THE WEIGHT OF NATIONS

MATERIAL OUTFLOWS FROM INDUSTRIAL ECONOMIES

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COVER PHOTO

ISBN 1-56973-439-9

Library of Congress Catalog Card No. 00-107192

Printed in the United States of America on chlorine-free paper with recycled content of 50%, 20% of which is post-consumer.

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PREFACE

This report, *The Weight of Nations: Material Outflows from Industrial Economies*, is the second product of a remarkable collaboration between the World Resources Institute and research partners in Europe and Japan. Our task has been to document the materials that flow through industrial economies and develop sets of national physical accounts that can be used alongside national monetary accounts. In addition, we have developed indicators of material flows that complement such economic indicators as gross domestic product (GDP).

Standard economic indicators—those that describe the financial flows in an economy—provide incomplete information on the environmental consequences or implications of economic activity. There is an urgent need for new information tools and new metrics if we are to monitor progress toward the development of more ecoefficient economies and long-term sustainability. Indicators should measure the physical dimensions of national economies, not just their financial dimensions.

By its very nature, economic growth poses a fundamental challenge to sustainable development. As long as continued growth in economic output implies continued growth in material inputs to and waste outputs from the economy, there is little hope of limiting the impacts of human activity on the natural environment.

Over the next 50 years, while the world's population is forecast to increase by 50 percent, global economic activity is expected to increase roughly fivefold. Conventional demand studies suggest that global energy consumption is likely to rise nearly threefold and manufacturing activity at least threefold, driven largely by industrialization and infrastructure growth in developing regions. Global throughput of material is also likely to triple, according to conventional projections. These projections indicate that some measure of "decoupling" is probable: that is, the world economy is expected to grow faster than the rate of resource use. However, a 300 percent rise in energy and material use still represents a substantial increase. Unless economic growth can be dramatically decoupled from resource use and waste generation, environmental pressures will increase rapidly.

How will we know whether the necessary degree of decoupling is occurring? How can we design policies to promote decoupling and gauge their effectiveness, sector by sector? Such questions illustrate the case for comprehensive measures of material flows. Good indicators will make it much easier for us to measure physical flows accurately and compare them to economic flows.

In 1997, our first report, *Resource Flows: The Material Basis of Industrial Economies*, documented material inputs to industrial economies and showed that the total material requirement of major OECD countries (Germany, Japan, the Netherlands, and the United States) is currently between 45 and 80 metric tons per capita annually. Except for the relatively modest quantities of materials recycled or added each year to stock in use (largely in the form of infrastructure and durable goods), physical inputs are quickly returned to the environment as pollution or waste, with potential for environmental harm.

This new report completes the material cycle by documenting and analyzing the material output flows for the four original study countries, plus Austria. These countries differ in terms of their size, climate, resource endowment, economic structure, and lifestyles. Yet, patterns of material outputs from their economies to the environment have much in common.

Outputs of some of the materials known to be hazardous to human health or damaging to the environment have been regulated and successfully reduced or stabilized. Examples include sulfur emissions to air and releases of some heavy metals, chlorine, and phosphorus. We have found, however, that many hazardous or potentially hazardous material flows are increasing, especially when they occur during material extraction (for example, mining) or during product use and disposal, rather than at the processing and manufacturing stages. For example, our estimates indicate that flows of fuel-related contaminants to the U.S. environment increased by about 25 percent between 1975 and 1996.

This report shows conclusively that the atmosphere is by far the biggest dumping ground for the wastes of industrial economies. Output flows are dominated by the extraction and use of fossil energy resources: when bulky flows like water, soil erosion and earth moving are excluded, carbon dioxide accounts, on average, for 80 percent by weight of material outflows in the five study countries. There are positive trends. Quantities of solid wastes sent to landfills have stabilized or declined, in some cases by 30 percent or more. Reductions have been achieved thanks to increased recycling efforts and greater use of incineration as a disposal option. This latter practice, however, has resulted in waste outputs being diverted from land to air, contributing further to atmospheric pollution.

To what extent are industrial economies breaking the link between economic growth and material throughput? The evidence for decoupling is either strong or weak, depending on the measure used. Despite strong economic growth over the period 1975–1996, resource inputs and waste outputs rose relatively little on a per capita basis and fell dramatically when measured against units of economic output. Given declining real prices for most resource commodities, and continued subsidies for resource extraction and use in most OECD countries, the extent of decoupling may be regarded as remarkable and possibly symptomatic of profound underlying structural changes in the nature of industrial economies.

However, even as decoupling between economic growth and resource throughput occurred on a per capita and per unit GDP basis, it is important to understand that overall resource use and waste flows into the environment continued to grow. Between 1975 and 1996, total quantities of conventional wastes, emissions, and discharges in the five study countries increased by between 16 percent and 29 percent. Despite the rapid rise of e-commerce and the shift over several decades from heavy industries toward knowledge-based and service industries, we found no evidence of an absolute reduction in resource throughput in any of the countries studied.

Given the likelihood of common economic aspirations in developing and industrialized countries, developing countries can be expected, over time, to attain roughly the same physical basis—the same level of per capita material throughput—as will then be found in economically advanced countries. Only if the level of materials intensity to which industrialized and developing countries eventually converge is substantially below that found in the industrialized countries today can there be hope of mitigating global environmental problems, such as climate change. It is, therefore, clear that efforts at genuine dematerialization have a strong claim on the policy agenda. There is a particular need for accelerated technology transfer from industrialized countries so that developing countries can "leapfrog" older polluting and inefficient technologies.

The findings presented in this report show that, although increasing wealth, technological advances, and economic restructuring in industrialized countries have contributed to significant decoupling between rates of economic growth and material throughput, they have not achieved any overall reduction in resource use or waste volumes. Targeted policies will be needed to accelerate the trend toward dematerialization and to encourage substitution of benign materials for those that are environmentally harmful.

We would like to acknowledge the support of the United States Environmental Protection Agency in making possible WRI's contribution to this joint research effort and the publication of this report. We also acknowledge the financial support of the Swedish International Development Cooperation Agency; the Statistical Office of the European Communities (EUROSTAT); the Netherlands Ministry of Housing, Spatial Planning and the Environment; the Environment Agency of Japan through the Global Environment Research Fund; the Austrian Federal Ministry for Agriculture, Forestry, Environment and Water Management; and the Austrian Federal Ministry for Transport, Innovation and Technology.

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ACKNOWLEDGMENTS

We wish to acknowledge the many individuals who have generously given their time to help us develop the databases that underpin this report. They include staff at the United States Geological Survey; the Federal Environmental Agency of Germany, Berlin; the Central Bureau of Statistics of the Netherlands; the Environment Agency of Japan; and the Austrian Federal Environmental Agency.

The authors wish to thank numerous colleagues who provided helpful comments and information during the course of this study. They include Alan Brewster, John Ehrenfeld, Thomas Graedel, Grecia Matos, Robert Socolow, Anton Steurer, Iddo Wernick and, from within WRI, Duncan Austin, Kevin Baumert, Allen Hammond, Fran Irwin, Tony Janetos, Jim MacKenzie, Janet Ranganathan, and Dan Tunstall.

Special thanks are due to WRI's publications editor Carollyne Hutter, and to Hyacinth Billings and Maggie Powell for their management of the production process.

As before, our work has benefitted immeasurably from that of other researchers, and previous work on materials flow accounting. Materials flow balances for national economies were developed independently at the beginning of the 1990s in Austria,[1, 2] Germany,[3] and Japan.[4] The approach was also applied to the United States, notably in the work of Ayres,[5] Rogich,[6] and Wernick.[7] In Europe, materials flow accounts have already been introduced to official statistics of European Free Trade Area (EFTA) countries and some member states of the European Union.[8] Adopting new approaches for environmental statistics, the German Federal Statistical Office prepared a national materials flow balance in 1995.[9] The Statistical Office of the European Union has affirmed the importance of materials flow analysis (MFA) and supports the further use and development of MFA within the framework of integrated environmental and economic accounting, and as a basis for the derivation of indicators for sustainability.[10] Most recently, the European Environment Agency (EEA) produced an indicator report with headline indicators, most of which correspond to the main input and output categories of a national materials flow balance.

