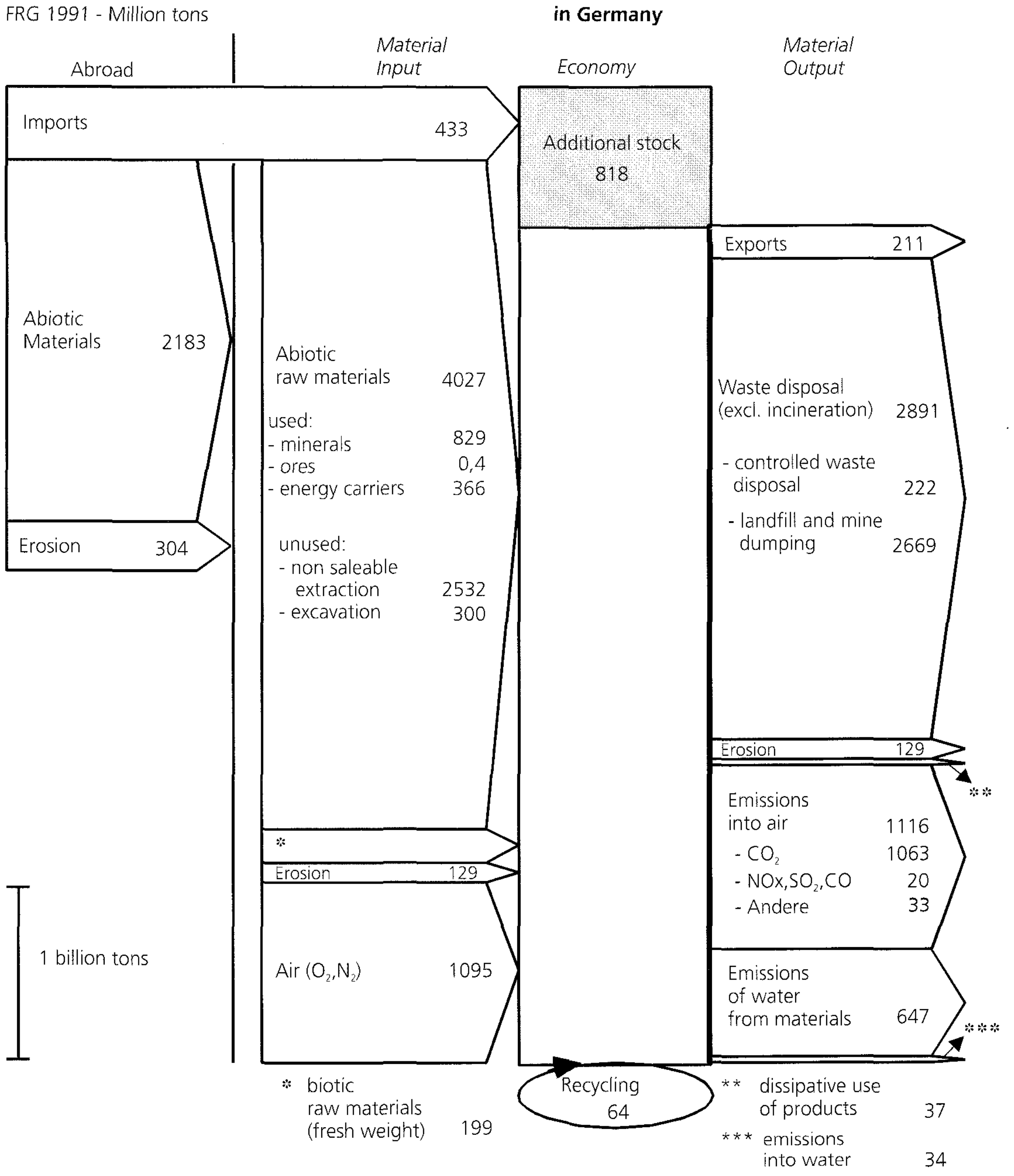
Note: Hidden flows for semi-manufactures are estimated from the aggregate hidden flows of imports.

same flows in the Netherlands were surprisingly high, due to the relatively large flows from foreign sources of materials in all categories. Except for Japan, TMR per capita was also similar. Despite the differences in detail, the United States, Germany, and the Netherlands had almost identical figures, all of them much larger than the levels of natural resource use in Japan. Japan's relatively low figure is due to much lower levels of energy consumption, as well as generally smaller rates of resource use and low rates of soil erosion.

Exports and Hidden Flows

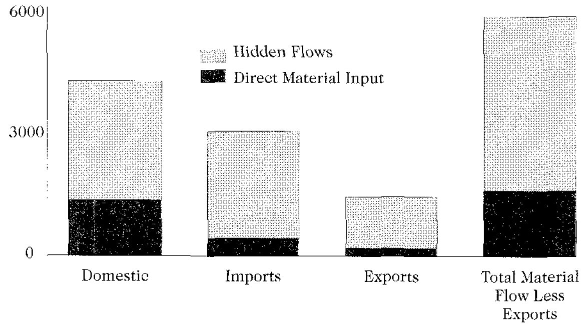
Among the physical outputs of an economy are raw materials, semi-manufactures, and finished goods exported to other countries. Data on the quantity and nature of these exports help explain the structure of a country's material requirements and the ultimate disposition of some outputs. The Export Table does not just detail exports, it also shows differences between the four countries' economies, and the ultimate fate of the material they mobilize for that economy.

FIGURE 8 **MATERIAL FLOW ACCOUNT OF GERMANY**



Source: S. Bringezu and H. Schütz, Wuppertal Institute, January 1997.

FIGURE 9 **TOTAL MATERIAL ACCOUNT OF GERMANY**



The Netherlands, for example, is a relatively large exporter of fossil fuels, natural gas and refined petroleum products. Those exports are about 10 percent of its TMR. Japan and Germany export trivial amounts of such fuels. The export of renewable resources is also large for the Netherlands, and is large in absolute terms for the United States, which reflects these countries' large agricultural sectors.

Germany, on the other hand, exports large amounts of semi-manufactures and finished goods, showing the importance of its manufacturing sector in transforming material and the importance of exports to that sector. The Netherlands, however, stands out on a per capita basis as the largest exporter of semi-manufactures and finished goods among the four countries. The total material exports of the Netherlands make up almost 19 percent of its total material requirements and dwarfs those of the other countries on a per capita basis, fully six times larger than Germany, for example.

Understanding the magnitude and importance of exports requires comprehending the hidden flows that support them. In the table Exports and Hidden Flows, hidden flows associated with each category of export have been calculated for the United States. These flows can be large (especially in the case of fossil fuels and renewables) and are 5.2 times the mass of the actual exports of the United States. Exports and their associated flows account for 12.6 percent of the TMR of the United States.

Comprehensive Material Accounts

In a complete accounting system, measurements of TMR would be complemented by measures of total material outputs, and one of those components would be exports. This study did not attempt to provide this complete accounting, but work on this topic has begun. Figures 8 and 9 show highly aggregate data for Germany and the Netherlands that provide a preliminary form of such an accounting. These figures illustrate that requirements are balanced by outputs, including additions to stock. Tracing flows associated with imports and indigenous resource extraction through the economy to outputs as exports and wastes expands the understanding of a country's economy beyond what is obtainable from economic accounts.

The Wuppertal Institute prepared Figure 8, the Material Flow Account of Germany. The Figure provides information on the location of the flow, flows that cross international boundaries, and flows into the environment. Not all the material used by the German economy ends up as output. Much of this material, 818 million tons, is added to the stock of materials use by people (such as buildings, infrastructure, and durable goods). The economy creates many products that are exported for use elsewhere. The hidden flows associated with exports are shown in Figure 9. The economy also generates large amounts of waste in the form of landfills and mining wastes. Emissions into air and water make up a large proportion of all output.

FIGURE 10 **MATERIAL FLOW ACCOUNT OF THE NETHERLANDS**

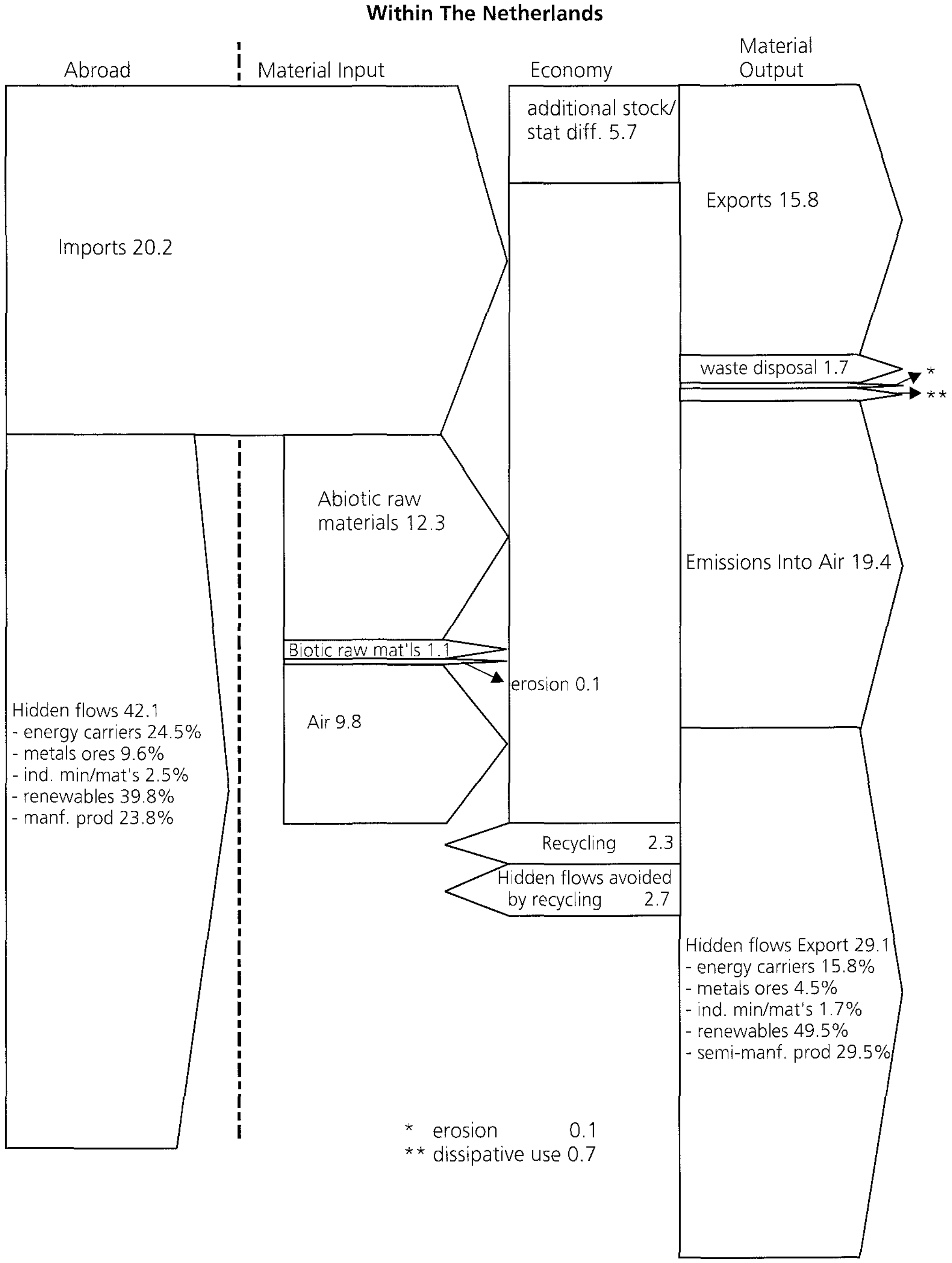


Figure 10, the Material Flow Account of the Netherlands, parallels that of Germany but is presented on a per capita basis. Unlike the German example, the Netherlands example includes as output the hidden flows associated with exports. Recycling is included (and is relatively large compared to that of Germany) and the hidden flows avoided by recycling material are accounted for.

APPENDIX

Overview

No international institution or standard methodology exists for tracking material flows that support an economy. There is also no international consensus on what data constitutes the minimum to describe those flows. While researchers have developed methods to look at these flows in a specific country (e.g., Germany in the case of the Wuppertal Institute), the challenge for this report has been to develop, apply, and test such a method in a cooperative international context. In this study, the authors created a set of guidelines, based on the initial work of the Wuppertal Institute, for use in each of the study countries. These guidelines were then used to develop each national data set based on national and international sources, academic studies, interpolation and extrapolation from known data, and estimation techniques. The authors harmonized their efforts by agreeing to common definitions, boundaries, and conventions.

The participants agreed to be as comprehensive as possible in their accounting of flows that support national economies, excluding only air, water, and agricultural tillage. Since the intent of the study in the first place was to obtain an approximation of the overall magnitude of the material flows in each country, it was agreed that minor flows could be excluded even if they might have significant environmental implications (e.g. flows of certain heavy metals). The accounting ranges from 1975 to 1994. The year 1975 was chosen as the earliest date from which a reliable time-series could be constructed for all four countries. As part of indicator construction, 1991 was chosen as a base comparable year, the first year for which reliable data after the reunification of Germany were available.

In principle, annual flows are only counted when they cross an imaginary boundary between the ecosphere and the anthroposphere, essentially when they are mobilized to support the industrial economy, or to create the infrastructure that supports it. Since this study focused only on the requirements of industrial economies, once materials enter the economy they are no longer counted, even if they are shifted about several times. When calculating the flows, a distinction is maintained between the direct input (e.g., the commodity when it first enters commerce), and the total material flow, which includes hidden flows (material that does not enter commerce) that had to be mobilized to obtain the direct input. Whether the flows occur in or external to a country is also differentiated. Imports of metals and minerals are problematical since they may be imported as ore, several different grades of concentrated ores, or in a relatively pure form (in this situation it would be counted as a semi-manufacture). In all cases the total hidden flows are harmonized among the four countries.

In each of the four countries, material flows associated with infrastructure were estimated by a variety of means. In some cases, annual time series data were available (e.g., dredging in the United States). In others, such as roadway and general construction, countries calculated material flows based on economic data and cost-estimation methodologies, while others made direct estimates of the material excavated. Where deemed appropriate, adjustments were made to the calculated values for consistency.

Flows from renewable resources were estimated similarly to those from non-renewable sources. Soil erosion, the primary hidden flow from agricultural and forestry activities, is categorized separately. Agricultural and forestry production is counted as the net weight of all major crops and the associated non-saleable above ground biomass. A tree, for example, is counted as the mass of roundwood, and the hidden flows are the associated limbs, leaves, stumpage, and erosion (if not counted separately). Livestock, fish, and other animal biomass are counted only when fed from non-agricultural feeds (since in theory human supplied food is counted as an agricultural flow). Fish harvested from wild stock are counted—fish raised in aquaculture are not. Livestock produced primarily from grazing are counted, those raised on grain are not.