KEY FINDINGS

Industrial economies are becoming more efficient in their use of materials, but waste generation continues to increase.

Despite strong economic growth in all countries studied, resource inputs and waste outputs between 1975 and 1996 rose relatively little, on a per capita basis, and fell dramatically when measured against units of economic output.

Even as decoupling between economic growth and resource throughput occurred on a per capita and per unit GDP basis, however, overall resource use and waste flows into the environment continued to grow. We found no evidence of an absolute reduction in resource throughput.

One half to three quarters of annual resource inputs to industrial economies are returned to the environment as wastes within a year.

Material outputs to the environment from economic activity in the five study countries range from 11 metric tons per person per year in Japan to 25 metric tons per person per year in the United States.

When "hidden flows" are included—flows which do not enter the economy, such as soil erosion, mining overburden, and earth moved during construction—total annual material outputs to the environment range from 21 metric tons per person in Japan to 86 metric tons per person in the United States.

Outputs of some hazardous materials have been regulated and successfully reduced or stabilized but outputs of many potentially harmful materials continue to increase.

Examples of successes include the reduction or stabilization of emissions to air of sulfur compounds and lead from gasoline, phosphorus in detergents, and some heavy metals. Quantities of municipal solid wastes sent to landfills have also stabilized or declined in all countries studied.

Many other hazardous, or potentially hazardous, material flows are poorly controlled because they occur at the extraction phase or the use and disposal phases of the material cycle, which are outside the traditional area of regulatory scrutiny. Our estimates indicate that many potentially hazardous flows in the United States increased by 25 to 100 percent between 1975 and 1996.

The extraction and use of fossil energy resources dominate output flows in all industrial countries.

Modern industrial economies are carbon-based economies. Fossil energy consumption is still rising. Carbon dioxide accounts, on average, for more than 80 percent by weight of material outflows from economic activity in the five study countries. The atmosphere is by far the biggest dumping ground for industrial wastes.

Physical accounts are urgently needed, because our knowledge of resource use and waste outputs is surprisingly limited.

Neither traditional monetary accounts nor environmental statistics are an adequate basis for tracking resource flows into and out of the economy. They record only a part of resource inputs, lose sight of some materials in the course of processing, and entirely miss major flows of materials that do not enter the economy at all, such as soil erosion from cultivated fields.

On the output side, monetary accounts and environmental statistics record few material flows that are not subject to regulation or classified as wastes requiring treatment. Nor do they differentiate among the many materials that are aggregated in products.

1

INTRODUCTION

In the emerging discipline of industrial ecology, researchers view modern economies, metaphorically, as living organisms. Industrial economies "ingest" raw materials, which are "metabolized" to produce goods and services, and they "excrete" wastes in the form of discarded materials and pollution. In 1997, our report *Resource Flows: The Material Basis of Industrial Economies* documented for the first time the total material requirement (TMR) of four industrial economies—Germany, Japan, the Netherlands, and the United States.[1] We showed that national resource requirements include both direct inputs of commodities to the economy and "hidden" flows of materials, which are associated with making those commodities available for economic use but do not themselves enter the economy. Examples of hidden flows are rock and earth moved during construction and soil erosion from cultivated fields. In calculating the TMR, we included all foreign hidden flows of materials associated with imported commodities. Total resource requirements for each study country were shown to be 45 metric tons of material per person annually in Japan, and more than 80 metric tons per person annually in the other three study countries.

The 1997 study of the input side of industrial economies provoked much interest in the policy, academic, and nongovernmental organization (NGO) communities. It demonstrated that physical accounts provide an integrated framework for analyzing flows of materials from the natural environment into the human economic system, in terms of their size, their composition, and their relation to economic growth over time. Today, there is evidence of a growing international momentum to develop physical accounts that can be used in parallel with traditional monetary accounting systems. Our report has helped to stimulate similar research efforts in other countries, including Australia, Brazil, Egypt, Finland, Italy, Malaysia, Poland, Sweden, and the European Union as a whole. A number of European Union countries have established long-term national targets for material and energy efficiency, together with indicators for measuring progress, which is likely to stimulate demand for the collection of materials flow statistics. At the time of writing, the OECD Working Group on the State of the Environment is likely to establish a forum for collaborative efforts on the development and implementation of materials flow models. This forum will provide a focal point for discussions, seminars, and workshops, where interested countries and organizations can exchange information and possibly develop collaborative efforts towards harmonized models.

This report builds on, and complements, our earlier work by presenting the output side of industrial economies. It documents the materials that flow from the human economy back into the environment at every stage of economic activity, from commodity extraction or harvest, through processing and manufacturing, product use, and final disposal. In addition, the report documents materials that do not rapidly exit the economy, but which accumulate as stock in the form of durable goods, buildings, and other infrastructure. Hidden flows are again reported because, in system terms, they represent a simultaneous input and output.

The scope of this new study has been expanded from the first report and now includes Austria in addition to Germany, Japan, the Netherlands, and the United States. Based on the physical accounts developed for each country, we have developed a number of new indicators and measures that (i) summarize national trends in outputs of material to the environment between 1975 and 1996, (ii) show how material output flows have changed in relation to population size and economic activity, and (iii) compare the level of material output flows from different economic sectors (such as industry, transport, and households) and into different environmental media (air, land, and water).

Our first report raised two important questions, one concerning methodology and one concerning policy-relevance, that must be addressed directly.

1. Indicators of materials flow are created by summing the weights of many different materials. We recognize that a few very large flows, such as rock and earth (from mining and construction) and carbon dioxide from fossil fuel combustion, dominate these indicators. Very small flows, such as synthetic organic chemicals or heavy metals, hardly show up. We stress that summing different materials is not intended to imply parity among them. Indicators, such as total material requirement (TMR), or total domestic output (TDO), are presented simply as physical descriptors of the economic system, just as economic indicators like gross domestic product (GDP) are monetary descriptors of the economic system. With this in mind, we have attempted to create "value-neutral" physical accounts that include all materials, regardless of their economic importance or environmental impact. Nevertheless, some subjectivity is unavoidable; we chose to exclude freshwater flows, for example, primarily on the grounds that they are so large they would overwhelm the other data.

2. Highly aggregated indicators of materials flow should not be interpreted as direct indicators of environmental impact. A ton of iron ore is not equivalent to a ton of mercury. Big flows are not automatically bad, and small flows are not automatically better. However, we believe that indicators are useful measures of potential environmental impact. All resource use involves environmental impacts of some kind at every stage of the material cycle from extraction or harvesting to final disposal. Unless technologies are changed dramatically, increases in resource throughput imply increases in environmental impacts. Therefore, indicators of materials flow that tell us whether overall

resource throughput is rising or falling, and whether national economies are becoming more or less efficient in their use of resources, are valuable starting points for analysis. Indicators help to determine strategy. We recognize that it is at the level of sub accounts—the examination of specific material flows, and categories of like flows—that materials flow analysis will have most relevance to detailed policy-making.