Domestic semi-manufactures and final products were not included in this accounting since the flows of raw materials to produce them are already counted. Imported semi-manufactures, such as Portland cement, are counted along with the hidden flows of foreign origin associated with them. Participating institutions agreed to a harmonized set of factors for estimating hidden flows associated with the importation of semi-manufactured goods. Imported finished goods are counted only as the direct tonnage involved, primarily due to lack of data on actual materials embodied in each product.

Recycled materials (e.g. scrap metal and paper) are not counted in these estimates except when imported. Exports of any kind were not deducted in calculating the material requirements presented in this report, although export data are presented separately.

To permit comparisons of material flows in relation to economic activity, each country's economic data are harmonized to constant 1985 denominated monetary units for each country.

To show what data and methodologies were used by the participating countries, a separate annex, prepared by each country, is included in this Appendix.

German Material Requirements

The physical basis of the German economy originates from both domestic and foreign material flows. Although commodity imports account for only 30% of domestic production of raw materials, the hidden flows associated with imports is only about one third smaller than the total domestic hidden flows. German imports carry on the average a significantly higher hidden flow than domestic raw materials. Domestic extraction from the environment provides mainly construction materials, industrial minerals, and fossil fuels, as well as renewable materials. Ores are usually imported as is a significant proportion of total fossil fuels. Since 1975, imports of semi-manufactures and final products play an increasing role Germany's total material requirement. Thus, environmental pressure from material flows associated with the German economy has most probably been shifted to foreign countries in recent years.

The overburden removed by the surface mining of lignite dominates the domestic hidden flows of raw material production. Together with the non-saleable portion extracted from underground hard-coal mining, it accounts for about 78% of the total domestic hidden flows. About 52% of the total hidden flows associated with imports is associated with raw material imports and about 48% associated with imported semi-manufactures. A large portion of the hidden flows of imported raw materials is linked to ores, coal, and industrial minerals, especially diamonds and other precious stones. The hidden flows of imported semi-manufactures is mainly associated with metals.

Fossil fuel materials and their hidden flows dominate the total material requirement of the German economy, contributing about 45% to total TMR. Construction materials, iron, copper, and industrial minerals and imported semi-manufactured metals and their hidden flows represent about 47% of the TMR of the German economy.

Excavation for infrastructure accounts for about 300 million metric tons or roughly 10% of the total domestic hidden flows. This number refers to the reunited Germany in 1991. More recent trends in construction activities indicate that excavation for infrastructure may have increased significantly since 1991.

Erosion within Germany accounts for about 130 million metric tons or roughly 4% of the total domestic hidden flows. However, in recent years, the trend is increasing, mainly due to an increasing cultivation of crops with high erosion risks, especially maize for animal feed. On the one hand, the average rate of domestic erosion exceeds the soil regeneration rate by a factor of ten. On the other hand, erosion associated with imported renewable materials is higher than domestic erosion if related to the absolute quantities of the commodity masses. This is mainly due to imports from regions with severe erosion problems, such as parts of Africa, Southeast Asia, and Latin America.

Please note that data concerning domestic and imported hidden flows are based upon an origin-oriented definition, i.e. they refer to the country where the materials are extracted from the environment. Metal imports are accounted for as the absolute mass of the ore or the concentrate.

Data Sources and Methodology

General references:

FSOG: Federal Statistical Office Germany, several official publications, especially Production Statistics, Foreign Trade Statistics, Water Statistics, Waste Statistics, Statistics of Economic and Environmental Accounting.

FMEM: Federal Ministry for Economy and Mining Authorities for the Federal States: mining industry and statistics, annual publication.

FMNAF: Federal Ministry for Nutrition, Agriculture and Forestry, Annual Statistical Yearbook.

FIGR: Federal Institution for Geosciences and Raw Materials, annual reports.

GGSI: Association of the German Gravel and Sand Industry, annual reports

Material Requirements 1975-1994
Federal Republic of Germany

(Domestic Requirements 1991 to 1994 for re-united Germany, Imports 1991-94 for Western Germany only)

Unit:1000 metric tons	*1975*	*1976*	*1977*	*1978*	*1979*	*1980*	*1981*	*1982*	*1983*	*1984*
DOMESTIC										
Non-renewables										
I. Energy Carriers										
Lignite	123,377	134,535	122,948	123,587	130,608	129,862	130,649	127,352	124,365	126,703
Hard Coal	92,393	89,269	84,513	83,541	85,799	86,574	87,864	88,442	81,653	78,858
Crude Oil	5,741	5,524	5,401	5,059	4,774	4,631	4,459	4,256	4,116	4,055
Crude Oil Gas	*301*	*329*	284	*261*	*218*	*226*	*77*	*201*	*177*	*181*
Natural Gas	13,406	14,118	13,886	15,516	15,616	13,543	14,616	11,714	13,414	13,000
II. Metal Ores										
Iron	3,288	2,256	2,573	1,601	1,657	1,948	1,575	1,314	980	1,060
Lead and Zinc	308	302	301	260	266	271	253	242	256	253
Pyrite and Pyrrhotite	492	523	531	502	460	502	483	508	554	514
Bauxite	1	0	0	0	0	0	0	0	0	0
Uranium	*0*	*0*	*3*	*10*	*0*	*11*	*0*	*6*	*0*	*7*
III. Ind. Minerals										
Phosphate	*81*	*86*	*80*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
Potash	4,518	4,310	5,953	6,253	6,728	6,777	6,487	5,241	6,101	6,500
Salt	9,314	11,314	12,319	12,655	15,086	7,631	13,297	11,748	10,867	12,211
Clay	5,286	5,863	6,125	6,047	6,479	6,706	6,257	6,300	6,510	6,693
Limestone (industrial)	2,816	2,411	2,384	2,615	2,381	2,346	2,004	1,419	1,466	1,454
Other	16,192	14,206	13,460	13,570	12,439	20,753	13,352	17,596	18,489	19,330
Total	38,207	38,190	40,320	41,140	43,113	44,212	41,397	42,305	43,433	46,188
IV. Construction Minerals										
Sand and Gravel	389,518	374,214	363,508	378,399	398,036	377,408	328,017	294,758	289,638	280,091
Crushed Stone (incl. limestone)	*173,187*	*182,561*	*193,099*	*188,290*	*192,865*	*205,210*	*187,975*	*132,857*	*184,854*	*163,649*
Clay for bricks	21,929	24,867	18,908	21,243	24,043	23,228	21,208	17,159	18,119	16,948
V. Excavation										
Non-saleable production (incl. overburden gangue)	786,615	851,723	861,132	838,634	978,039	1,105,025	1,089,106	1,118,201	1,128,369	1,087,553
Excavation for infrastructure	143,802	147,634	153,307	158,935	170,044	167,526	153,307	149,955	149,780	149,660
Renewables										
I. Plant biomass										
Agricultural Harvest	131,864	122,640	137,238	138,693	131,060	125,886	138,298	144,247	119,319	138,208
Logging	*19,264*	*21,109*	*21,833*	*20,712*	*20,123*	*22,443*	*21,726*	*21,355*	*19,235*	*21,507*
Plant Biomass from "wild harvest"	7,333	7,398	7,464	7,529	7,594	7,660	7,583	7,664	7,887	7,995
II. Animal biomass										
Fishing	434	415	395	359	323	287	282	276	285	293
Hunting	46	48	50	48	46	44	44	43	44	45
Soil Erosion	70,454	71,282	73,101	74,183	74,306	75,255	76,374	77,781	78,446	79,940
IMPORTS										
Non-renewables										
I. Energy Carriers										
Lignite	1,647	1,565	1,615	1,474	1,606	2,142	2,728	2,681	2,652	2,615
Hard Coal	6,248	5,970	6,353	6,565	7,773	9,124	10,321	10,635	9,122	8,847
Crude Oil	88,414	97,669	96,290	94,375	107,355	96,876	79,247	72,542	65,213	66,934
Natural Gas	19,598	22,575	25,553	29,847	36,117	36,454	35,831	34,627	34,188	34,497
II. Metal Ores										
Iron	44,828	47,157	40,049	42,514	52,160	50,174	44,612	39,171	35,801	42,924
Iron-Manganes-meltings and slags	1,813	1,739	1,529	1,833	2,075	1,791	1,626	1,558	1,377	1,496
Manganese	228	229	153	292	260	149	283	133	131	180
Copper	1,409	1,505	1,402	1,050	1,107	1,095	997	970	533	591
Lead	209	190	195	170	191	182	215	192	218	207
Zinc	551	601	563	499	503	619	506	557	542	594
Chromium	561	547	416	372	547	329	268	244	247	338
Nickel	7	14	16	17	16	14	12	14	12	12
Pyrrhotite	498	175	154	117	99	133	58	72	80	149
Other Ores and Metalashes	669	919	952	896	1,074	1,053	1,204	965	894	1,005
Bauxite Kryolithe	4,215	4,092	4,093	3,615	3,697	4,179	3,913	3,535	3,158	4,057
III. Ind. Minerals										
Phosphate raw	2,270	2,362	2,684	2,435	2,579	2,560	2,208	1,830	1,980	1,906
Potash	0	0	0	0	0	0	0	0	0	1
Other salt	642	777	796	700	915	599	671	650	622	640
Precious stones etc.	2	2	1	2	2	2	1	1	1	2
IV. Construction Minerals										
Stones, Clays, and Other Construction Materials	25,839	23,058	21,970	23,274	23,717	24,857	22,522	20,233	20,569	21,672

Material Requirements 1975-1994
Federal Republic of Germany

(Domestic Requirements 1991 to 1994 for re-united Germany, Imports 1991-94 for Western Germany only)

Unit:1000 metric tons

	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
DOMESTIC										
Non-renewables										
I. Energy Carriers										
Lignite	120,718	114,360	108,852	108,622	109,876	107,589	279,403	241,805	221,802	207,077
Hard Coal	81,843	80,262	75,818	72,872	70,999	69,763	66,481	65,906	60,288	54,344
Crude Oil	4,105	4,017	3,793	3,937	3,770	3,606	3,487	3,247	3,051	2,936
Crude Oil Gas	154	143	209	207	189	140	210	189	117	111
Natural Gas	11,779	10,472	12,331	11,486	11,396	11,280	15,434	11,972	13,238	13,714
II. Metal Ores										
Iron	1,034	717	147	69	106	83	120	120	120	120
Lead and Zinc	263	231	226	162	124	113	105	105	105	105
Pyrite and Pyrrhotite	512	471	412	313	342	302	219	219	219	219
Bauxite	0	0	0	1	0	0	0	0	0	0
Uranium	0	0	4	6	7	1	5	5	5	5
III. Ind. Minerals										
Phosphate	0	0	0	0	0	0				
Potash	6,365	5,435	5,656	5,638	5,584	5,633				
Salt	13,080	13,102	13,466	12,447	11,793	11,580				
Clay	6,125	6,260	6,532	7,333	8,592	8,855				
Limestone (industrial)	1,805	1,924	1,882	1,838	2,101	1,940				
Other	18,654	20,019	18,609	21,251	23,250	24,086				
Total	46,030	46,740	46,144	48,508	51,320	52,094	53,043	53,043	53,043	53,043
IV. Construction Minerals										
Sand and Gravel	254,892	271,913	265,280	282,917	309,534	312,678	362,000	398,000	401,908	459,546
Crushed Stone (incl. limestone)	174,634	177,076	177,829	176,765	218,130	208,191	364,876	409,731	411,792	477,173
Clay for bricks	13,202	13,014	13,360	13,632	14,161	16,321	22,579	24,973	27,121	34,144
V. Excavation										
Non-saleable production (incl. overburden gangue)	1,123,916	996,129	985,881	1,070,919	1,083,771	1,091,130	2,531,631	2,149,482	1,971,669	1,840,774
Excavation for infrastructure	137,429	145,950	145,538	151,859	161,754	170,000	300,233	293,300	295,895	342,616
Renewables										
I. Plant biomass										
Agricultural Harvest	141,674	141,655	135,091	142,147	152,364	137,680	175,115	175,115	175,115	175,115
Logging	23,040	21,533	21,161	21,777	23,424	49,895	23,313	23,313	23,313	23,313
Plant Biomass from "wild harvest"	7,965	7,856	7,679	7,599	7,594	7,708				
II. Animal biomass										
Fishing	191	161	160	142	166	154	301	301	301	301
Hunting	46	47	48	50	51	56	75	75	75	75
Soil Erosion	81,532	81,892	82,118	81,940	82,192	82,098	128,704	128,704	128,704	128,704
IMPORTS										
Non-renewables										
I. Energy Carriers										
Lignite	2,471	2,493	2,187	1,905	2,013	2,080	2,764	3,017	2,575	2,417
Hard Coal	9,862	9,999	8,170	7,172	6,409	10,857	14,071	14,134	12,448	14,529
Crude Oil	64,193	66,569	63,840	72,037	66,327	72,400	77,979	90,887	94,154	102,194
Natural Gas	35,509	31,757	35,136	34,653	38,137	39,260	43,964	42,930	42,049	41,426
II. Metal Ores										
Iron	45,320	42,045	39,910	45,170	47,171	43,730	42,190	40,558	34,821	42,009
Iron-Manganes-meltings and slags	1,159	1,067	972	1,256	1,236	1,304	1,247	1,178	1,177	1,131
Manganese	65	61	52	514	546	369	252	285	101	11
Copper	597	636	480	567	630	505	543	600	514	660
Lead	237	194	226	235	222	206	176	200	192	98
Zinc	593	621	664	605	596	593	625	640	695	612
Chromium	385	275	259	273	344	246	277	231	204	172
Nickel	13	11	13	15	12	11	11	17	17	10
Pyrrhotite	187	203	151	159	65	84	121	104	105	175
Other Ores and Metalashes	1,117	979	986	921	957	993	846	983	634	790
Bauxite Kryolithe	4,036	3,660	2,881	2,577	2,880	3,077	2,544	2,617	2,243	2,268
III. Ind. Minerals										
Phosphate raw	1,911	1,528	1,429	1,157	1,206	902	671	519	412	281
Potash	0	0	0	0	0	0	0	1	0	0
Other salt	688	653	710	724	629	660	929	1,139	1,039	1,132
Precious stones etc.	1	1	1	1	1	1	1	1	2	1
IV. Construction Minerals										
Stones, Clays, and Other Construction Materials	19,203	20,325	18,426	20,109	20,300	21,632	25,534	29,823	24,402	26,214

Material Requirements 1975-1994
Federal Republic of Germany

(Domestic Requirements 1991 to 1994 for re-united Germany, Imports 1991-94 for Western Germany only)