This report takes some steps toward examining the links between material flows and their environmental impacts. In addition to documenting quantities of material outputs, we develop a system of flow characterization that allows flows to be disaggregated according to their medium of entry into the environment (flows to air, land, and water), and by their mode of use. We focus on dissipative flows, where nonrecoverable dispersion into the environment is an inherent quality of product function, as is the case with pesticide sprays. We document a number of small but high impact flows, such as those of heavy metals and other hazardous substances. Finally, we develop a detailed, pilot characterization scheme for material output flows in the United States. This scheme enables us to identify flows according to their physical and chemical characteristics, as well as their medium of entry into the environment, and their residence time in the economy; details are provided in the U.S. country report. (*See Annex 2.*)

Subsequent sections of the report set out the approach and methodology for our study, present the main findings, and provide practical illustrations of how documentation of physical outputs to the environment can directly assist in policy formulation. A summary of the data underlying the indicators presented in this report can be found in Annex 1. More detailed descriptions of material output flows in each of the study countries are provided in Annex 2.

2

APPROACH AND METHODOLOGY

Our first report, which documented total resource requirements in four industrial economies, established a number of goals for any subsequent report. These goals were to

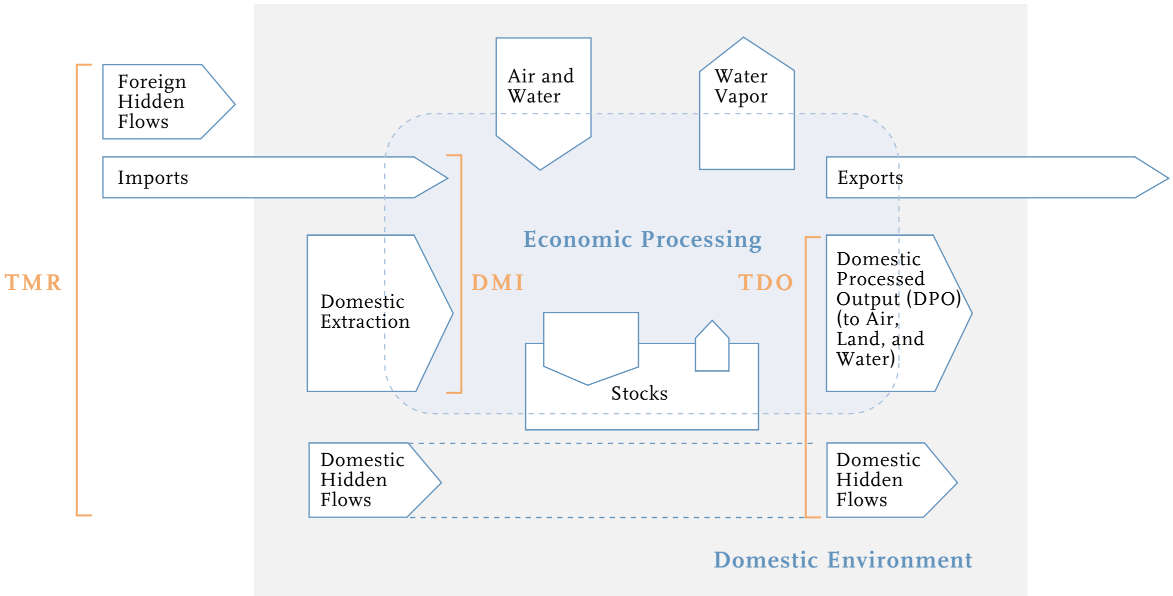
- provide a more complete accounting system and develop aggregate indicators for the output side of material flows;
- compare total material requirements (including imports) with total material outputs (including exports) to allow creation of national flow accounts;
- focus on the roles of economic sectors in the material cycle;
- separate domestic and foreign flows, to avoid double counting as the number of countries developing physical accounts grows; and
- develop a materials flow characterization scheme to distinguish better the quality and potential environmental impact of flows.

Our present methodology provides a conceptual model of the complete material cycle in the industrial economy. It documents the quantity and composition of physical outputs to the environment generated by five industrial economies, and develops indicators that relate the size of material output flows to population and economic growth over time. Information is also provided on the environmental media to which material flows are released, and on the share of outputs generated by different economic sectors.

2.1 THE MATERIAL CYCLE

Figure 1 is a schematic representation of material flows through the modern industrial economy. The left-hand side of the chart indicates the flows documented in our 1997 report—the input side of the economy. The right-hand side of the chart covers the flows documented in the present report—the output side of the economy. We also document materials that are retained in the economy in the form of infrastructure and long-lived durable goods (stocks).

FIGURE 1 THE MATERIAL CYCLE



TMR (Total Material Requirement)=DMI+Domestic Hidden Flows+Foreign Hidden Flows

DMI (Direct Material Input)=Domestic Extraction+Imports

NAS (Net Additions to Stock)=DMI–DPO–Exports

TDO (Total Domestic Output)=DPO+Domestic Hidden Flows

DPO (Domestic Processed Output)=DMI–Net Additions to Stock–Exports

Note: The system boundary of our materials flow studies is the interface between the natural environment and the human economy. Materials cross the boundary into the economy when they are purchased. Materials recross the boundary back into the environment when they are no longer available to play a role in the economy. Hidden flows are not purchased; they never enter the economy, nor do they leave it. But these flows occur and should be included in an accounting scheme. Classifying hidden flows as a simultaneous input to and output from the economy is a convention that enables these flows to be measured in an accounting year, without creating an imbalance on either the input or output side of the accounts.

All countries obtain physical inputs from their domestic environments, and from other countries, via imports of commodities, semimanufactures, and finished goods. These inputs are transformed in a materials cycle (via economic processes) into the following: materials that accumulate in the economy as net additions to stock in the form of long-lived durable goods and infrastructure; outputs to the environment in the form of wastes, emissions, discharges, system losses, and dissipative flows; and exports to other countries. Outputs to the environment occur at every stage of the material cycle, from extraction to final disposal. In some cases, an output is avoided by recapturing wastes, which are returned to an earlier step in the material cycle. For example, many metals are recycled. In other cases, the economic system chooses to release materials to the environment as controlled wastes. In still other cases, the nature of the losses and uses of a material preclude recapture (system losses, dissipative flows).

In our previous study, we examined the total material requirement (TMR) of a country's economy. That study, which focused on defining the total inputs to the economy, did not subtract exports and included the hidden flows that occurred in foreign countries in the course of producing goods that the study countries then imported. In the present study, imports are included in the materials that contribute to domestic outputs to the environment, but foreign hidden flows (flows associated with production of commodities imported by the study countries) are excluded. Exports from the study countries are excluded from the calculation of total domestic output (TDO), because exported materials become wastes in another country. However, some portion of TDO (for example, some air-borne and water-borne pollutants) may ultimately affect other countries' environments. These flows have not been separately estimated in this study.

2.2 ACCOUNTING FOR OUTPUT FLOWS

By analyzing the output side of the material cycle, we can learn a number of things about the potential environmental burden of material outflows.

Industrial economies are ultimately once-through systems. One critical variable is the total quantity of materials flowing out of the economy in a year. We call the annual material outflows from a domestic economy to the environment the "domestic processed output" (DPO). This report shows that DPO in each of the study countries ranges from 11 metric tons per person in Japan to more than 25 metric tons per person in the United States. The flows that constitute DPO correspond roughly to conventionally described wastes, emissions, and discharges in official statistics, although our data are more complete. When domestic hidden flows are added to DPO, the summed annual outputs are called the "total domestic output" (TDO). TDO ranges from 21 metric tons per person in Japan to 86 metric tons per person in the United States.

A second critical variable is the average retention time of materials in the economy, which is increased by such practices as recycling and reuse. Our study indicates that between one half and three quarters of direct material inputs pass through the economies of the study countries and out into the environment within a year. The material that is retained in the economy for a longer period, in the form of durable goods and physical infrastructure, is called the "net addition to stock" (NAS). All stock materials eventually become waste outflows, too.