	1975	*1976*	*1977*	*1978*	*1979*	*1980*	*1981*	*1982*	*1983*	*1984*
Unit:1000 metric tons										
Renewables										
I. Plant biomass										
Agricultural Harvest	18,611	20,998	19,242	19,623	18,909	19,302	18,344	18,561	17,632	17,181
Logging	1,861	2,273	2,298	2,445	2,482	2,367	2,123	1,844	1,861	1,703
Natural Rubber and Gums	208	228	232	223	225	220	208	214	227	238
II. Animal biomass										
Fishing	312	337	339	344	364	403	371	377	403	406
Semi-manufactures										
Total	79,374	89,238	91,435	104,451	105,212	102,068	95,990	95,058	103,108	104,307
Final Products										
Total	15,680	20,588	19,246	18,473	16,931	17,559	16,937	18,626	23,413	24,375
Hidden Flows from Imported Raw Materials										
Energy Carriers	76,221	77,396	81,734	84,464	98,814	109,199	117,218	116,914	106,101	104,663
Metal Ores	*242,681*	*258,573*	*234,102*	*206,502*	*234,383*	*230,386*	*210,278*	*193,242*	*146,698*	*172,076*
Industrial Minerals	856,267	577,118	509,298	542,470	613,813	613,117	505,902	328,350	329,300	538,845
Construction Minerals	7,752	6,917	6,591	6,982	7,115	7,457	6,757	6,070	6,171	6,502
Plant Biomass from Cultivation	104,985	113,907	109,051	114,449	116,528	120,887	116,155	123,120	117,079	111,734
Total	1,287,906	1,033,910	940,776	954,867	1,070,654	1,081,046	956,309	767,696	705,348	933,821
Hidden Flows from Imported Semi-Manufactures										
Total	323,955	359,414	357,936	365,779	375,437	419,329	348,676	364,523	369,987	404,474
Social & Economic Indicators										
Western Germany's Population	61,829	61,531	61,400	61,327	61,359	61,566	61,682	61,638	61,423	61,175
Re-united Germany's Population	X	X	X	X	X	X	X	X	X	X
GDP (constant prices 1985) (Millions DM)	1,471,220	1,549,800	1,593,910	1,641,640	1,709,170	1,727,510	1,730,520	1,714,140	1,740,900	1,789,350
Domestic Total	2,021,959	2,088,937	2,100,794	2,098,503	2,278,991	2,391,752	2,305,292	2,240,634	2,264,924	2,216,710
Imports without Hidden Flows	315,693	344,807	337,576	355,607	385,916	374,250	341,198	325,290	323,984	336,877
Hidden Flows of Raw Material Imports	1,287,906	1,033,910	940,776	954,867	1,070,654	1,081,046	956,309	767,696	705,348	933,821
Hidden Flows of Imported Semi-manufactures	323,955	359,414	357,936	365,779	375,437	419,329	348,676	364,523	369,987	404,474
INDICATORS										
Total										
Total Material Requirements (TMR)	3,949,514	3,827,068	3,737,082	3,774,757	4,110,998	4,266,377	3,951,474	3,698,144	3,664,243	3,891,882
TMR DM per kilogram	0.37	0.40	0.43	0.43	0.42	0.40	0.44	0.46	0.48	0.46
TMR(kilogram) per DM	2.68	2.47	2.34	2.30	2.41	2.47	2.28	2.16	2.10	2.18
Per Capita (metric tons)										
TMR Per Capita	64	62	61	62	67	69	64	60	60	64
Domestic TMR Per Capita	33	34	34	34	37	39	37	36	37	36
Imports Per Capita without Hidden Flows	5	6	5	6	6	6	6	5	5	6
Hidden Flows of Raw Material Imports Per Capita	21	17	15	16	17	18	16	12	11	15
Hidden Flows of Semi-manufact. Imports Per Capita	5	6	6	6	6	7	6	6	6	7

Material Requirements 1975-1994
Federal Republic of Germany

(Domestic Requirements 1991 to 1994 for re-united Germany, Imports 1991-94 for Western Germany only)

1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	
										Unit:1000 metric tons
										Renewables
										I. Plant biomass
20,527	19,811	20,254	19,335	19,432	19,706	20,721	20,937	20,001	19,479	Agricultural Harvest
1,694	1,610	1,519	1,586	1,734	1,406	1,166	1,245	893	1,051	Logging
257	254	254	266	292	289	281	289	243	262	Natural Rubber and Gums
										II. Animal biomass
432	476	433	473	527	614	659	670	635	710	Fishing
										Semi-manufactures
108,096	109,499	109,928	105,583	108,900	112,661	123,707	127,064	121,038	124,687	Total
										Final Products
24,539	30,452	29,648	33,354	34,117	40,850	45,021	49,596	38,259	46,165	Total
										Hidden Flows from Imported Raw Materials
109,981	108,950	97,496	90,544	87,987	117,004	145,090	148,689	135,407	147,780	Energy Carriers
174,967	169,530	151,795	176,244	188,344	179,719	182,513	185,508	157,868	191,221	Metal Ores
293,959	256,349	395,793	394,010	394,163	462,194	496,142	495,516	564,621	423,917	Industrial Minerals
5,761	6,097	5,528	6,033	6,090	6,490	7,660	8,947	7,321	7,864	Construction Minerals
129,306	131,232	138,998	131,793	134,148	140,335	143,168	148,727	149,018	144,886	Plant Biomass from Cultivation
713,974	672,158	789,611	798,625	810,733	905,742	974,573	987,387	1,014,234	915,668	Total
										Hidden Flows from Imported Semi-Manufactures
433,618	432,330	391,014	685,095	538,972	627,913	652,272	618,659	552,972	596,399	Total
										Social & Economic Indicators
61,024	61,066	61,077	61,450	62,063	63,254	64,100	64,900	65,500	65,800	Western Germany's Population
X	X	X	X	X	X	80,000	80,600	81,100	81,400	Re-united Germany's Population
1,823,180	1,863,770	1,890,280	1,960,510	2,027,330	2,130,500	2,647,600	2,705,866	2,675,434	2,750,773	GDP (constant prices 1985) (Millions DM)
2,224,959	2,114,640	2,082,082	2,195,929	2,301,271	2,320,882	4,327,334	3,979,604	3,787,881	3,813,434	**Domestic Total**
343,091	345,179	338,530	350,647	354,682	374,436	406,300	429,665	398,853	428,483	Imports without Hidden Flows
713,974	672,158	789,611	798,625	810,733	905,742	974,573	987,387	1,014,234	915,668	Hidden Flows of Raw Material Imports
433,618	432,330	391.014	685,095	538,972	627,913	652,272	618,659	552,972	596,399	Hidden Flows of Imported Semi-manufactures
										INDICATORS
										Total
3,715,642	3,564,307	3,601,237	4,030,295	4,005,658	4,228,973	6,360,478	6,015,314	5,753,941	5,753,984	Total Material Requirements (TMR)
0.49	0.52	0.52	0.49	0.51	0.50	0.42	0.45	0.46	0.48	TMR DM per kilogram
2.04	1.91	1.91	2.06	1.98	1.98	2.40	2.22	2.15	2.09	TMR(kilogram) per DM
										Per Capita (metric tons)
61	58	59	66	65	67	86	81	77	76	TMR Per Capita
36	35	34	36	37	37	54	49	47	47	Domestic TMR Per Capita
6	6	6	6	6	6	6	7	6	7	Imports Per Capita without Hidden Flows
12	11	13	13	13	14	15	15	15	14	Hidden Flows of Raw Material Imports Per Capita
7	7	6	11	9	10	10	10	8	9	Hidden Flows of Semi-manufact. Imports Per Capita

ASCI: Association of the German Stones and Clays Industry, annual reports

MAMS: Metal Association (Frankfurt/Main, Germany, metal statistics

SCI: Statistics of the Coal Industry, annual statistics

Fossil Fuels

Liquid (Crude Oil): Domestic production of commodity mass and non-saleable extraction were obtained from FMEM, imports from FSOG. The hidden flows of imported crude oil was obtained from the database of the Wuppertal Institute, Department of Material Flows and Structural Change.

Gaseous (Natural Gas and Crude Oil Gas): Domestic production of commodity mass was obtained from FMEM (natural gas and minor quantities of crude oil gas), imports (natural gas only) from FSOG. The domestic hidden flows for natural gas were estimated by accounting for the difference between crude gas and purified gas on the basis of average contents of individual substances, and taking into account the sulfur which is recovered from H_2S in the crude gas. The hidden flows of imported natural gas were estimated in a similar way, by using a number of individual publications on average crude gas compositions according to locations and quantitative, country-specific information on the amounts of flared or re-injected gas *(Annual Survey of Energy Resources)*.

Solid (Coal): Domestic production of commodity mass and non-saleable extraction (overburden) were obtained from FMEM (hard coal) and SCI (lignite), imports from FSOG and SCI. Overburden of imported coal was estimated using country-specific data from several publications (e.g. *Manstein, 1995, Wuppertal Papers No. 51, Wuppertal Institute*).

Metals

Aluminum (Al): Domestic production of commodity mass and non-saleable extraction were obtained from FMEM (negligible; e.g., 319 metric tons of commodity mass in 1990), corresponding imports from FIGR. Imported bauxite contains about 24% net metal (Al). Overburden of imported bauxite was estimated using country-specific data from several publications (e.g., *Rohn et al,. 1995, Wuppertal Papers No. 37, Wuppertal Institute*).

Gold: No domestic production, imports only for semi-manufactures and final products (FIGR). The hidden flows for imported gold were estimated by applying the corresponding hidden flow factor for imports from the United States as reported by WRI in this study, and applying an average hidden flow factor of 350,000 tons per ton (metric ton of hidden glow per metric ton of commodity) for all other imports (*Wilmouth et al., 1991*).

Copper(Cu): No domestic production, imports from FIGR. Imported copper concentrate contains about 27% net metal (Cu). Hidden flow factors for imported copper were estimated on the basis of 0.8% copper content in crude ores and 2 tons of overburden per ton of crude ore mined (database of the Wuppertal Institute).

Iron ore (Fe): (Domestic production of commodity mass and non-saleable extraction were obtained from FMEM (small quantities of iron and manganese ores, e.g., 83,473 metric tons of total production in 1990, about 25% Fe content), corresponding imports from FIGR. Imported iron ores or concentrates contain about 58% net metal (Fe) on the average. Hidden flows for imported iron were estimated assuming 1.8 metric ton of overburden per metric ton of crude ore mined (at 58% Fe content) (data base of the Wuppertal Institute).

Other: Domestic production of commodity mass and non-saleable extraction were obtained from FMEM (lead and zinc, pyrite and pyrrhotite), corresponding imports (comprising 17 individual categories) from FIGR. Domestic production is small, e.g. amounting to 104,726 metric tons of lead and zinc ores and 450,474 metric tons of pyrite and pyrrhotite in 1991. Domestic hidden flow factors in 1991 were 2.36 tons per ton and 0.69 tons per ton respectively. The following hidden flow factors were attributed to imports (all taken from the data base of Wuppertal Institute): lead 9.9 tons per ton (for 61% metal content in concentrate), zinc 11.5 tons per ton (for 61% metal content in concentrate), nickel 17.5 tons per ton (for 15% metal content in concentrate), tin 1,448.9 tons per ton (for 29% metal content in concentrate), manganese 2.3 tons per ton (for 40% metal content in concentrate) and tungsten 63.1 tons per ton (for 54% metal content in concentrate). For a number of other imported metals only preliminary hidden flows numbers were available: chromium 7.9 tons per ton (for 100% metal, imported raw material—i.e.. crude ore—contained 31% metal), mercury 230.6 tons per ton (for 100% metal, imported raw material contained 50% metal, crude ore was assumed to contain 0.5% metal content), molybdenum 665.1 tons per ton (for 100% metal, imported raw material contained 53.9% metal, crude ore was assumed to contain 0.2% metal content), silver 7,499 tons per ton (for 100% metal, imported silver contained 100% metal, crude ore was assumed to contain 0.03% metal content), vanadium 127.7 (for 100% metal, imported raw material contained 10.1 % metal, crude ore was assumed to contain 0.95% metal content), antimony 12.6 tons per ton (for 100% metal, imported raw material contained 61% metal, crude ore was assumed to contain 9% metal content), titanium 232 tons per ton (for 100% metal, imported raw material contained 57% metal, crude ore was assumed to contain 0.52% metal content), niob 83.6 tons per ton (for 100% metal, imported raw material contained 40.2% metal, crude ore was assumed to contain 2% metal content), silicium (1.6 tons per ton (for 100% metal from SiO_2) and Cer 39.5 tons per ton (for 100% metal, imported raw material was assumed to contain 38.8% metal, crude ore was assumed to contain 3% metal content). For a number of other metals, no hidden flow factor was applied because they are well characterized as typical by products of other mining: cobalt, bismuth, cadmium, indium, thallium, circonium, and hafnium, gallium, germanium, magnesium, arsenic, and tellur. No information was obtained about lithium, beryllium, cesium, and strontium. The content of metals in corresponding imported ferro-alloys was assumed to be vanadium 42%, nickel 33%, molybdenum 2%, titanium 30%, chromium 70%, manganese 75%, niob 1%, silicium 52.5%, and tungsten 80%.

Recycling rates were applied for hidden flow factor estimates of imported metals, assuming the following content of secondary material in metals: copper 40%, aluminum 30%, iron 17%, lead 40%, zinc 11%, and nickel 40%. Recycled materials were not accounted as TMR (Data from the database of Wuppertal Institute, from MAMS, from *Gocht* or from *Wilmout et al.*).

Industrial Minerals

Salt: Domestic production of commodity mass and non-saleable extraction were obtained from FMEM (rock salt, industrial brine, boiling salt), imports from FSOG. Domestic hidden flow factors were derived from non-saleable extraction divided by production of commodity mass and applied to imports as well.

Gypsum: Domestic production of commodity mass and non-saleable extraction were obtained from FMEM, imports from FSOG. Domestic hidden flow factors were derived from non-saleable extraction divided by production of commodity mass and applied to imports as well.

Clay: Domestic production of commodity mass and non-saleable extraction were obtained from FMEM (special clays, slate clay, bentonite, and kaolin), imports from FSOG. Domestic hidden flow factors were derived from non-saleable extraction divided by production of commodity mass and applied to imports with the exception of imported kaolin from the United Kingdom for which a hidden flow factor of 8 tons per ton was reported.

Sand and Gravel (industrial): Domestic production of commodity mass (special sand) and non-saleable extraction were obtained from FMEM (commodity mass also from GGSI), imports from FSOG. Domestic hidden flow factors were derived from non-saleable extraction divided by production of commodity mass and also applied to imports.

Potash: Domestic production of commodity mass and non-saleable extraction were obtained from FMEM (K_2O content from FSOG), imports from FSOG (negligible amounts, e.g., 346.2 tons in 1991). Domestic hidden flow factors were derived from non-saleable extraction divided by production of commodity mass and also applied to imports.

Phosphate: No domestic production, imports from FSOG. The hidden flow factors for imports was obtained from the data base of the Wuppertal Institute. It represents a global average according to the quantitative distribution of different types of natural deposits. P_2O_5 content of imports was assumed to be 27%.

Other: Domestic production of commodity mass and non-saleable extraction were obtained from FMEM (altogether about 30 individual categories, varying by number from year to year), imports from FSOG. Domestic hidden flow factors were derived from non-saleable extraction divided by production of commodity mass and applied to imports as well unless country specific information was available.

Construction Materials

Crushed Stone: Domestic production was obtained from FSOG, ASCI, and FIGR (different kinds of natural stones like granite, marble, limestone, and dolomite rock), imports from FSOG. Data for total domestic production were checked for consistency and avoidance of double-counting in cooperation with FSOG (personal communication). Domestic hidden flow factors were obtained from an internal study of the Wuppertal Institute and applied to imports as well.

Sand and Gravel (construction): Domestic production was obtained from GGSI, imports from FSOG. Domestic hidden flow factors were obtained from an internal study of the Wuppertal Institute and applied to imports as well.

Clay for bricks: Total domestic production of clay was obtained from ASCI. The quantity of clay for bricks was estimated by the production of various kinds of bricks as reported by FSOG. The empirical base for this estimate, as well as the hidden flow factor, was obtained from an internal study of the Wuppertal Institute.

Infrastructure

Excavation (excluding dredging): Domestic excavation of soil in metric tons is reported by FSOG in waste statistics. However, due to limits in reporting of small-sized enterprises, these numbers do not account for the total. Bridging this gap, GGSI estimates the total amount of soil excavation by construction activities. In order to check those numbers, a bottom-up approach was performed in this study. A range of individual figures about specific soil excavation in metric tons per meter of road (different types) constructed and per number of buildings constructed was applied to estimate total annual soil excavation in Germany (Wuppertal Institute, personal communications). The result for soil excavation obtained from this bottom-up approach corroborated the numbers reported by GGSI.

Dredging: Dredging is reported by the Federal Environmental Agency in metric tons (fresh weight). Their number refers to dredging in harbors, shipping routes, and estuaries in the North Sea.

Erosion

Domestic erosion was estimated using numbers from BUND (Friends of the Earth Germany). Erosion associated with imported goods (raw materials and semi-manufactures) was taken from the database of the Wuppertal Institute. It refers to country-specific calculations of the land-use in hectares for imported agricultural goods and average erosion rates in metric tons per hectare. The latter were derived from a number of individual publications (especially by Pimentel and Lal).

Renewables

Domestic production of plant biomass (agriculture and gardening), forestry (logging), and animal biomass (from fishing and from hunting) was derived mainly from FMNAF, and corresponding imports also from FMNAF and from FSOG.

Imports

All imports are reported by FSOG foreign trade statistics in metric tons and by individual counties of origin. The classification of imports according to raw materials, semi-manufactures and final products given by FSOG was adopted. The reference on corresponding commodities from domestic production or import is provided by FSOG. Due to a very user friendly provision of data, imports of metals (raw materials and semi-manufactures) were taken from FIGR and MAMS, imports of coals from SCI, and imports of renewables from FMNAF. Hidden flows of imported semi-manufactures were estimated on the basis of corresponding values for raw materials. Country specific hidden flow factors were applied for a number of imported materials: 27 categories of non-renewable raw materials and 39 corresponding semi-manufactures, 35 categories of renewable raw materials, and 5 of corresponding semi-manufactures. Altogether, the German TMR is based on the accounting of about 450 individual categories of imported materials (including final products).

Japanese Material Requirements

The material flows that support the Japanese economy originate from both domestic and foreign sources, but the economy is highly dependent on the import of natural resources. Imported commodities account for about one-third of the mass of direct inputs (DMI) to the economy and account for about one-half of the total material requirements (TMR) including hidden flows.

Imports provide the Japanese economy with essential materials, including fossil fuels, metal ores, and agricultural and forestry products. Import dependency is particularly high for metal ores and fossil fuels. Recent trends revealed that commodities increasingly tend to be imported in more manufactured forms, (e.g., refined metals rather than metal ores) and imports of semi-manufactured

Material Requirements 1975-1994
Japan

Unit:million metric tons	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
TOTAL MATERIAL REQUIREMENT	4,186	4,429	4,500	4,485	4,608	4,448	4,411	4,390	4,393	4,551
DOMESTIC TOTAL	2,092	2,142	2,178	2,209	2,239	2,200	2,172	2,094	2,025	2,005
DOMESTIC COMMODITIES	1,057	1,043	1,142	1,255	1,282	1,272	1,236	1,193	1,146	1,151
Non-renewables	945	932	1,025	1,136	1,162	1,155	1,119	1,072	1,027	1,029
Energy Carriers	25	25	25	25	23	23	23	23	22	22
Solid	19	18	18	19	18	18	18	18	17	17
Liquid	1	1	1	1	1	0	0	0	0	0
Gaseous	6	6	6	6	5	5	5	5	5	5
Metal Ores	2.6	2.3	2.0	1.7	1.6	1.7	2.1	1.4	1.4	1.3
Iron Ore	0.7	0.8	0.7	0.5	0.5	0.5	1.0	0.4	0.4	0.4
Copper Ore	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0
Lead and Zinc Ore	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Other Metal Ores	1.4	1.1	1.0	0.8	0.8	0.8	0.8	0.7	0.7	0.7
Industrial Minerals	161	171	180	195	202	196	175	176	176	173
Limestone	121	125	134	146	151	144	139	132	132	130
Stone for industry	15	19	18	18	18	19	5	15	14	13
Silicon	9	9	10	13	14	14	13	13	14	14
Silica	4	4	4	4	5	5	4	4	4	5
Dolomite	5	6	6	6	6	6	6	5	4	4
Other Industrial Minerals	8	8	8	8	8	8	8	8	8	8
Construction Minerals	756	733	819	914	935	934	919	871	827	832
Sand and Gravel	353	344	385	420	430	405	382	363	327	322
Construction Stone	403	389	434	494	505	529	537	508	500	510
Renewables	112	111	117	119	121	117	116	121	119	122
Plant Biomass (agriculture)	79	77	83	86	88	83	84	89	86	88
Plant Biomass (forestry)	24	25	24	23	23	24	22	22	22	23
Animal & Fish Biomass	10	10	10	10	10	10	10	10	11	12
DOMESTIC HIDDEN FLOWS	1,035	1,099	1,036	954	956	928	937	901	879	854
Total Excavation	1,028	1,091	1,028	947	949	921	929	893	872	846
Non-saleable production	43	42	42	40	40	39	39	37	37	36
of fossil fuels	8	8	8	8	8	8	8	8	8	8
of metals	22	21	20	17	15	15	16	14	14	14
of minerals	13	13	14	15	16	16	15	14	15	15
Infrastructure, Surplus Soils	984	1,049	986	907	910	882	890	857	835	811
Construction, Soil Residue	414	423	431	439	447	455	458	461	464	467
Residential Development, Soil	570	626	556	468	463	427	432	396	372	344
Soil Erosion	8	8	7	7	7	7	7	7	7	8
TOTAL FOREIGN FLOWS	2,094	2,287	2,322	2,276	2,369	2,248	2,238	2,296	2,368	2,546
IMPORTED COMMODITIES	553	574	590	564	614	603	564	555	543	595
Non-renewables	475	488	499	468	510	501	474	461	444	491
Energy Carriers	315	326	338	327	349	335	322	312	309	338
Solid	62	61	61	52	59	68	78	79	75	88
Liquid (crude oil)	229	233	242	236	245	221	198	185	180	186
Liquid (refined products)	14	20	20	20	23	19	18	19	24	27
Gaseous	10	12	15	19	23	27	27	29	30	37
Metal Ore	149	150	150	130	147	152	139	136	122	140
Iron Ore	132	134	133	115	130	134	123	122	109	125
Copper Ore	3	3	3	3	3	3	3	4	3	3
Lead and Zinc Ore	1	1	1	1	1	1	1	1	1	1
Bauxite	5	4	5	5	5	6	4	3	4	4
Nickel Ore	3	4	4	3	4	4	4	3	2	3
Manganese Ore	4	3	3	2	3	3	3	2	2	2
Chromium ore	1	1	1	1	1	1	1	1	1	1
Other Metal ores	1	1	1	0	0	0	0	0	0	1
Industrial Minerals	11	10	11	11	12	12	11	10	11	11
Phosphate	3	2	3	3	3	3	2	2	2	2
Salt	6	6	6	6	7	8	7	6	6	7
Other Industrial Minerals	1	2	2	2	2	2	2	2	2	2
Construction Minerals	0	1	1	1	2	2	2	2	2	2

Material Requirements 1975-1994
Japan

Unit:million metric tons

	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
TOTAL MATERIAL REQUIREMENT	4,430	4,737	4,883	5,156	5,344	5,682	5,716	5,494	5,566	5,657
DOMESTIC TOTAL	1,986	2,035	2,112	2,240	2,375	2,560	2,567	2,509	2,504	2,490
DOMESTIC COMMODITIES	1,128	1,154	1,204	1,274	1,358	1,476	1,424	1,330	1,285	1,274
Non-renewables	1,005	1,030	1,082	1,155	1,239	1,357	1,311	1,217	1,182	1,164
Energy Carriers	22	21	19	16	15	13	13	13	13	12
Solid	16	16	13	11	10	8	8	8	7	7
Liquid	1	1	1	1	1	1	1	1	1	1
Gaseous	5	5	5	4	4	4	5	5	5	5
Metal Ores	1.3	0.9	0.9	0.6	0.7	0.6	0.6	0.5	0.4	0.2
Iron Ore	0.3	0.3	0.4	0.2	0.3	0.2	0.2	0.2	0.1	0.0
Copper Ore	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lead and Zinc Ore	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1
Other Metal Ores	0.6	0.4	0.3	0.2	0.2	0.2	0.1	0.1	0.1	0.1
Industrial Minerals	165	157	161	173	184	190	194	193	190	191
Limestone	122	118	121	129	137	143	147	147	144	147
Stone for industry	12	10	10	11	13	12	12	12	12	12
Silicon	15	14	15	17	17	18	19	19	19	18
Silica	4	4	4	4	4	4	4	4	4	4
Dolomite	4	4	4	5	5	5	5	5	5	4
Other Industrial Minerals	7	7	7	7	7	7	7	7	7	6
Construction Minerals	817	851	902	965	1,039	1,154	1,103	1,011	978	961
Sand and Gravel	310	312	327	333	354	408	370	350	338	341
Construction Stone	507	539	575	632	685	746	733	661	640	620
Renewables	123	124	122	119	120	119	113	113	104	110
Plant Biomass (agriculture)	89	91	90	86	88	89	84	86	79	85
Plant Biomass (forestry)	23	22	22	22	21	21	20	19	18	18
Animal & Fish Biomass	11	11	11	11	11	10	9	8	7	7
DOMESTIC HIDDEN FLOWS	858	881	908	966	1,017	1,084	1,143	1,179	1,219	1,216
Total Excavation	850	873	900	959	1,009	1,076	1,136	1,172	1,212	1,209
Non-saleable production	60	57	55	57	57	32	31	31	35	32
of fossil fuels	8	8	6	5	4	3	3	3	3	3
of metals	11	10	8	7	7	9	7	7	6	4
of minerals	40	39	41	45	46	21	21	21	26	26
Infrastructure, Surplus Soils	791	817	845	902	952	1,044	1,105	1,141	1,177	1,177
Construction, Soil Residue	470	507	544	582	619	656	692	729	765	765
Residential Development, Soil	321	310	301	320	333	387	412	412	412	412
Soil Erosion	8	8	8	8	8	8	8	8	7	7
TOTAL FOREIGN FLOWS	2,445	2,702	2,771	2,916	2,970	3,122	3,149	2,984	3,062	3,167
IMPORTED COMMODITIES	588	580	599	654	678	696	710	663	669	701
Non-renewables	484	472	478	519	542	560	570	532	535	555
Energy Carriers	331	330	338	364	380	400	408	385	388	406
Solid	93	91	93	105	106	108	112	112	114	118
Liquid (crude oil)	171	164	161	167	178	196	205	192	195	207
Liquid (refined products)	28	34	43	48	50	46	38	28	24	25
Gaseous	39	40	42	44	46	50	52	54	55	57
Metal Ore	139	128	124	137	142	139	142	126	127	128
Iron Ore	125	115	112	123	128	125	127	114	115	116
Copper Ore	3	3	3	3	3	4	4	4	4	4
Lead and Zinc Ore	1	1	1	1	1	2	2	2	2	1
Bauxite	4	2	2	2	2	2	2	2	2	2
Nickel Ore	3	3	3	3	4	3	4	4	3	3
Manganese Ore	2	2	2	2	2	2	2	1	1	1
Chromium ore	1	1	1	1	1	1	1	1	1	1
Other Metal ores	1	1	1	1	1	1	1	1	1	0
Industrial Minerals	12	11	11	12	12	12	12	12	11	11
Phosphate	2	2	2	2	2	2	2	2	1	1
Salt	7	7	7	7	8	8	8	8	7	8
Other Industrial Minerals	2	2	2	3	3	3	3	3	3	3
Construction Minerals	3	3	5	7	7	8	9	9	8	9