A third critical variable is the destination of output flows within the environment. We disaggregate material outflows according to their first point of entry to the environment, which we call the "environmental gateway." Our study shows that there has been a steady increase in the share of outflows to the atmosphere and a corresponding decrease in the share of flows going to land and water. It should be noted that, while this study disaggregates these material flows according to the medium by which they enter the environment, it documents flows only up to this first point of entry. It does not track secondary deposition, such as nitrogen flows from fertilized land to water, or sulfur flows from air to land.

Material output flows can be analyzed further, according to their source (the economic sector directly responsible for the output) or their mode of dispersal (we focus here on dissipative flows, in which material dispersal into the environment is an unavoidable or necessary consequence of product use). Box 1 presents summary definitions of the indicators developed for this study and the various ways in which we disaggregate the physical accounts.

BOX 1 | ## DEFINITIONS OF INDICATORS AND OUTPUT FLOWS

Domestic Processed Output (DPO): the total weight of materials, extracted from the domestic environment and imported from other countries, which have been *used in the domestic economy*, then flow to the domestic environment. These flows occur at the processing, manufacturing, use, and final disposal stages of the economic production-consumption chain. Exported materials are excluded because their wastes occur in other countries. Included in DPO are emissions to air from commercial energy combustion (including bunker fuels) and other industrial processes, industrial and household wastes deposited in landfills, material loads in wastewater, materials dispersed into the environment as a result of product use (see dissipative flows below), and emissions from incineration plants. Recycled material flows in the economy (e.g., metals, paper, and glass) are subtracted from DPO. Note that an uncertain fraction of some dissipative use flows (manure, fertilizer) is recycled by plant growth, but no attempt has been made to estimate this fraction and subtract it from DPO.

Domestic Hidden Flows (DHF): the total weight of materials moved or mobilized in the domestic environment in the course of providing commodities for economic use, which *do not themselves enter the economy*. Hidden flows occur at the harvesting or extraction stage of the material cycle. They comprise two components: ancillary flows (for example, plant and forest biomass that is removed from the land along with logs and grain, but is later separated from the desired material before further processing), and excavated and/or disturbed material flows (for example, overburden that must be removed to permit access to an ore body, and soil erosion that results from agriculture). For purposes of aggregation, both categories have been combined into the single category of domestic hidden flows, although their environmental impacts may be different. Hidden flows were also accounted for as part of the total material requirement (TMR) of industrial economies. For the purposes of physical accounting—in system terminology—hidden flows represent a simultaneous input and output.

Total Domestic Output (TDO): the sum of domestic processed output and domestic hidden flows. This indicator represents the total quantity of material outputs to the domestic environment caused directly or indirectly by human economic activity.

Gateway Flows: the share of DPO, or TDO, which exits the economy by each of three environmental gateways, namely, air, land, and water. Gateways are the first point of entry of a material flow into the environment; this study does not account for secondary deposition. Both domestic processed output and total domestic output can be disaggregated to show the quantity, and major constituents, of material flows to air, land, and water; gateway flows are a means of differentiating material flows in order to provide more information about their potential environmental impacts.

Sector Flows: the share of DPO, or TDO, which can directly be attributed to the activities of individual economic sectors. This report documents outputs from the industry (manufacturing and mining), agriculture, energy supply (utilities), construction, transport, and household sectors in each of the study countries. Outputs from combustion

BOX 1 (CONTINUED)

processes, including energy use, have been attributed to different economic sectors, including utilities, based on the location of direct output flows. Hidden flows associated with all forms of mining (including coal mining) have been attributed to the industry sector. Both domestic processed output and total domestic output can be disaggregated to show the quantity of material output generated by each sector.

Dissipative Flows: the quantity (weight) of materials dispersed into the environment as a deliberate, or unavoidable (with current technology), consequence of product use. These flows comprise two components: dissipative uses (for example, fertilizers and manure spread on fields, and salt spread on roads) and dissipative losses (for example, rubber worn away from car tires, particles worn from friction products, such as brakes and clutches, and solvents used in paints or other coatings). Dissipative uses can be part of an ultimate throughput flow, e.g., mineral fertilizer, or part of recycling, e.g., manure, compost, and sewage applied on fields for nutrient recycling.

Net Additions to Stock (NAS): The quantity (weight) of new construction materials used in buildings and other infrastructure, and materials incorporated into new durable goods, such as cars, industrial machinery, and household appliances. New materials are added to the economy's stock each year (gross additions) and old materials are removed from stock as buildings are demolished and durable goods discarded. These decommissioned materials, if not recycled, are accounted for in DPO. The balance is the net addition to stock. For all study countries other than the United States, NAS is calculated indirectly as the balancing item between the annual flow of materials that enter the economy (direct material input), plus air inputs (e.g., for oxidization processes), minus domestic processed output, water vapor, and exports. In the case of the United States, net additions to stock are calculated directly as gross additions to stock, minus the material outputs of decommissioned building materials (as construction and demolition wastes), disposed durable goods, and materials recycled.

2.3 WHAT'S IN AND WHAT'S OUT

This report seeks to present comprehensive physical accounts for the five study countries, but we had to make some essentially subjective decisions about system boundaries.

Water flows are excluded from this study, with some exceptions noted below, for a number of reasons. Water flows are so large that they would completely dominate all other material flows and would obscure the meaning and, thus, the usefulness of the indicators. Secondly, while the extraction of water from aquifers, groundwater reserves, rivers, and lakes may create environmental problems at the local or regional level, problems depend largely on the availability of water, which varies considerably among regions. National level data on mass flows of water are not particularly useful. A set of physical accounts developed at the regional or sectoral level, particularly if supplemented with geographic information systems analysis, should include data on water flows. Thirdly, current data are inadequate to track the role of water flows as the transport medium for pollutants in some of the study countries. Contaminants in water flows have been recorded where possible, but data are less complete than those for air pollutants.

Water is included in this study only where it is present as an embedded component of materials (for example, fuels) and where it is part of the fresh weight of certain outputs (for example, municipal wastes, where it is difficult to exclude it with any accuracy). Agricultural grains, feedstuffs, wood products, sewage, and manure, however, are accounted for at a standardized low water content weight. Water vapor, a major outflow from fossil fuel combustion, and human and livestock respiration, is documented in the country reports (*see Annex 2*),[12] but is not included in our indicators.

Oxygen is drawn from the atmosphere during fossil fuel combustion and other industrial chemical reactions; it accounts for at least 20 percent by weight of material inputs to industrial economies. Oxygen was accounted for in our 1997 study as part of the materials balance calculated for Germany and the Netherlands, but it was not included in the indicators of input to industrial economies (TMR and DMI). In this study, we take a different approach. In the course of industrial processes, oxygen binds to other elements, such as carbon, nitrogen, sulfur, and hydrogen, and is emitted back to the atmosphere in the form of combustion and processing waste products. These waste products include carbon dioxide, oxides of nitrogen, sulfur dioxide, and water vapor, among others. Oxygen in itself is an almost constant additive on the input and the output sides of the material balance. However, in binding to other elements, it becomes a constituent of important environmental pollutants. We have, therefore, chosen to include oxygen in emissions from industrial processes in our output indicators.

In addition to its role in industrial processes, oxygen is also inhaled during human and livestock respiration and exhaled as carbon dioxide and water vapor. For information value, respiration emissions have been calculated and are presented in the comprehensive materials flow balance for Germany (*see p. 37*), and in the country reports for Austria, Germany, Japan, and the Netherlands. However, respiration-related emissions are not included in the indicators presented in the main report. Emissions from human and animal respiration are assumed to be approximately balanced by plant photosynthesis.

2.4 CHARACTERIZING MATERIAL FLOWS

This report does not attempt to show the relative environmental impacts of material flows by using a weighting or scoring system. With a few exceptions, material flows cannot be assigned values indicating that they are good or bad. Impacts depend on a material's form and a material's fate, that is, where it ends up. Nitrogen absorbed in agricultural plant tissue is good, nitrogen dissolved in groundwater may be bad. Asbestos bound in concrete is harmless, asbestos in human lungs is harmful. Material flows follow complex paths, and one weighting value cannot adequately capture the full picture. More importantly, it is not the purpose of accounting systems to prejudge complicated issues by providing answers: rather, they should provide information that enables people to ask the right questions.

To this end, we have identified material outputs according to various characteristics, to permit their disaggregation into the categories outlined above: outflows to air, land, and water; outflows exiting the economy within one year of entry; outflows remaining in the economy for more than one year; and dissipative outflows. These categories permit a number of policy-relevant questions: Which materials flow to land, to water, and to air, and in what quantities? Which materials are dissipated into the environment with no or limited possibility of recovery? How much material is potentially recoverable and recyclable? How much toxic and hazardous material flows to the environment each year?[13] And how are these outputs changing over time?

These are basic questions. It is our hope that researchers using these data will improve on them, for example, by developing sophisticated weighting schemes applicable to single material pathways or conducting environmental and social cost-benefit analyses on the impacts of specific flows. We have taken a first step in this direction by developing a more detailed pilot characterization scheme for the U.S. materials database. This scheme assigns values to the 460 material flows documented, based on a range of physical and chemical characteristics, as well as their residence time in the economy and their mode of entry to the environment. (*See U.S. country report.*) These values do not correlate with any degree of environmental impact. Their purpose is to enable users to identify and search for quantities of materials of specific interest. (An example might be a database search to identify material outputs between 1975 and 1996 that are: unprocessed but chemically active, resident in the economy for less than two years, and dispersed directly on land in solid, partially solid, or liquid form.)

2.5 DATA ACCESS AND QUALITY

The national physical accounts databases on which this report is based, along with detailed technical notes and sources, can be accessed on the Internet via the home pages of our institutions (*see p. 125*). The indicators presented in this report were developed using data obtained from national statistics on wastes and emissions, and estimates based on use information. The reliability of the data and the methods used varied by country and material. In some cases, modeled estimates supplemented missing or incomplete data. The comprehensive nature of national statistics on emissions and wastes for countries other than the United States and Japan made them the source for the majority of these countries' data. For the United States, data on outputs were derived from statistics on production, net imports, and recycling, coupled with disaggregated information on how commodities were used. Consistent data sources and methods were used for the entire 1975–96 time frame. While some data were available on hidden flows, for the most part hidden flow quantities were estimated on the basis of national average statistics, engineering practice, and the scale of the activity producing the hidden flow.

Our experience with using official statistics as the basis for compiling national physical accounts leads us to the following conclusions:

- In the European countries studied, good quality data are available on waste. However, in all the countries studied, we had to supplement official statistics to provide complete time series from 1975 to 1996 on waste disposal in controlled landfills. The Netherlands appears to have the most comprehensive data. In Austria and Germany, official sources provided the basis for study estimates. In Germany, future waste statistics will probably provide more complete information for national material flow accounts. In the United States, official governmental statistics are insufficient and in most cases served only indirectly as a basis for study estimates. In Japan, official sources provide good time-series data for municipal wastes disposal, but data on industrial wastes are of inadequate quality.

- Emissions to air are adequately documented in official statistics for CO_2, SO_2, and NO_2 in all the study countries. Except in Germany, emissions of CFCs and halons were not represented in official data. The current study extends official reports by including bunker fuel emissions in national data.

- Emissions of substances to water are small in quantity, relative to other emissions. Nevertheless, accounting for emissions to water appears to be underdeveloped given the range of substances discharged. Also, information on the temporal trend indicating possible developments of nonpoint source releases and the effectiveness of sewage treatment is lacking in study countries other than the Netherlands.

- Among dissipative material outflows, those representing recycling flows, such as manure, compost, and sewage sludges spread on agricultural land, are well documented in official statistics. Among the throughput flows, mineral fertilizers and pesticides are also recorded in official statistics. Minor flows, such as the use of grit materials on roads, are insufficiently documented, except in the United States. Materials used for other purposes were considered only in the country studies of Germany and the United States. Dissipative losses were accounted for by Austria, Germany, and the United States.

- Until recently, hidden flows have been ignored in official data. There is now increasing recognition of their importance. Overburden from mining has been included in waste statistics in Germany since 1993; the Austrian Environmental Policy Plan (1995) mentions hidden flows but does not provide data, which are only now being prepared. The Japanese Environmental Year Book of 1998 also records hidden flows. No mention is yet made of hidden flows in official data sources in either the Netherlands or the United States. Among hidden domestic flows, we could quantify soil excavation for all five countries in this study. Generally, official statistics provided the basis for our estimates. We were able to account for most mining wastes directly from official statistics in all countries except the United States, where we had to make estimates. Dredging wastes are adequately reported in Germany, the Netherlands, and the United States. Although soil erosion from cultivated land represents a major environmental concern, we were obliged to estimate quantities for most countries. The United States was the exception, where the Department of Agriculture provides official estimates of soil erosion. Data for soil erosion and dredging wastes were not available, or estimated, for Austria.

2.6 THE IMPORTANCE OF PHYSICAL ACCOUNTS IN UNDERSTANDING MATERIAL FLOWS

Physical accounts are commonly used to track inputs and outputs in the mining sector, in many industries at the sector and firm level, and even in households (for example, units of energy consumption). Physical accounting is the norm in plant operations. However, at the national level, physical accounts are either absent or are compiled only for a limited number of natural resources, using methodologies that are not comparable across sectors or among countries.

Traditional monetary accounts are not an adequate basis for tracking material flows. They record only a part of resource inputs, lose sight of some materials in the course of processing (for example, in the United States, lead "disappears" in monetary terms when it is incorporated into glass products), and miss many hidden flows entirely.[14] Monetary accounts record few material output flows that are not subject to regulation or classified as wastes requiring treatment; nor do they differentiate among the myriad materials that are aggregated in products. Although attempts to attach monetary values to output flows (pricing externalities) are useful, these methodologies remain subjective and controversial. They clearly are relevant for prioritizing clean-up and remediation efforts relating to specific flows, but are of less value in characterizing mass flows.

Current environmental statistics and monitoring policies do not capture the whole picture of material flows either. Environmental policy tends to focus on specific materials known to be harmful to the environment or human health at specific stages of their life cycle. Regulations and economic instruments seek to prevent or mitigate certain impacts, but they rarely take sufficient account of upstream or downstream effects. Comprehensive, integrated physical accounts, covering the entire material cycle, permit the formulation of environmental and economic policy based on the big picture. Such an approach allows us to pinpoint where flows of a harmful material are concentrated, where they originate, and where they end up. It also helps to identify which activities or products are primarily responsible for these flows and to devise interventions which stand the best chance of being environmentally effective and economically efficient.

3

STUDY FINDINGS

This chapter presents an overview of material outflows in the five study countries. It documents current levels of material outflows, analyzes the composition of these flows, reviews 21-year trends in the indicators TDO, DPO, and NAS, and draws comparisons among the five study countries through the use of per capita data. The study findings provide policy-relevant information about the links between economic growth and population growth, economic structure, quantities and types of material outputs, and the fate of materials in the economy or the environment. The findings also help to explain how and why patterns of material outputs are changing over time. For ease of comparison, summary tables of the data discussed in the following pages are presented in Annex 1. Annex 2 provides more detailed analyses of material flows in each country.

3.1 TOTAL DOMESTIC OUTPUT (TDO)

Total domestic output (TDO) is the aggregate measure of domestic processed output (material outflows from the economy) plus domestic hidden flows (which do not enter the economy). It represents the total quantity of material outputs and material displacement within national borders and is the best proxy indicator of overall potential output-related environmental impacts in each country.