Material Requirements 1975-1994
Japan

	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
Unit:million metric tons										
Renewables	56	64	67	69	74	69	62	64	66	66
Plant Biomass (agriculture)	28	31	33	35	37	38	37	38	40	41
Cereals and Fodder	21	23	25	26	28	28	27	27	29	30
Oil seeds	5	5	5	6	6	6	6	6	7	6
Others	3	4	4	4	4	4	4	5	5	5
Plant biomass (forestry)	27	31	32	33	35	30	23	25	24	23
Animal & Fish Biomass	1	1	1	1	1	1	1	2	2	2
Semi-manufactures	18	19	20	22	26	27	23	25	29	32
Chemical Products	2	2	2	3	4	4	4	4	4	5
Refined Metals	1.3	1.7	1.9	2.6	3.9	3.9	4.8	6.0	6.6	7.9
Iron & Steel	0.6	0.9	1.0	1.4	2.5	2.4	3.1	4.0	4.5	5.8
Aluminum	0.4	0.5	0.6	0.8	0.8	1.0	1.2	1.5	1.6	1.4
Copper	0.2	0.2	0.3	0.3	0.4	0.3	0.3	0.4	0.3	0.5
Others	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2
Scrap Metals	3	2	2	3	4	3	2	2	4	4
Wood Products (chip, pulp, etc.)	8	9	9	9	10	12	9	9	9	10
Other Semi-manufactures	4	5	5	5	5	4	4	5	5	5
Final Products	3	4	4	5	5	6	5	5	5	6
Fertilizer	1.5	1.3	1.6	1.6	1.7	1.9	1.5	1.7	1.9	1.8
Meat & Dairy Products	0.6	0.8	0.8	0.8	0.9	0.8	0.9	0.8	0.9	0.9
Paper and Paper Products	0.2	0.2	0.3	0.4	0.5	0.7	0.6	0.8	0.8	0.8
Machinery	0.6	0.6	0.7	0.9	1.0	1.5	1.4	1.0	1.0	1.4
Others	0.5	0.6	0.7	0.7	0.8	0.9	0.8	0.9	0.9	1.0
HIDDEN FLOWS OF IMPORTED COMMODITIES	1,541	1,713	1,732	1,713	1,755	1,645	1,674	1,742	1,825	1,951
Fossil Fuel (Coal)	578	648	648	652	616	512	559	655	753	798
Metal Ores	538	561	587	546	592	610	597	601	549	563
Copper	197	213	239	240	248	260	271	279	265	240
Iron	314	319	316	274	311	319	294	291	261	299
Others	26	29	32	32	34	32	31	31	24	24
Industrial Minerals	12	10	11	11	12	12	10	10	11	10
Soil Erosion	124	127	149	127	135	142	116	127	129	131
Plant Biomass (cut-down forest)	68	86	84	86	89	76	60	61	57	53
Animal Biomass (cattle)	2	3	3	3	3	3	3	3	3	3
Social Parameters										
Population (10^6)	111.9	113.1	114.2	115.2	116.2	117.1	117.9	118.7	119.5	120.3
GDP at 1985 constant prices (trillion Yen)	215.6	224.3	235	247.1	260.6	268.8	277.4	287.2	295.8	309.1
Indicators										
TMI Per Capita (metric tons)	37.4	39.2	39.4	38.9	39.7	38.0	37.4	37.0	36.8	37.8
Commodity Per Capita (metric tons)	14.4	14.3	15.2	15.8	16.3	16.0	15.3	14.7	14.1	14.5
Metal & Minerals	3.0	3.0	3.1	3.0	3.2	3.2	2.9	2.8	2.7	2.9
Fossil Fuels	3.1	3.1	3.2	3.1	3.2	3.1	3.0	2.9	2.8	3.0
Construction Minerals	6.8	6.5	7.2	8.0	8.1	8.0	7.8	7.4	6.9	6.9
Renewables Per Capita (metric tons)	1.6	1.7	1.7	1.8	1.8	1.7	1.6	1.7	1.7	1.7
Hidden Flows Per Capita (metric tons)	23.0	24.9	24.3	23.2	23.3	22.0	22.2	22.3	22.6	23.3
Metal & Minerals	7.0	7.6	7.5	7.4	7.8	7.8	7.9	7.5	7.3	7.9
Fossil Fuels	5.3	5.9	5.8	5.8	5.5	4.6	4.9	5.7	6.5	6.9
Renewables	0.8	1.0	0.9	0.9	1.0	0.8	0.7	0.7	0.7	0.7
Excavation Per Capita (Infrastructure, metric tons)	8.8	9.3	8.6	7.9	7.8	7.5	7.6	7.2	7.0	6.7
Soil Erosion Per Capita (metric tons)	1.2	1.2	1.4	1.2	1.2	1.3	1.1	1.1	1.1	1.2
TMI/GDP (metric tons/ trillion Yen)	19.4	19.7	19.2	18.2	17.7	16.6	15.9	15.3	14.9	14.7
TMI/GDP1985 Yen (1985 =100)	142.0	144.4	140.0	132.7	129.3	121.0	116.3	111.8	108.6	107.7
Import/Total including Hidden Flows	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.6
Import/Total excluding Hidden Flows	0.3	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
TMI, Agriculture (metric tons/capita)	2.4	2.4	2.7	2.5	2.6	2.6	2.4	2.5	2.5	2.5
TMI, Energy (metric tons/capita)	8.2	8.8	8.9	8.7	8.5	7.4	7.7	8.3	9.1	9.6
TMI, Construction (metric tons/capita)	17.9	18.3	18.3	18.1	18.4	17.9	17.5	16.7	15.9	15.8
TMI, Others (metric tons/capita)	8.7	9.5	9.4	9.5	10.0	9.9	9.8	9.3	9.2	9.7

Material Requirements 1975-1994
Japan

1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	Unit:million metric tons
68	69	74	76	77	76	76	76	76	86	**Renewables**
42	43	44	46	46	47	48	48	49	52	Plant Biomass (agriculture)
30	31	32	34	33	33	34	35	35	37	Cereals and Fodder
7	7	7	7	7	7	7	7	7	7	Oil seeds
5	5	5	6	6	7	7	7	6	8	Others
24	24	28	27	29	27	25	24	24	31	Plant biomass (forestry)
2	2	2	3	3	3	3	3	3	3	Animal & Fish Biomass
31	33	40	51	50	50	54	46	48	49	**Semi-manufactures**
5	6	6	7	7	7	7	7	7	8	Chemical Products
6.7	7.2	10.0	14.3	14.2	15.5	17.9	12.2	12.6	12.5	Refined Metals
4.5	5.2	7.5	11.1	10.9	11.7	13.8	8.9	9.2	9.1	Iron & Steel
1.6	1.4	1.9	2.4	2.4	2.7	2.9	2.6	2.7	2.7	Aluminum
0.4	0.3	0.4	0.5	0.6	0.7	0.7	0.4	0.5	0.5	Copper
0.2	0.2	0.3	0.3	0.3	0.4	0.4	0.3	0.2	0.2	Others
4	4	3	2	2	2	1	1	1	1	Scrap Metals
10	11	14	20	19	19	21	20	22	22	Wood Products (chip, pulp, etc.)
5	6	7	8	9	7	7	6	6	6	Other Semi-manufactures
6	6	7	8	9	10	10	10	10	11	**Final Products**
1.8	1.9	2.4	2.5	2.4	2.4	2.4	2.3	2.4	2.5	Fertilizer
0.9	1.0	1.2	1.4	1.5	1.5	1.7	1.9	1.9	2.1	Meat & Dairy Products
0.9	1.0	1.1	1.2	1.4	1.2	1.3	1.2	1.2	1.3	Paper and Paper Products
1.4	1.2	0.9	0.9	1.2	1.7	1.7	1.6	1.5	1.8	Machinery
1.1	1.1	1.7	2.1	2.6	3.1	2.8	2.8	2.9	3.3	Others
1,856	2,122	2,172	2,261	2,291	2,426	2,439	2,321	2,392	2,466	**HIDDEN FLOWS OF IMPORTED COMMODITIES**
734	867	922	914	928	1,037	1,049	1,055	1,106	1,148	Fossil Fuel (Coal)
567	564	580	604	636	629	662	652	665	634	Metal Ores
235	252	260	255	272	273	298	320	335	302	Copper
297	275	267	294	305	299	303	271	273	277	Iron
35	37	53	55	59	58	61	61	58	55	Others
10	9	10	8	7	7	7	7	6	6	Industrial Minerals
132	139	131	158	140	123	140	127	141	154	Soil Erosion
55	50	57	51	55	48	44	43	42	51	Plant Biomass (cut-down forest)
3	4	5	6	6	6	7	8	8	9	Animal Biomass (cattle)
										Social Parameters
121	121.7	122.2	122.7	123.2	123.6	124	124.5	124.8	125.1	Population (10^6)
324	333.3	349.8	370.6	387.5	407.2	422	424.7	423.2	425.3	GDP at 1985 constant prices (trillion Yen)
										Indicators
36.6	38.9	40.0	42.0	43.4	46.0	46.1	44.1	44.6	45.2	TMI Per Capita (metric tons)
14.2	14.3	14.8	15.7	16.5	17.6	17.2	16.0	15.7	15.8	Commodity Per Capita (metric tons)
2.7	2.6	2.6	2.8	3.0	3.0	3.0	2.8	2.8	2.8	Metal & Minerals
3.0	2.9	3.0	3.1	3.3	3.4	3.5	3.3	3.3	3.4	Fossil Fuels
6.8	7.0	7.4	7.9	8.5	9.4	9.0	8.2	7.9	7.8	Construction Minerals
1.7	1.7	1.8	1.8	1.8	1.8	1.8	1.8	1.7	1.8	Renewables Per Capita (metric tons)
22.4	24.7	25.2	26.3	26.9	28.4	28.9	28.1	29.0	29.4	Hidden Flows Per Capita (metric tons)
7.8	8.7	8.5	9.0	9.1	9.3	9.2	8.3	8.3	8.3	Metal & Minerals
6.3	7.4	7.8	7.7	7.8	8.6	8.7	8.7	9.1	9.4	Fossil Fuels
0.7	0.7	0.9	0.9	1.0	0.9	0.9	0.9	0.9	1.0	Renewables
6.5	6.7	6.9	7.4	7.7	8.4	8.9	9.2	9.4	9.4	Excavation Per Capita (Infrastructure, metric tons)
1.2	1.2	1.1	1.4	1.2	1.1	1.2	1.1	1.2	1.3	Soil Erosion Per Capita (metric tons)
13.7	14.2	14.0	13.9	13.8	14.0	13.5	12.9	13.2	13.3	TMI/GDP (metric tons/ trillion Yen)
100.0	103.9	102.1	101.7	100.9	102.0	99.0	94.6	96.2	97.3	TMI/GDP1985 Yen (1985 =100)
0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.5	0.6	0.6	Import/Total including Hidden Flows
0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4	Import/Total excluding Hidden Flows
2.5	2.6	2.5	2.7	2.6	2.4	2.5	2.4	2.5	2.7	TMI, Agriculture (metric tons/capita)
9.0	10.0	10.5	10.5	10.7	11.7	11.9	11.7	12.1	12.5	TMI, Energy (metric tons/capita)
15.4	15.8	16.5	17.6	18.8	20.3	20.3	19.5	19.6	19.5	TMI, Construction (metric tons/capita)
9.5	10.4	10.2	10.9	11.0	11.3	11.2	10.3	10.3	10.4	TMI, Others (metric tons/capita)

goods and final products have been increasing. Large hidden flows are associated with metals (particularly with copper and iron), coal, as well as agricultural and forestry products.

Those flows associated with construction activities dominate both DMI and TMR from domestic sources, nearly 90% of both in 1991. This may be because of a poor stock of modern infrastructure. Domestic limestone, crushed stone, and sand and gravel are used to create and improve buildings, roadways, water reservoirs, and other infrastructure. A large percentage of TMR from foreign sources can be identified as serving domestic construction activities, as is the case of iron ore and coking coal for steel production.

Excavation for infrastructure, even in this rough estimate, occupies a high percentage of TMR. This is partly because Japan is a mountainous country, where flat areas must be created for such purposes as "new-town" development around existing metropolitan areas. In such cases, excavated soil is used on site to change the topography. Other public works, such as roadway construction and river modification, generate large amount of surplus soils. Transporting surplus soil and construction materials by heavy duty trucks is a major source of pollution from traffic in Japan.

There are no formal statistics on soil erosion from Japanese agricultural land. The estimates used in this accounting are relatively small. Soil erosion is more important as one of the hidden flows attached to imported agricultural products from countries with heavier erosion problems.

The hidden flows that accompany commodities are based on limited data and might even be underestimated. Some of these flows, such as those associated with imported metals, are estimated from information provided by the U.S. and German co-authors from their countries' experience, and do not necessarily reflect the actual flows experienced by Japan's real trading partners for these commodities.

Data Sources and Methodology

General references:

JEA (Japan Environment Agency)

"Preliminary Material Flow Balance," prepared for the *Quality of the Environment* report. (A preliminary material balance has been compiled by JEA, and has been published since 1992 in the *Quality of the Environment* report (White paper). This balance covers the mass of domestically produced and imported commodities, as well as amounts of waste and recycled materials. Data sources and figures for these preliminary accounts are carefully reviewed, and supplemented and modified whenever necessary.)

MITI (Ministry of International Trade and Industry)

Yearbook of Minerals and Non-Ferrous Metals Statistics.
Yearbook of Coal and Coke Statistics
Yearbook of Crushed Stone Statistics
Statistical Compendium of Mining Industry ("Kougyou Binran")
White Paper of International Trade

MAFF (Ministry for Agriculture, Forestry and Fisheries)

Crop Survey
Survey on Production and Shipment of Vegetables
Yearbook of Industrial Crops Statistics
Survey on the Marketing of Lumber

MOC(Ministry of Construction)

Census on By-products of Construction Activities for 1990

MOF (Ministry of Finance)/Japan Tariff Association

Japan Export & Import (Trade Statistics)

Fossil Fuels

Domestic coal—Non-saleable production is calculated as gross production reported in MITI statistics minus net production.

Imported coal—Hidden flows are mainly overburden removed for open-pit mining. They are estimated by applying country specific or world average factors (hidden flows per commodity mass) provided by the Wuppertal Institute and the World Resources Institute. Country specific factors are applied to 5 large coal exporters to Japan, Australia 12.02 tons per ton, Canada 18.62 tons per ton, the USA 6.27 tons per ton in 1991 (calculated for each year based WRI 's estimates), South Africa 3.13 tons per ton, Russia 1.216 tons per ton. For other exporters, 6.03 tons per ton—the estimated world average—is applied.

Liquid—Original figures are converted to weight by applying the following factors; crude oil 0.87kg/l, gasoline 0.67 kg/l, kerosene 0.81 kg/l, diesel oil 0.84 kg/l, and heavy oil 0.89 kg/l. No hidden flows were calculated for liquid fuels.

Gas—Japan imports natural gas as LNG (liquefied natural gas), and while it is known that the energy input for liquidization is not negligible, such interlinked (indirect) material input such as processing energy is not included in this paper. No hidden flows have been calculated for gaseous fuels.

Metals

Domestic production—Data on annual production for major metal ores (including gold, silver, copper, lead, zinc, iron, chromium, tungsten, molybdenum, manganese, tin , etc.) are available from MITI's Statistics,. Estimates in the summary table are on a net weight basis. Ancillary mass is estimated based on the average grade of proved reserves. (Grade estimates may be substituted by actual grades of annual production, which are reported for a limited number of metals). Overburden is not included because of limited data availability. This will not seriously influence the TMR given the small total volume of metal mining in Japan.

Imported—Figures on the summary table are actual commodity weights (including ancillary mass) reported in trade statistics. Hidden flows are estimated by applying factors provide by WI and/or WRI as world average or typical figures. Hidden flows are estimated both for ores and refined metals. In order to avoid double-counting, hidden flows do not include ancillary mass which is actually imported as part of a commodity's mass. Factors are applied as follows (ton-hidden flows per ton-net metal content): gold 303,030 tons per ton, silver 14,265 tons per ton, copper 304 tons per ton-net for 27% grade ore, 184 tons per ton for refined metal with 40% secondary input, lead 16.2 tons per ton-net for 61% grade ore, 10.1 tons per ton for refined metal with 40% secondary input, zinc 18.9 tons per ton-net for 61% grade ore, 17.3 tons per ton refined metal with 11% secondary input, iron 2.39 tons per ton-commodity mass of 60% grade, 4.64 tons per ton for crude iron, chromium 3.2 tons per ton , tungsten 117 tons per ton, molybdenum 665 tons per ton, manganese 7.3 tons per ton, tin 5002 tons per ton, nickel 117 tons per ton-net for 15% grade ore, 73 tons per ton for refined metal with 40% secondary input, bauxite 0.48 tons per ton-commodity mass, aluminum 4.92 tons per ton.

Industrial Minerals

Domestic production—Data on annual production are available from MITI's Statistics. Data on grade are available only for limestone and dolomite, for which ancillary mass is calculated. Figures for a minimum percentage of overburden (which here means mass actually mixed with mined ores) are applied for estimating hidden flows. Limestone and dolomite for cement production are included in this category.