TDO varies widely among the study countries: 23 billion metric tons in the United States; 3.5 billion metric tons in Germany; 2.6 billion metric tons in Japan; 381 million metric tons in the Netherlands; and 171 million metric tons in Austria. These differences are due in large part to disparities in the size of domestic hidden flows, which are dominated by mining overburden (in those countries with a significant mining sector), earth moved during construction, and soil erosion from cultivated fields. The size of national hidden flows is, therefore, closely linked to the presence or absence of a mining sector, the country's geographic scale (which determines the size of infrastructure and related earth moving), and the scale and type of agriculture (which influences soil erosion). Uniquely, dredging wastes—the bulk of which are landfilled or deposited in open waters—are the largest hidden flow in the Netherlands.

The relative dependence of an economy on imports also significantly affects the size of total domestic output. For example, the United States and Germany produce many of their own mineral resources, and hidden flows associated with domestic mining activities (such as overburden and waste ore) are included in the TDO of these countries. Austria, Japan, and the Netherlands, by contrast, import most of their mineral requirements, and mining flows occurring in the exporting countries (foreign hidden flows) are not included in TDO reported for these three study countries.[15]

Material output flows are not closely correlated with the size of a national economy, but there is a relationship between the two. Figure 2 compares TDO in the study countries on a per capita basis. Table 1 provides information on the absolute and relative sizes of each country's economy, total domestic output, and domestic processed output. The relationship between size of economy and size of outflows is noticeably closer between GDP and DPO. The United States is exceptional, generating larger material flows than might be expected from the size of its economy, even when hidden flows are excluded.

TRENDS IN TOTAL DOMESTIC OUTPUT (TDO)

In most study countries, TDO did not change substantially between 1975 and 1996. Total outputs fell by 5 percent in Austria, and rose by less than 3 percent in the Netherlands and the United States. For Germany, data before reunification of the country in 1990 refer to the Federal Republic of Germany only. After reunification, there was a significant decline in TDO. (*See Figure 3*.) Only Japan experienced an increase in TDO of 19 percent; the most significant difference from other countries being an atypical increase of 18 percent in hidden flows. Domestic hidden flows in Japan are caused primarily by large, publicly funded construction programs.

The otherwise relatively stable pattern in TDO is attributable primarily to national reductions in domestic hidden flows, offset to a greater or lesser extent by increases in flows of domestic processed output from the economy. The United States substantially reduced its rates of soil erosion after imple-

TABLE 1 THE RELATION BETWEEN MONETARY AND MATERIAL OUTPUT FLOWS, 1996

Country	GDP		DPO		TDO	
	Billion $US	Ratio	Million Metric Tons	Ratio	Million Metric Tons	Ratio
Austria	235.3	1.0	100.8	1.0	171.3	1.0
Netherlands	410.5	1.7	281.3	2.8	381.1	2.2
Germany	2,446.6	10.4	1,074.7	10.7	3,492.2	20.4
Japan	5,338.9	22.7	1,406.5	14.0	2,632.1	15.4
United States	7,390.6	31.4	6,773.8	67.0	23,261.0	135.8

Note: GDP for all countries is expressed in 1996 U.S. dollars, based on data provided in *World Bank Development Indicators, 1999* (Washington D.C.: World Bank, 1999).

FIGURE 2

TOTAL DOMESTIC OUTPUT (TDO), 1996

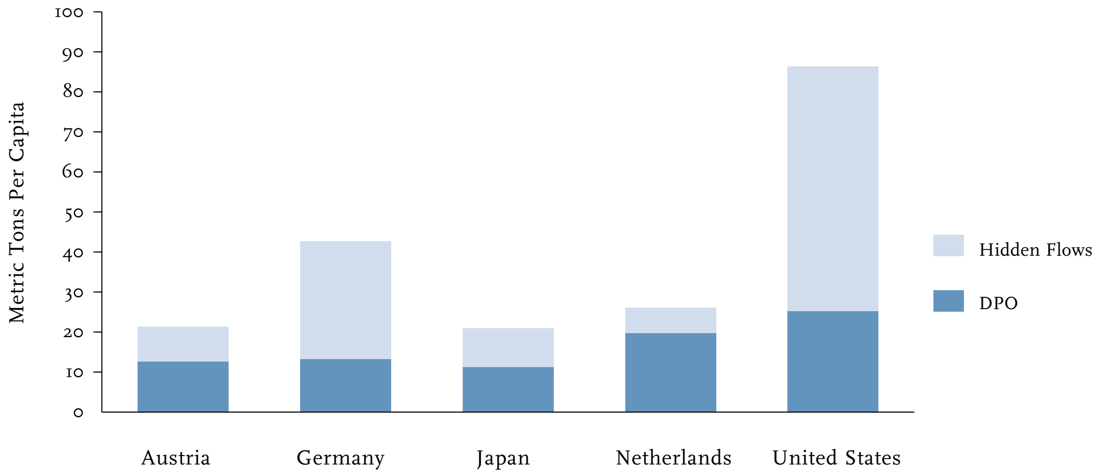
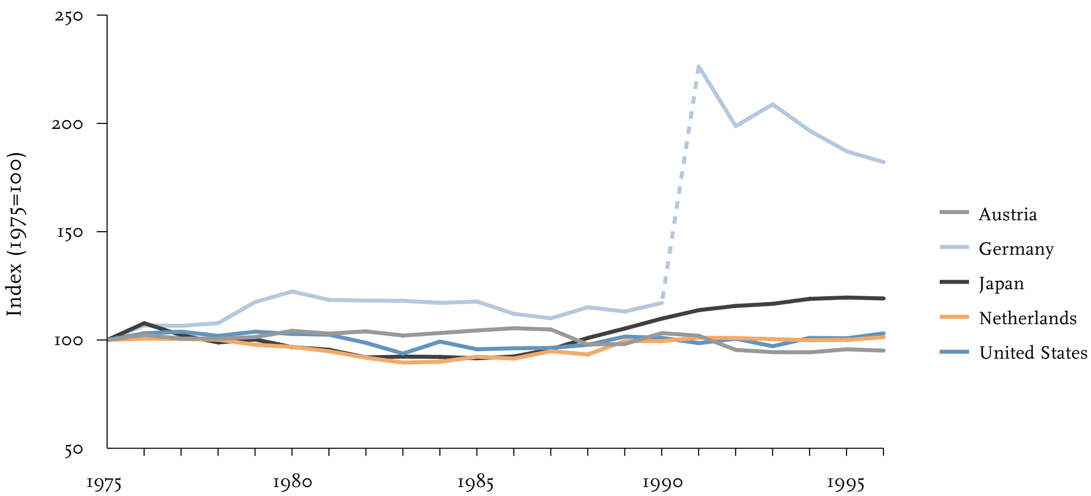


FIGURE 3

TRENDS IN TDO, 1975–1996 (INDEX)



menting the Conservation Reserve Program, although this trend was countered by an increase in the amount of overburden and gangue from mining activity. Austria and Germany achieved dramatic reductions in quantities of overburden as lignite mining was scaled back, which more than offset increases in construction-related earth moving. In the Netherlands, lower rates of soil erosion and a steep fall in the quantities of earth moved during construction, possibly because of completion of the national road network, reduced hidden flows by more than 25 percent.

BOX 2

MATERIAL OUTFLOWS AND ENVIRONMENTAL DEGRADATION

Economic activity transforms materials into different physical and chemical forms or mobilizes them in ways that may be hazardous to human health, toxic in the environment, or disruptive of biogeochemical cycles. Useful carbon enters the economy as coal, gas, or oil, is burned, and exits as climate-changing carbon dioxide. Zinc or mercury are safe enough until they are mined and dispersed into air, soil, or water. Nitrogen, the most abundant gas in the atmosphere, is fixed by a variety of human actions and transformed into nitrogen gases that contribute to global warming, acid rain, and depletion of the ozone layer, and into nutrients that, in excess quantities, stimulate eutrophication and algal blooms and contaminate drinking water. The scale of modern industrial activity, even today, when four fifths of the world is still relatively non-industrialized, is great enough to have changed significantly the natural global cycles of carbon and nitrogen. The atmospheric concentration of carbon dioxide has risen from 280 parts per million (ppm) in preindustrial times to 367 ppm today.[16] The rate of nitrogen fixation, thanks to fertilizer manufacture and fossil fuel combustion, is now double the preindustrial rate.[17]

Domestic Hidden Flows, which never enter the economy as traded commodities, represent the displacement of materials from their original position in the environment to another. Some degradation or landscape alteration is often involved, as when earth is excavated during construction. Hidden flows may also involve physical or chemical transformation. Topsoil, excavated and displaced, loses much of its structure and natural fertility; soil eroded from cultivated fields is of little further use once transformed into sediment in rivers.[18] Hazardous chemicals, such as selenium, may be leached from overburden when rock and earth are newly exposed to air, and sulphide rocks can contribute to acid mine drainage.

3.2 DOMESTIC PROCESSED OUTPUT (DPO)

Domestic processed output (DPO) comprises solid wastes, and liquid and gaseous emissions and discharges; these flows are partially captured in official national statistics, though many individual flows are missed. The DPO indicator is more directly comparable across the study countries, because it captures the economic activities common to all and excludes the highly variable hidden flows. On a per capita basis, the quantities of domestic processed output generated in each country vary at most by a factor of just over two. (*See Figure 2.*)

Trends in DPO: Growth and Decoupling

In marked contrast to the relative stability of TDO, domestic processed output in four of the five countries has risen by between 16 percent and 28 percent since 1975. (*See Figure 4a.*) The exception is Germany, where DPO rose slightly and fell again between 1975 and reunification in 1990, and has fallen from its new higher level since then. This atypical pattern was largely because of fuel-switching away from high-carbon energy sources, which reduced emissions of carbon dioxide. The shift to lower-carbon oil and gas occurred earlier in the other study countries; therefore, their gains in carbon efficiency are less pronounced during the study period.

Economic growth in all study countries was strong over the same 21-year period. GDP grew by between 62 percent in the Netherlands and 106 percent in Japan. At first glance, therefore, we see considerable decoupling between economic growth and generation of material outflows. (*See Figure 4b.*) The materials outflow intensity (DPO/GDP) of all five countries has fallen impressively since 1975, although the trend appears to have slowed in recent years. Decoupling is partly the result of successful attempts to reduce waste volumes, especially landfilled wastes, and to increase recycling. (*See section 3.4.*) Decoupling appears to owe more to efficiency improvements and the ongoing shift away from traditional energy- and material-intensive industries toward knowledge-intensive industries, and the financial and other service sectors. As one example, the share of Japan's GDP contributed by the manufacturing sector fell from 30 to 24 percent between 1975 and 1996, while the share of the services sector rose from 52 to 60 percent.[19] Shifts within sectors, from heavy industries to high technology industries, for example, are still more pronounced.

In spite of the trend toward decoupling between economic growth and material output, progress is less evident at the more tangible level of material outputs per person. Figure 4c displays erratic and contrasting trends, reflecting cycles of economic recession and prosperity and changing population structures. At the end of the 21-year period, however, per capita domestic processed output had declined slightly in only one country, Germany, and had increased in all the others. This means that the average citizen in the study countries generates slightly more waste outputs today than he or she did in 1975.

FIGURE 4a | DOMESTIC MATERIAL OUTPUT (DPO), 1975–1996 (INDEX)

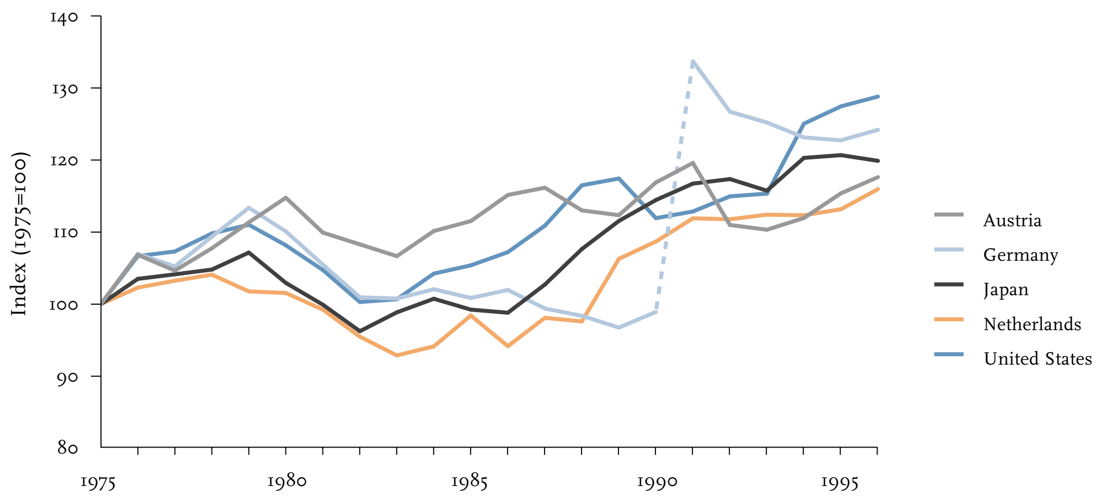


FIGURE 4b | MATERIAL OUTFLOW INTENSITY (DPO/GDP), 1975–1996 (INDEX)

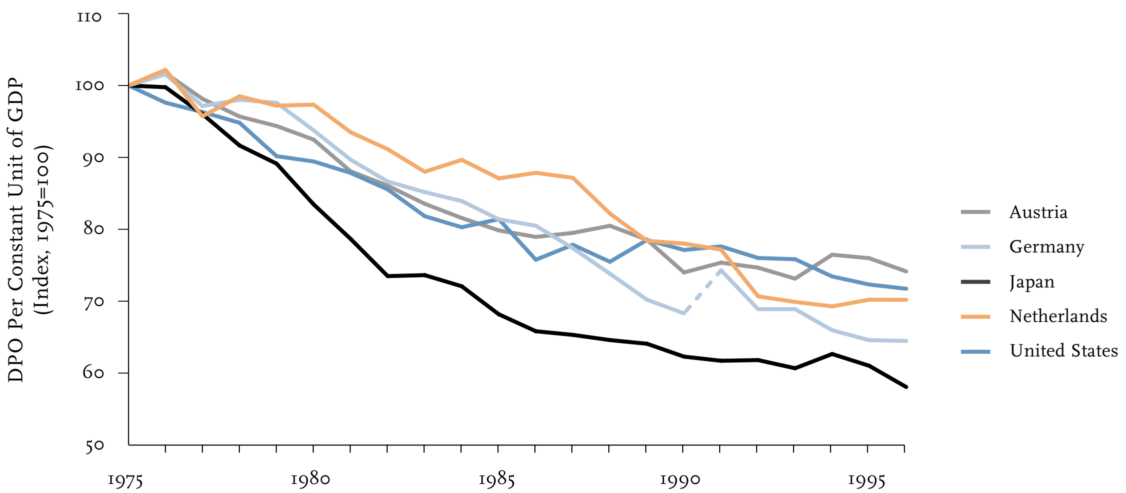


FIGURE 4c

MATERIAL OUTFLOW INTENSITY (DPO PER CAPITA), 1975–1996 (INDEX)