Imported data on commodity mass is based on trade statistics. For estimating hidden flows, 5.1 tons per ton is applied for phosphate based on the U.S. estimates by the WRI. The figure of mining waste per commodity reported in the Global 2000 report is applied for stones (0.073 tons per ton). The same hidden flow factors are used domestically when any other appropriate figures are not available.

Construction materials

Domestic production of crushed stone, sand and gravel for construction is reported by MITI's Statistics. No hidden flow is estimated because these materials are usually supplied by surface mining. The estimate of imported stones for construction is based on trade statistics.

Infrastructure

Surplus soil—The first comprehensive, nation-wide survey was conducted in 1990 by MOC. This survey counted the amount of soil moved from inside to outside a construction site and did not include soil re-used at the same site. The time series is estimated assuming that the amount of soil moved is proportional to the total amount of money (at a constant price) invested in construction. Considerable earth is used where it is excavated and so the amount of earth moved reported in this time series must be smaller than that actually excavated.

Residential area development—Usually, when developing a new residential area, particularly on slopes, the balance of cut and fill is carefully designed to minimize the transport of earth to other sites. Based on Environmental Impact Statements of several actual development projects, and personal communication with civil engineers, the average excavation factor per unit area developed is set as 3 cubic meters per square meter, and 1.75 tons per cubic meter.

Erosion

There is no formal nationwide survey of soil erosion on agricultural areas. Rough estimates are made by applying the universal soil loss equation (USLE) modified by MAFF researchers for Japanese situations. Parameters for rainfall intensity, slope, soil type are considered. National average erosion rate of agricultural field is calculated as 6 tons per hectare. This constant factor is multiplied by the area of agricultural fields.

Renewables

The commodity mass of domestic production is based on MAFF's statistics, and imported commodities are based on trade statistics. The hidden flows of imported agricultural products are estimated, as follows: applying a productivity factor (yield per area) by type of crops, the total area required to produce products exported to Japan is calculated. Then the erosion rate (erosion per unit area) is applied to the total area required. The erosion rate of the U.S. (15 tons per hectare) is used, as the U.S. is Japan's largest trading partner for agricultural products. Hidden flows of imported meat is estimated by assuming 5.5 tons of feed per ton of meat. For timbers and semi-manufactured timber products (plywood, wood chips) imported from tropical South-East Asia, it is assumed that 5.5 times as much timber volume is cut down as is traded.

Imported Semi-manufactures and Final Products

Individual physical amounts (weight or other unit that can be converted to weight) of traded commodities are reported for about 90% (price basis) of total imports. The weight of the remaining 10% was estimated assuming that the weight per price is similar for similar commodities. Hidden flows of semi-manufactures other than refined metals and timber products are roughly estimated by applying a average factor of 4 tons per ton (derived from German estimates).

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Netherlands Material Requirements

Data Sources and Methodology

General References:

The majority of the Dutch data has been obtained from a single source: Central Bureau of Statistics (CBS). Only in cases that CBS-data were not available have other sources have been used. The following other sources were used.

- RIVM, *Milieubalans van Nederland [National Environmental Outlook of the Netherlands], 1993-2015* (ISBN 90 6092 881 4): for data on emissions into the environment.
- *Ontgrondingen [Earth Removal]*, N&M11, 1978 (ISBN 90 70211 07 6): for earlier data on domestic industrial and construction minerals.
- *Ruimtebeslag in Nederland [Land Use and Land Cover in the Netherlands]*: for more recent data on domestic extraction.
- POSW data on dredging
- Organisation for Economic Co-operation and Development data on iron scrap

Wherever possible the data are presented with the same number of significant figures as reported by CBS or the other sources. Missing years were estimated through interpolation or extrapolation. In the case that only indirect information was available, the required data have been calculated using certain assumptions; all data derived this way are presented in rounded figures.

Mass Flow Categories

The reported mass flows concern four commodity categories: domestic, import, export, and transit. In the data for the Netherlands, these commodity categories, as well as the connected hidden flows on imports and exports, are presented separately. As the international trade and transport functions play an important role in the Dutch economy, both the export and the transit flows are relatively large. The influence of export and transit flows on the TMR for the Netherlands are shown in the graph, "Dutch TMR With and Without Transit Flows." This graph visually confirms that the Netherlands is an intermediary in international flows and a major exporter in its own right.

Corrections Applied

The Netherlands serves as the entry point for many imports into Europe. These transit goods can be defined into two categories: direct transit flows that are immediately transhipped to other destinations, and indirect transit, goods that are stored for a period prior to shipment. The TMR for the Netherlands is defined as total flows less direct transit flows.

The import and export figures from CBS also include direct transit flows. The indirect transit flows, however, which are stored for some time period , are not accounted for by CBS, so these figures had to be derived from other sources. In the data table presented for the Netherlands, the imports and exports are corrected only for the direct transit flows as reported by the CBS.

Methods Used for Presentation of Domestic Production

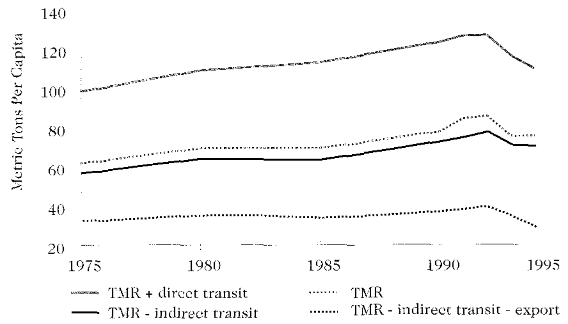
Energy carriers: CBS energy figures were converted from petajoules into metric tons using the following factors:

Coal	29 MJ/kg
Oil	42 MJ/kg
Natural gas	0.8 kg/m^3

Excavation necessary for the construction of buildings and roads is estimated on the basis of the number of houses newly built and the length of the added road mileage using the following assumptions:

Excavation	
per house	72 m^3
per km	
highway	60,000 m^3
other roads	8,000 m^3
Conversion	1.75 metric tons per m^3

FIGURE 11 **DUTCH TMR WITH AND WITHOUT TRANSIT FLOWS**



Materials from dredging are calculated on the basis of POSW data for the period 1990-95 (obtained from the Dutch Ministry of Waterworks) assuming 50% of that value for 1965 and 75% for 1980. For the other years a linear interpolation was applied.

Renewables

Soil erosion is taken as 10% gross weight of root type biomass. In the Netherlands the common type of soil erosion does not occur due to the flat and cultivated nature of the country. The Netherlands exist because of erosion by wind and water elsewhere. Intensive cultivation and subsequent drainage often leads to compacting soil due to the lower ground water levels, rather than a loss of soil. Foreign erosion is captured in the hidden flows of

Material Requirements 1965-1994
The Netherlands

Unit:1000 metric tons	1965	1970	1975	1980	1985	1990	1991	1992	1993	1994
DOMESTIC										
Non-renewables										
I.Energy Carriers										
Coal	11,609	4,391	0	0	0	0	0	0	0	0
Oil	2,400	1,920	1,570	1,643	4,143	4,048	3,786	3,405	3,357	4,452
Natural Gas	1,537	28,084	80,316	81,270	71,970	69,320	64,625	64,900	66,200	62,800
Total	15,546	34,396	81,886	82,913	76,113	73,368	68,411	68,305	69,557	67,252
II. Metal Ores										
(none)	0	0	0	0	0	0	0	0	0	0
III.Industrial Minerals										
Marl	4,000	4,000	4,000	3,500	3,500	3,000	3,000	3,000	3,000	2,800
Common salt	1,707	2,871	2,690	3,464	3,500	3,500	3,500	3,500	3,500	3,500
Carnalite	0	0	0	0	500	500	500	520	550	600
Total	5,707	6,871	6,690	6,964	7,500	7,000	7,000	7,020	7,050	6,900
IV. Construction Minerals										
Gravel	11,400	11,400	6,700	4,500	5,000	5,000	5,000	5,000	5,032	6,914
Sand, indust.	24,000	24,000	24,000	23,000	23,000	23,000	23,000	23,000	22,246	25,086
Sand, construction	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	24,632	35,476
Clay	6,000	6,000	6,000	5,500	5,500	5,500	5,500	5,500	5,500	5,000
Total	66,400	66,400	61,700	58,000	58,500	58,500	58,500	58,500	57,410	72,476
V. Excavation										
Infrastructure	92,368	116,446	54,667	38,878	28,280	27,495	27,391	28,766	27,184	27,458
Dredging	12,000	14,000	16,000	18,000	21,000	24,000	24,000	24,000	24,000	24,000
Total	104,368	130,446	70,667	56,878	49,280	51,495	51,391	52,766	51,184	51,458
Renewables										
I. Plant Biomass (fresh weight)										
Grass	9,500	9,500	9,500	9,898	9,468	10,210	8,946	8,302	8,300	8,300
Wheat	838	776	640	1,069	1,032	1,304	1,144	1,233	1,253	1,189
Rye	303	204	76	47	23	44	41	42	50	32
Barley	452	399	407	313	239	265	288	247	305	276
Oat	440	241	192	114	70	20	22	22	37	34
Peas	53	47	27	18	86	74	39	27	17	11
Bean	9	14	17	7	11	8	11	9	8	6
Coleseed	13	26	44	35	37	31	25	17	9	5
Flax	114	135	125	119	136	151	135	77	102	126
Potatoes	9,266	13,646	10,861	16,667	19,781	19,654	20,435	22,198	21,363	19,671
Potatoes (industrial)	4,363	10,000	10,245	9,772	10,384	10,034	8,886	9,852	11,122	10,241
Sugar beets	14,292	18,844	23,708	23,724	25,340	34,492	28,756	33,004	29,916	24,596
Onions	1,929	2,411	2,894	3,376	3,376	4,389	4,466	5,527	5,845	4,485
Corn (for cattle)	0	0	14,301	23,168	30,411	36,057	35,660	39,612	44,510	41,626
Vegetables	8,484	13,391	15,093	16,408	18,228	22,588	24,962	26,837	26,000	26,297
Fruit	2,585	3,190	2,910	3,050	2,765	2,550	2,100	2,635	3,865	3,250
II. Plant Biomass, Wild Harvest										
Wood	529	529	529	529	545	551	551	551	551	551
III.Animal Biomass, Wild Harvest										
Fish	535	421	517	509	840	767	740	732	812	750
Total Renewables	53,705	73,772	92,085	108,821	122,772	143,188	137,206	150,923	154,065	141,446
	13,473	14,143	15,103	16,558	17,000	18,907	17,140	17,268	17,543	16,724
Erosion	700	1,057	1,123	1,255	1,383	1,611	1,460	1,642	1,578	1,370
	40,232	59,630	76,982	92,263	105,772	124,281	120,066	133,656	136,521	124,721
Total Domestic	246,426	312,941	314,150	314,831	315,547	335,162	323,968	339,156	340,844	340,903
IMPORTS										
Non-renewables										
I.Energy Carriers										
Solid fuels	7,734	4,695	4,953	10,402	12,013	19,621	22,165	21,643	15,963	
Crude oil and products	54,719	105,514	127,086	127,869	113,234	111,416	134,546	124,986	117,654	
Natural Gas	0	0	0	2,650	1,650	2,125				
II. Metal Ores										
Ores and metal residues	9,171	11,632	13,424	14,910	6,304	10,176	10,157	9,659	5,652	
III. + IV. Industrial & Construction Minerals										
Crude industrial and building materials	24,617	42,076	29,251	30,359	40,684	45,637	44,586	45,594	35,195	
Renewables										
Agricultural products including livestock	6,698	10,965	13,844	11,742	13,194	13,546	14,189	15,388	15,745	
Foodstuffs including fodder and concentrates	6,315	4,109	8,352	17,472	23,688	22,472	31,499	33,581	32,053	

Material Requirements 1965-1994
The Netherlands

	1965	1970	1975	1980	1985	1990	1991	1992	1993	1994
Unit:1000 metric tons										
Semi-manufactures										
Metals	2,167	3,043	2,138	3,332	4,311	7,062	7,919	8,491	6,211	
Fertilizers	4,149	4,106	2,858	4,133	4,244	3,905	3,241	3,180	2,267	
Final Products										
Chemical products	306	4,055	3,197	7,835	15,516	17,054	20,250	21,375	16,201	
Other final goods	1,080	2,095	2,398	4,924	8,830	12,058	14,013	14,872	15,738	
Total Imports	116,955	192,290	207,502	235,628	243,667	265,073	302,565	298,770	262,679	275,000
Direct Material Inputs (DMI) Domestic + Import	363,381	505,231	521,653	550,459	559,214	600,235	626,533	637,926	603,523	615,903
HIDDEN FLOWS FROM IMPORTS										
Non-renewables										
I. Energy Carriers	55,159	45,051	50,051	83,403	90,524	135,980	154,515	149,853	114,601	
II. Metal Ores	55,023	69,789	80,547	89,458	37,823	61,055	60,944	57,955	33,914	
III. & IV. Industial and Construction Minerals	8,862	15,147	10,530	10,929	14,646	16,429	16,051	16,414	12,670	
Renewables	71,567	82,907	122,079	160,679	202,851	198,101	251,287	269,329	262,887	
Semi-manufactured Products	57,158	71,651	50,211	76,634	93,641	138,165	149,244	158,551	115,674	
Total Hidden Flows from Imports	247,769	284,546	313,419	421,104	439,485	549,731	632,042	652,102	539,745	540,000
EXPORTS										
Non-renewables										
I.Energy Carriers										
Solid fuels	5,312	1,860	862	3,279	1,861	4,023	8,234	8,646	2,071	
Crude oil and products	29,978	71,009	95,267	87,233	82,826	85,060	121,501	121,132	122,629	
Natural gas	32	10,021	43,611	39,300	31,675	27,025				
II. Metal Ores										
Ores and metal residues	5,987	6,710	6,419	7,797	(272)	2,583	3,267	2,783	1,271	
III. + IV. Industrial and Construction Minerals										
Crude industrial and building materials	13,141	16,666	4,678	4,457	17,992	21,174	21,561	22,612	19,474	
Renewables										
Agricultural products including livestock	4,703	6,660	8,722	6,779	8,374	9,873	10,300	10,724	10,390	
Foodstuffs including fodder and concentrates	*2,824*	*1,230*	*4,343*	*10,125*	*16,045*	*17,433*	*19,745*	*20,272*	*20,317*	
Semi-manufactured Products										
Metals	1,461	2,374	2,997	4,425	5,483	7,296	8,066	8,290	7,560	
Fertilizers	3,952	3,460	3,654	5,017	5,722	7,166	6,318	6,155	6,110	
Chemical products	603	5,372	5,187	10,132	20,731	23,165	26,816	26,131	26,797	
Final Products	241	279	1,229	2,527	5,921	9,373	11,144	11,989	13,251	
Total Exports	*68,232*	*125,641*	*176,970*	*181,071*	*196,357*	*214,172*	*236,952*	*238,735*	*229,870*	*230,000*
HIDDEN FLOWS WITH EXPORTS										
Non-renewables										
I. Energy Carriers	36,674	24,525	29,136	41,494	30,751	43,155	68,842	71,255	32,045	
II. Metal Ores	35,919	40,257	38,517	46,780	1,633	15,497	19,604	16,699	7,628	
III. & IV. Industrial and Construction Minerals	4,599	5,833	1,637	1,560	6,297	7,411	7,546	7,914	6,816	
Renewables	*54,189*	*56,808*	*94,069*	*121,712*	*175,817*	*196,606*	*216,328*	*223,170*	*221,087*	
Semi-manufactured Products	36,567	44,601	52,738	75,966	91,662	119,733	124,349	126,112	117,486	
Total Hidden Flows with Exports	167,948	172,024	216,097	287,511	306,161	382,402	436,670	445,151	385,062	400,000
INDICATORS										
Total Material Requirement (TMR)	570,918	730,148	758,089	879,299	892,927	1,025,685	1,138,509	1,156,372	1,006,746	1,031,181
TMR adjusted for exports and recycling	334,737	432,483	365,022	410,717	390,410	429,111	464,887	472,487	391,814	401,181
Avoided Hidden Flows from recycling	*7,325*	*9,324*	*15,498*	*22,753*	*29,510*	*38,951*	*39,273*	*41,713*	*44,397*	*46,047*
TMR per capita (metric tons)	46	56	56	62	62	69	76	76	66	67
Domestic TMR Per Capita (metric tons)	27	33	27	29	27	29	31	31	26	26

imported renewables. Disturbed soil caused by ploughing, although a significantly larger quantity than erosion, is not reported.

Hidden Flows of Imports and Exports

To estimate the hidden flows of imports and exports, the following procedure was adopted.

With respect to import and export data either the aggregated statistical data are in money values or in mass, and are very detailed. The approach chosen here was to use the existing mass data on transport, including transit traffic in which a change of carrier has occurred. Next the data were aggregated into 10 categories.

1. Agricultural products including livestock
2. Foodstuffs, fodder, and concentrates
3. Solid fuels
4. Crude oil and oil products
5. Ores and metal residues
6. Metals
7. Raw industrial minerals and building materials
8. Fertilizers
9. Chemical products
10. Finished goods

Data were not available for all requested years; Therefore, averages were calculated from the available data for both the transit traffic and the aggregated 10 categories mentioned. This gave a consistent set, indicating that the import and export package of the Netherlands did not change too drastically in the period taken into consideration. From different statistics a more detailed description was available for 1985. This was used to calculate the hidden flows for the above categories, with data from the Wuppertal Institute for German imports as a basis.

Recycling materials avoids hidden flows. For 1991 the avoided hidden flows caused by the reuse of paper, scrap, aluminum, copper, and building or road construction wastes were 39.3 million metric tons, which represents about 6% of the total hidden flows of imports.

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United States Material Requirements

Material flows supporting the United States' economy are almost totally due to domestic activities—with only about 5% associated with the imports of raw materials, semi-manufactures, or finished goods. This concentration of material extraction within its borders means that the bulk of the flows necessary to feed and house workers and extract that material (for example, fuel for machinery) are also accounted for. These additional flows are not included with the hidden flows of imports; so a country like the United States with limited imports will show relatively higher material flows than those countries with a greater share of imports in their material flow accounts.

One of the largest material flows in the United States arises from the surface mining of coal. Overburden is removed from above coal seams and,

Material Requirements 1975-1994
United States

	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
Unit:million metric tons										
NON-RENEWABLES										
Industrial Minerals										
Gypsum										
Domestic Production	9	11	12	14	13	11	10	10	12	13
Imports	5	6	6	8	7	7	7	6	7	8
Total Hidden Flows	1	1	1	1	1	1	1	1	1	1
Clay										
Domestic production	47	51	51	55	52	46	42	33	38	42
Gangue	2	3	3	3	3	2	2	2	2	2
Overburden	141	152	154	165	157	137	125	99	114	126
Sand and Gravel (Industrial)										
Domestic production	25	27	28	30	30	26	27	25	24	27
Overburden	0	1	1	1	1	1	1	0	0	1
Salt										
Domestic production	38	40	39	39	42	38	35	34	30	36
Imports	3	4	4	5	5	5	4	5	5	7
Potash										
Domestic production	2	2	2	2	2	2	2	2	2	2
Imports	3	4	5	5	6	5	5	4	5	5
Foreign Hidden Flows	10	13	15	15	17	16	15	12	14	15
Domestic Hidden Flows	18	18	16	17	18	17	17	14	15	16
Phosphate										
Domestic production (phosphate rock)	44	45	47	50	52	54	54	37	43	49
Domestic Hidden Flows	228	230	244	257	266	280	276	193	219	253
Construction Materials										
Crushed Stone										
Total production	816	817	865	952	995	892	792	717	781	867
Domestic overburden	8	8	9	10	10	9	8	7	8	9
Domestic gangue	49	49	52	57	60	54	48	43	47	52
Sand and Gravel (Construction)										
Total production	716	776	814	874	858	692	625	538	593	700
Overburden	14	16	16	17	17	14	13	11	12	14
Metals										
Aluminum										
Bauxite imports	12	13	13	14	14	14	13	10	8	9
Alumina imports	4	4	5	5	5	5	4	4	3	3
Foreign overburden bauxite	6	6	6	7	7	7	6	5	4	5
Foreign overburden alumina	4	4	4	5	5	5	4	3	3	3
Foreign gangue alumina	4	4	5	5	5	5	4	4	3	3
Domestic gangue bauxite	9	10	10	10	10	11	10	8	6	7
Domestic gangue alumina	2	2	2	2	2	2	2	2	1	2
Total Hidden Flows	24	22	23	24	24	25	22	18	13	16
Gold										
Total Gold production (metric tons)	35	35	35	35	35	30	43	46	62	65
Gangue	10	10	10	10	10	9	14	17	39	27
Overburden	27	27	27	27	27	23	37	46	105	73
Total domestic Hidden Flows	37	37	37	37	37	32	51	62	144	100
Copper										
Domestic mine production	1	1	1	1	1	1	2	1	1	1
Domestic gangue	205	220	205	211	232	202	247	181	172	163
Domestic overburden	289	310	289	297	327	285	347	255	242	229
Domestic Hidden Flows	494	529	495	508	558	488	594	436	414	392
Copper imports	0	0	0	1	0	1	0	0	1	1
Foreign gangue	23	41	39	50	26	51	40	48	59	50
Foreign overburden	32	57	55	71	36	73	56	67	84	72
Iron Ore										
Crude ore mined	218	228	161	238	260	216	231	112	117	162
Production usable ore	80	81	56	82	87	71	74	36	38	52
Imports usable ore	48	45	39	34	34	26	29	15	14	18
Foreign gangue	18	17	15	13	13	10	11	6	5	7
Foreign overburden	95	90	77	68	69	51	58	29	27	35
Domestic gangue from imports	18	17	14	13	13	9	11	5	5	6
Domestic gangue	168	177	126	186	205	171	184	89	93	129
Domestic overburden	183	185	129	190	200	163	171	83	88	120
Total Hidden Flows	482	487	361	470	499	404	434	212	218	297
% of supply from secondary scrap	52	49	45	43	50	54	45	45	50	45

Material Requirements 1975-1994
United States

Unit:million metric tons

NON-RENEWABLES

	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
Industrial Minerals										
Gypsum										
Domestic Production	13	14	14	15	16	15	14	15	16	17
Imports	9	9	9	9	7	8	7	7	7	9
Total Hidden Flows	1	1	1	1	1	1	1	1	1	1
Clay										
Domestic production	43	42	40	41	43	43	41	40	41	42
Gangue	2	2	2	2	2	2	2	2	2	2
Overburden	128	126	121	124	130	129	123	121	123	127
Sand and Gravel (Industrial)										
Domestic production	27	25	25	26	27	26	23	25	26	27
Overburden	1	0	1	1	1	1	0	1	1	1
Salt										
Domestic production	36	34	34	36	36	37	36	36	39	40
Imports	6	6	5	5	6	6	6	5	6	10
Potash										
Domestic production	2	1	2	2	1	2	2	2	2	1
Imports	4	4	4	4	4	4	4	4	4	5
Foreign Hidden Flows	13	12	12	13	11	13	12	13	13	14
Domestic Hidden Flows	14	13	14	14	12	14	15	15	14	13
Phosphate										
Domestic production (phosphate rock)	51	40	41	45	50	46	48	47	36	41
Domestic Hidden Flows	262	207	211	234	256	238	248	242	183	212
Construction Materials										
Crushed Stone										
Total production	908	928	1,089	1,131	1,100	1,108	997	1,050	1,120	1,230
Domestic overburden	9	9	11	11	11	11	10	11	11	12
Domestic gangue	54	56	65	68	66	66	60	63	67	74
Sand and Gravel (Construction)										
Total production	725	800	812	836	813	831	708	834	869	891
Overburden	15	16	16	17	16	17	14	17	17	18
Metals										
Aluminum										
Bauxite imports	8	7	10	10	12	12	12	11	12	11
Alumina imports	3	2	3	4	4	4	5	5	4	3
Foreign overburden bauxite	4	3	5	5	6	6	6	5	6	5
Foreign overburden alumina	3	2	3	3	4	4	4	5	4	3
Foreign gangue alumina	3	2	3	4	4	4	5	5	4	3
Domestic gangue bauxite	6	5	7	8	9	9	9	9	9	8
Domestic gangue alumina	1	1	2	2	2	2	2	2	2	2
Total Hidden Flows	14	12	17	18	21	21	22	21	20	18
Gold										
Total Gold production (metric tons)	76	116	154	201	266	295	294	330	331	326
Gangue	31	51	81	118	156	184	184	220	221	217
Overburden	85	137	219	319	422	497	496	594	596	587
Total domestic Hidden Flows	116	187	300	437	578	681	680	814	816	804
Copper										
Domestic mine production	1	1	1	1	1	2	2	2	2	2
Domestic gangue	169	172	199	223	244	267	279	302	309	316
Domestic overburden	221	225	291	342	429	594	660	592	590	600
Domestic Hidden Flows	390	398	490	565	673	862	940	893	898	916
Copper imports	0	1	1	0	0	0	1	1	1	1
Foreign gangue	40	56	56	48	47	45	55	65	70	83
Foreign overburden	53	73	69	67	68	79	105	117	125	150
Iron Ore										
Crude ore mined	152	122	148	183	188	181	183	179	180	188
Production usable ore	50	40	48	58	59	56	57	56	56	58
Imports usable ore	16	17	17	20	20	18	13	13	14	18
Foreign gangue	6	7	6	8	8	7	5	5	5	7
Foreign overburden	32	34	34	40	39	36	27	25	28	35
Domestic gangue from imports	6	6	6	7	7	7	5	5	5	6
Domestic gangue	120	97	118	147	151	146	147	144	145	152
Domestic overburden	114	91	109	132	136	130	131	128	128	134
Total Hidden Flows	278	235	274	335	340	325	315	307	312	334
% of supply from secondary scrap	50	55	57	58	59	62	60	58	59	55

Material Requirements 1975-1994
United States

	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
Unit:million metric tons										
Infrastructure										
Dredging	560	517	512	490	491	512	597	477	498	579
Highway Construction	2,427	2,342	1,916	1,524	1,667	1,891	1,832	1,545	1,428	1,444
New General Construction	1,433	1,674	1,796	1,626	1,750	1,485	1,644	1,732	1,819	1,973
Fossil Fuels										
Total Fossil Fuels (Net)	1,767	1,841	1,935	1,908	2,022	1,980	1,924	1,869	1,786	1,946
Liquid										
Domestic production	497	483	489	510	503	505	505	506	509	522
Domestic Hidden Flows	40	39	39	41	40	40	40	41	41	42
Imports	301	363	437	415	420	343	298	254	251	270
Foreign Hidden Flows	24	29	35	33	34	27	24	20	20	22
Natural Gas										
Domestic production	356	353	354	354	364	359	355	330	298	323
Domestic Hidden Flows	107	106	106	106	109	108	106	99	89	97
Imports	18	18	19	18	23	18	17	17	17	16
Foreign Hidden Flows	5	5	6	5	7	5	5	5	5	5
Coal										
Domestic production	595	623	634	609	710	754	749	762	711	815
Domestic Hidden Flows	5,014	5,237	5,816	5,699	5,648	5,889	5,953	5,818	5,136	5,813
Imports	1	1	1	3	2	1	1	1	1	1
Foreign Hidden Flows	12	16	22	40	26	14	12	8	14	14
Total Fossil Fuel Hidden Flows	5,202	5,432	6,024	5,925	5,863	6,084	6,140	5,991	5,305	5,992
Soil Erosion										
Soil Erosion:non-federal	5,525	5,473	5,420	5,369	5,317	5,267	5,216	5,167	4,952	4,747
RENEWABLES										
Agriculture										
Agricultural Production	417	420	440	452	489	442	515	519	371	489
Agricultural Hidden Flows	166	167	177	183	199	176	210	211	145	200
Agricultural Imports	5	5	5	5	5	5	6	6	5	6
Agricultural Import Hidden Flows	69	69	69	69	69	70	72	73	68	77
Forestry										
Forestry (roundwood)	223	246	256	286	306	303	297	285	312	338
Forestry Hidden Flows	101	112	116	130	139	138	135	130	142	154
Animal Biomass										
Livestock	89	89	84	83	69	72	73	75	74	77
Wild fish harvest	3	3	3	3	4	4	4	4	4	5
IMPORTS OF SEMI-MANUFACTURES AND FINISHED PRODUCTS										
Semi-manufactures										
Semi-manufactures	35	35	35	35	35	35	35	31	42	55
Semi- manufactures Hidden Flows	120	120	120	120	120	122	124	117	176	238
Finished Products	31	31	31	31	31	27	24	31	38	47
INDICATORS										
Total Material Requirement (TMR)	21,463	22,050	22,370	22,013	22,402	21,982	22,151	20,888	20,056	21,526
TMR Per Capita (metric tons)	99	101	102	99	100	97	96	90	86	91
Direct Inputs (% of TMR)	21	21	22	23	24	22	21	21	21	22
TMR/GDP (1985 constant $US), Indexed 1985 = 100	138	135	131	123	122	121	120	115	107	108
Hidden Flows Per Capita (metric tons)	79	81	80	77	77	76	77	72	68	71

Material Requirements 1975-1994
United States

1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	
										Unit:million metric tons
										Infrastructure
520	536	458	496	562	479	516	439	473	518	Dredging
1,377	1,435	1,291	1,163	1,250	1,254	1,251	1,281	1,074	1,074	Highway Construction
1,790	1,856	1,797	1,626	1,908	1,904	1,707	1,943	1,862	1,862	New General Construction
										Fossil Fuels
1,904	1,939	1,987	2,058	2,095	2,136	2,098	2,112	2,101	2,197	Total Fossil Fuels (Net)
										Liquid
525	508	493	484	455	442	451	440	426	415	Domestic production
42	41	39	39	36	35	36	35	34	33	Domestic Hidden Flows
252	309	332	367	400	398	379	392	428	443	Imports
20	25	27	29	32	32	30	31	34	35	Foreign Hidden Flows
										Natural Gas
304	297	307	316	320	329	327	330	337	349	Domestic production
91	89	92	95	96	99	98	99	101	105	Domestic Hidden Flows
18	14	18	24	26	28	33	40	43	47	Imports
5	4	5	7	8	8	10	12	13	14	Foreign Hidden Flows
										Coal
803	809	835	864	892	935	905	907	860	936	Domestic production
5,363	5,552	5,623	5,820	5,903	5,982	5,711	5,718	5,630	5,864	Domestic Hidden Flows
2	2	2	2	3	2	3	3	7	7	Imports
20	23	17	21	29	27	33	37	69	68	Foreign Hidden Flows
5,541	5,733	5,804	6,012	6,104	6,183	5,919	5,932	5,881	6,119	Total Fossil Fuel Hidden Flows
										Soil Erosion
4,550	4,362	4,339	4,172	4,012	3,858	3,710	3,684	3,543	3,407	Soil Erosion:non-federal
										RENEWABLES
										Agriculture
530	494	469	380	471	503	478	558	456	586	Agricultural Production
218	201	189	148	189	205	193	228	180	239	Agricultural Hidden Flows
7	7	7	7	9	9	9	9	10	10	Agricultural Imports
87	85	85	85	113	116	120	123	126	130	Agricultural Import Hidden Flows
										Forestry
332	351	364	370	374	372	349	359	359	359	Forestry (roundwood)
151	159	166	168	170	169	159	163	163	163	Forestry Hidden Flows
										Animal Biomass
77	77	78	77	79	79	80	80	82	82	Livestock
5	5	6	6	6	6	5	6	6	6	Wild fish harvest
										IMPORTS OF SEMI-MANUFACTURES AND FINISHED PRODUCTS
										Semi-manufactures
53	52	53	55	39	42	47	52	58	65	Semi-manufactures
231	233	241	249	155	170	187	206	227	251	Semi- manufactures Hidden Flows
54	55	46	37	61	55	52	49	47	46	**Finished Products**
										INDICATORS
20,623	20,868	21,095	21,196	21,906	22,145	21,237	21,968	21,472	21,947	Total Material Requirement (TMR)
86	87	87	87	89	89	84	86	83	84	TMR Per Capita (metric tons)
24	24	25	25	25	25	24	25	25	26	Direct Inputs (% of TMR)
100	98	96	93	94	94	91	91	87	86	TMR/GDP (1985 constant $US), Indexed 1985 = 100
66	67	66	66	68	67	65	65	63	63	Hidden Flows Per Capita (metric tons)

according to law, is later returned and the area graded and reclaimed. The impact of this overburden removal on environmental qualities also varies by the amount, duration of mining, topography of the site, and the hydrological situation. The annual new excavation of this material (almost 6 billion metric tons) makes it a major human activity on this planet.

Erosion makes up another large component of the U.S. TMR. Although declining in recent years due to policies that cause farmers to set aside highly erosible land, soil erosion from crop and grazing lands makes up between 3 and 4 billion metric tons annually. This scale of soil erosion in the United States is due in part to its size and diversity of landscapes. But it is also due to the inherent erosive potential of much of its most productive soils and the continued use of relatively marginal lands for cropping and intensive grazing.

Road and infrastructure building in the United States continues on a scale without precedent in the world. Even though much of the vast highway system is complete, a program of highway improvements, infrastructure repair and replacement, and the increasing demand for wider and faster roadways, requires a high level of landscape modification and material usage. Unlike countries where dense rail and other public transport infrastructure minimize demand for roads, transport infrastructure in the United States reflects the cultural value given to the automobile and independence of movement.

Of the non-fossil fuel raw materials used in the United States, construction materials, copper, gold, and iron dominate all other material flows.

Data Sources and Methodology

General references:

MCS: *Mineral Commodity Summaries*, and annual report published by the U.S. Bureau of Mines (USBM), now currently part of the U.S. Geological Service (USGS).

MIS: *Mineral Industry Surveys* are commodity specific reports published annually or periodically by the USBM.

Statistical Compendium: A USBM Special Publication, published December 1993.
Annual Energy Review 1994, United States' Energy Information Administration.
FAOSTAT, United Nations Food and Agriculture Organisation.
FISHSTAT, United Nations Food and Agriculture Organisation.

Personal communication: Unless otherwise noted, this notation indicates that verbal information or estimates were obtained from USBM/USGS commodity specialists. The help of these specialists facilitated data gathering and was greatly appreciated.

Industrial Minerals

Gypsum: Apparent consumption, domestic production, and imports data were obtained from current and historical MCS. Overburden and gangue were estimated to total 5% of production (personal communication).

Clay: Apparent consumption and domestic production were obtained from the USBM Statistical Compendium, more recent years from MCS. Negligible amounts of clay are imported. Kaolin is estimated to have 25% gangue and to be about 20% of all clay mined. Overburden associated with clay mining varies from zero to 10 tons per ton, 3 tons per ton is considered to be a good average (personal communication). Common clay, which is used almost exclusively for construction purposes, averaged about 60% of domestic production.

Crushed stone, cement rock, lime, agricultural rock: Total domestic stone production was obtained from the MIS Annual Review-1994 and Statistical Compendium. This total includes cement and agricultural limestone. Domestic overburden is estimated to be 1% of production, gangue (stone fines) is estimated to be an additional 6% (personal communication).

Sand and gravel (construction): Apparent consumption data were obtained from the MCS and Statistical Compendium. Overburden is estimated to be 2% of production (personal communication).

Sand and gravel (industrial): Apparent consumption data were obtained from the MCS. This data is not embedded in the construction sand and gravel data. Overburden and gangue were estimated to be 2% of production (personal communication).

Salt: Apparent consumption data were obtained from the MCS and Statistical Compendium. No overburden or gangue data were included since almost all production is obtained by solution mining.

Potash: Apparent consumption and import data in K_2O equivalents were obtained from the MCS. A domestic ore average grade of 14% K_2O was used based on a time series obtained from USGS personnel. The foreign ore grade, mainly from Canada, was estimated to be 22% K_2O (personal communication). Potash is imported at about 66% K_2O.

Phosphate: The apparent consumption of P_2O_5 equivalents was obtained from Fertilizer Institute data. Phosphate rock production data were obtained from the MCS and Statistical Compendium. Phosphate rock as marketed contains on average 27% P_2O_5, U.S. production is about 5/6 from Florida and 1/6 from North Carolina with the Florida rock grade averaging 10% P_2O_5 and the North Carolina grade 24.5%, (personal communication). Additionally, Florida mine slimes were estimated to be about 6.3 tons per ton of P_2O_5, and the mill gypsum waste about 2.7 tons per ton of P_2O_5. For North Carolina, mine sands average 0.41 tons per ton of P_2O_5 and mill gypsum 2.67 tons per ton of P_2O_5 (personal communication). Overburden was calculated based on estimates of 1 ton per ton of ore for Florida and 4 tons per ton of ore for North Carolina (personal communication).

Metals

Aluminum: Apparent supply, which includes both new and old scrap whereas new scrap is excluded from apparent consumption, was obtained from the MCS and Statistical Compendium along with primary metal production and scrap data. For overall calculations, an average of 4 tons of bauxite was considered to yield 2 tons of alumina, which yields 1 ton of aluminum. All bauxite for primary metal production was assumed to be imported (personal communication). A worldwide weighted average of 0.48 tons of overburden per ton of bauxite was calculated based on global data contained in International Primary Aluminum Institute report "Bauxite Mine Rehabilitation Survey," by Peter Martyn, dated December 1992. Alumina import data for 1977-90 was not available, but was calculated to be 35% of the bauxite imports based on an average for 1991-95.

Gold: Domestic gold mine production was obtained from the MCS and Statistical Compendium. The change in the average ore grade for the U.S. was obtained from Figure 5 of USBM SP 24-94 "World

Gold," 1994. The worldwide average grade was obtained from Table E-3 of the same publication, which provided data for 1983 and 1992, a linear interpolation was used for the intervening years. A global weighted average of 2.56 tons overburden per ton of ore was calculated, based on 1992 data in SP24-94, for the United States, Canada, Australia, and South Africa. The overburden average for the U.S. was taken as 2.7 tons per ton of ore based on SP 24-94 (p.19).

Copper: Domestic mine production, apparent supply, imports, and scrap data were obtained from the MCS and Statistical Compendium. The U.S. and world average grade, and overburden to ore ratios, were obtained from the USBM Copper Availability Study, June, 1993 for the years 1984-95. Figures equal to 1984 were assumed for the years 1975-83.

Iron ore: Production of useable ore was obtained from the MCS and the Statistical Compendium. For the United States, useable ore is considered to have an average grade of about 63% (USBM IC 9128, Iron Ore Availability, 1987, and personal communication). U.S. crude ore mined for 1991-95 was calculated based on data from 1977-90. Average world ore grade was taken to be 43.3%, and average grade of imported useable ore was taken as 60% based on data in IC 9128 and personal communications. Domestic overburden was assumed to be 2.3 tons per ton of useable ore, and foreign overburden was taken to be 2 tons per ton of useable ore (personal communication). A calculated iron consumption was computed by taking 63% of the reported consumption of useable ore for all uses. This figure was used as the commodity consumption from primary sources. The amounts furnished from domestic and foreign sources was obtained using the ratio of domestic to foreign useable ore. The apparent consumption and steel from secondary sources were used to calculate the percent from secondary sources.

Metals recycling rates: Three different terms are sometimes used to describe scrap, secondary supply: old scrap, which is post consumer; new scrap, which is post fabricator (cuttings and turnings); and home scrap, which never leaves the mill (usually this is only considered for steel). To give an accurate picture of recycling whatever is included in supply or apparent consumption must also be included as part of secondary supply. In calculating the percent from secondary supply both new and old scrap are counted in the numerator and the denominator.

Infrastructure

Dredging: The dredging time series was obtained from the Dredging and Navigation Branch of the U.S. Corps of Engineers in terms of dollars and cubic yards per year for 1966-1995. Dredging is both for maintenance and new projects, with the majority being for maintenance. The predominant (about 80%) motive for dredging was harbor and channel improvement, with the remaining share being used for beach replenishment. All dredging has been included. In addition to dredging by the Corps, private dredging is permitted in the amount of 50-100 million cubic yards per year. It is not known exactly how much of the permitted private dredging is actually done. A time series was not available for the private activity, so an average of 75 million cubic yards per year was used all years. In situ density varies from 1,400-2,200 gr./liter, or 1.07-1.68 metric tons per cubic yard. An average of 1.375 metric tons per cubic yard was used for all conversions.

Highways: All information was obtained from annual reports of the Federal Highway Administration in the Department of Transportation. Obtained for each year was the total mileage of all roads (table HM-12), total capital outlay (table HF-2), and construction costs exclusive of right of way and engineering for the years 1977-86. Construction costs were estimated to be 83% of total capital outlay for the years 1987-94. In 1961 (Public Roads magazine Vol. 31 No. 10) excavation constituted 34% of the contract cost for all highway construction. Currently this percentage is much lower since most current activity is road upgrading rather than new construction. For estimating purposes excavation was assumed to be 30% of construction cost in 1975-77, exclusive of right of way and engineering, declining to 10 % in 1995. A time series of current dollar average contract price per cubic yard was obtained from publication number FHWA-PD-95-006, 1995. The contract price for excavation was used to estimate total excavation in cubic yards. An average density of 3,000 lbs per cubic yard was used to estimate total mass.

New general construction: Current dollar construction expenditures were obtained from table B-53 of the 1994 Economic Report to the President. Included were private residential new housing units and nonresidential construction, and public construction less total highway distributions (all segments of highway programs). Site preparation costs, the earth moving component of a general construction project, were estimated to be 2.13% of total project cost based on information from Construction Cost Systems Inc. of Fairfax, Virginia. As with highway construction, total construction costs were converted to project excavation expenditures, which were then converted to cubic yard and tonnage estimates. This was done on a year by year basis using the same conversion time series obtained from FHWA. This conversion factor was checked against current data from Construction Cost Systems Inc and found to agree with it.

Note: For both general construction and highways, it was not possible to separate estimates of the rehandling of material from estimates of initial excavation. In the interest of harmonizing this material flow category with estimates from other countries it was assumed that initial excavation and first transport constituted 50% of the calculated material flows for highways and general construction.

Fossil Fuels

Liquid and Gas: Fossil fuel data were obtained from the United States' Energy Information Administrations report *Annual Energy Review 1994*. Petroleum was converted to mass units on the basis of .136 metric tons per barrel. Natural gas was converted from cubic feet to metric tons on the basis of the weight of methane at standard temperature and pressure (653 grams per cubic meter). The hidden flows for liquid fuels was based on the Wuppertal Institute's calculation for petroleum's hidden flows. The hidden flows for natural gas was taken from the difference between gross and net production of dry natural gas found in the *Annual Energy Review 1994*.

Coal: Coal production can be separated into underground mining and surface mining. The hidden flows for underground coal was based on what the Wuppertal Institute used for Germany—10% of the coal mined. The hidden flows associated with surface mining are more complicated. Surface mines occur in three very different depth regimes. Eastern services mines tend to be deeper than Midwestern mines which are deeper than Western mines. Furthermore, the ratio of overburden to coal extraction is kept proprietary by the mining companies. Based on the one extant publication that compares four western (average overburden ratio 4.8:1) to one eastern surface mine (overburden ratio 26.9:1), the country was partitioned into 2 zones west (including mid-western) and east and these ratios were applied to production in each zone for each year using data found in the *Annual Energy Review 1994*.

Erosion

Erosion is derived from the United States *Natural Resource Inventory,* which is a physical survey of non-federal land resources in the United States every five years. Erosion estimates from federal lands, 21% of the total, are explicitly excluded. This is net erosion from wind and water. Intermediate years were estimated by interpolation and out years by extrapolation from known rates of change.

Renewables

Agricultural, forestry and livestock data were derived from *FAOSTAT 1995,* the electronic compilation of data from the United Nations Food and Agriculture Organization. Fish production data was extracted from *FISHSTAT 1995.* Roundwood data was used as the basis for estimating forestry's hidden flows (45% of roundwood mass, *Forestry Handbook,* J. Wiley, New York, 1984, p. 316). Grain, otherwise accounted for in agricultural production, is often fed to cattle before slaughter to improve their grade. Nonetheless, much of the weight of beef cattle slaughtered in the United States is due to grazing on rangeland and pasture not otherwise accounted for in the renewable resource flows. Aquaculture production was not accounted for in the fishery flows—grain fed to such fish is otherwise accounted for in agricultural production.

Imports

Imports of renewable raw materials, semi-manufactures, and final products were derived from the U.S. Army Corps of Engineers annual *Waterborne Commerce of the United States (Part 5, National Summaries)* (Washington, D.C.). Calculations of hidden flows for semi-manufactured imports used parameters supplied by the Wuppertal Institute which uses these parameters to estimate the same hidden flows for Germany. Imports of final products include all imports by air. Imports by land were not included. Such imports by land from Canada and Mexico are complicated by the extensive re-import of materials exported for labor only.

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