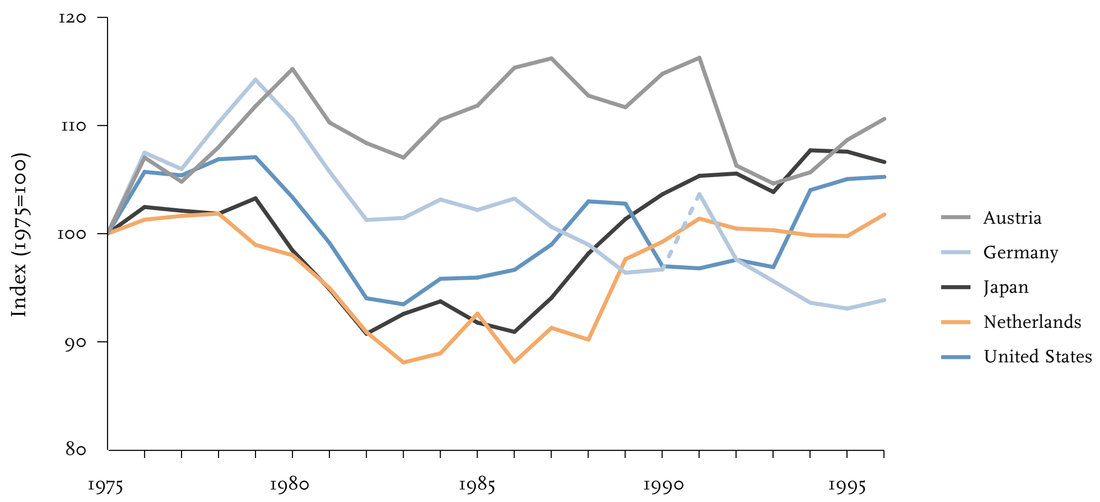


Table 2 presents the absolute values behind these 21-year trends: increases in DPO and GDP, decoupling between DPO and economic growth, and less pronounced decoupling between DPO and population growth.

These findings indicate that technological progress and restructuring toward service-based economies in the study countries have substantially weakened the link between economic growth and resource throughput. The development of new patterns of economic growth, such as e-commerce, may weaken the link further. However, actual dematerialization has not been achieved. We see here that, despite decoupling between growth rates in GDP and material throughput, quantities of wastes and emissions generated by the study countries have increased in absolute terms over the 21-year study period. On a per capita basis, some countries achieved modest decoupling during the 1980s, only to lose their gains in the more prosperous 1990s. (Stronger decoupling in Germany is explained largely by the unusual and temporary circumstance of declining carbon dioxide emissions).

Part of the explanation for the continued increase in overall waste quantities lies in the fact that traditional industries, despite their declining relative economic importance, are not necessarily declining in terms of their physical operations. In addition, even economies with sophisticated high technology sectors continue to use older generation, inefficient technologies where they represent low-cost options. For example, the United

States still makes use of old, coal-fired power stations, and poorly insulated houses remain the norm in the construction sector. Finally, cultural factors and consumption choices have helped to offset the real efficiency gains that have been made in industry. Consumer lifestyles have changed over the past quarter-century and affluence, for the most part, has encouraged more material acquisition, more mobility, and a preference for convenience and product disposability. In the absence of further policy incentives, structural economic change and technological efficiency gains alone appear unlikely to bring about a real reduction in resource use and waste outputs.

TABLE 2 **COMPARISON OF TRENDS IN ECONOMIC AND POPULATION GROWTH, AND DOMESTIC PROCESSED OUTPUT (DPO), 1975–1996**

Country		Population (millions)	DPO (million metric tons)	GDP (own currency *See notes*)	DPO/GDP (metric tons per million constant monetary units, own currency)	DPO/Capita (metric tons per capita)
Austria	1975	7.6	85.7	1,441.0	0.059	11.3
	1996	8.1	100.8	2,415.0	0.042	12.5
	% change	+6	+18	+68	−29	+10
Germany[1]	1975	61.8	865.3	1,838.5	0.47	14.0
	1996	81.8	1,074.7	3,541.5	0.30	13.1
	% change	+32	+24	+93	−36	−6
Japan	1975	111.9	1,173.0	244.3	4.80	10.5
	1996	125.9	1,406.5	504.4	2.78	11.2
	% change	+13	+20	+106	−42	+7
Netherlands	1975	13.6	242.6	413.0	0.59	17.8
	1996	15.5	281.3	667.6	0.42	18.1
	% change	+14	+16	+62	−29	+2
United States	1975	220.2	5,258.7	4,253.9	1.24	23.9
	1996	269.4	6,773.8	7,390.6	0.92	25.1
	% change	+23	+28	+74	−26	+5

Notes:
1 All data for Germany are affected by reunification in 1990, which increased the population of the country by 26 percent, GDP by 24 percent, and DPO by 35 percent.
GDP expressed in billion constant 1996 Austrian Schillings (Austria), billion constant 1996 Deutsch Marks (Germany), billion constant 1996 Yen (Japan), billion constant 1996 Guilders (Netherlands), and billion constant 1996 U.S. Dollars (United States).
U.S. GDP is based on World Bank data.[20]

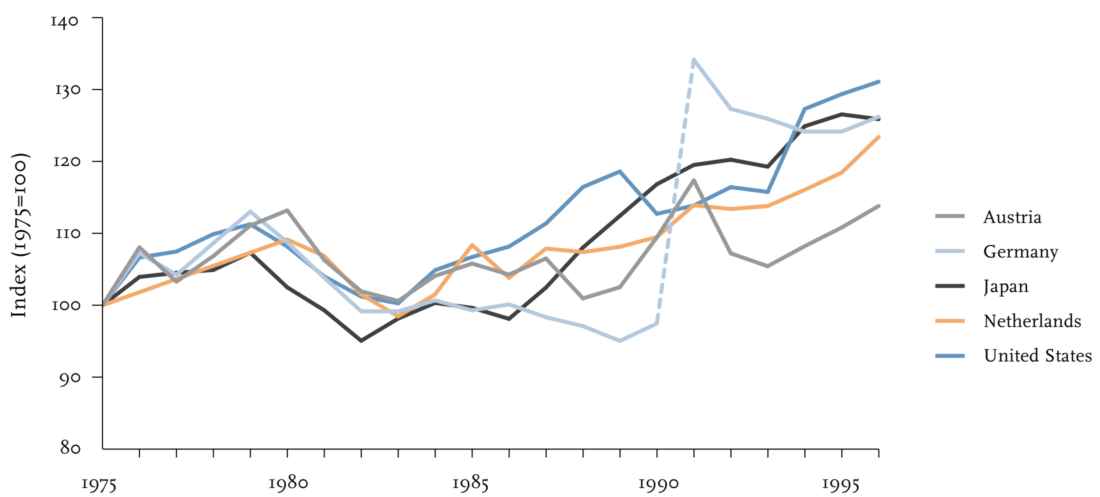
Trends in DPO: Composition

The composition of DPO is complex and dynamic over time. Data on the overall increase in DPO since 1975 conceal important changes in the size of individual flows (what's going up, what's going down) and changes in where outputs enter the environment (how much goes to air, land, or water, or is dispersed).

A notable change in DPO in most study countries since 1975 is the increase in carbon dioxide (CO_2) emissions from fossil fuel combustion, including emissions from bunker fuels and other industrial processes. (*See Figure 5a.*) CO_2 emissions rose in all countries except Germany, where emissions fell slowly between 1975 and 1990, and fell again from their new post-reunification level by another 6 percent. In the Federal Republic of Germany, the decoupling of economic growth and carbon dioxide emissions resulted from improved energy efficiency achieved following the oil crisis in the seventies and reduced dependence on high-carbon lignite fuels. Following reunification, the government closed many inefficient facilities in the former German Democratic Republic.

Carbon dioxide emissions in other countries have risen in both absolute terms and on a per capita basis. Despite this strong growth, CO_2 emissions rose only slightly as a proportion of domestic processed output. The size of the relative increase is determined by the interplay between the rate of increase in fossil fuel combustion, and the rate of increase in other materials in DPO.

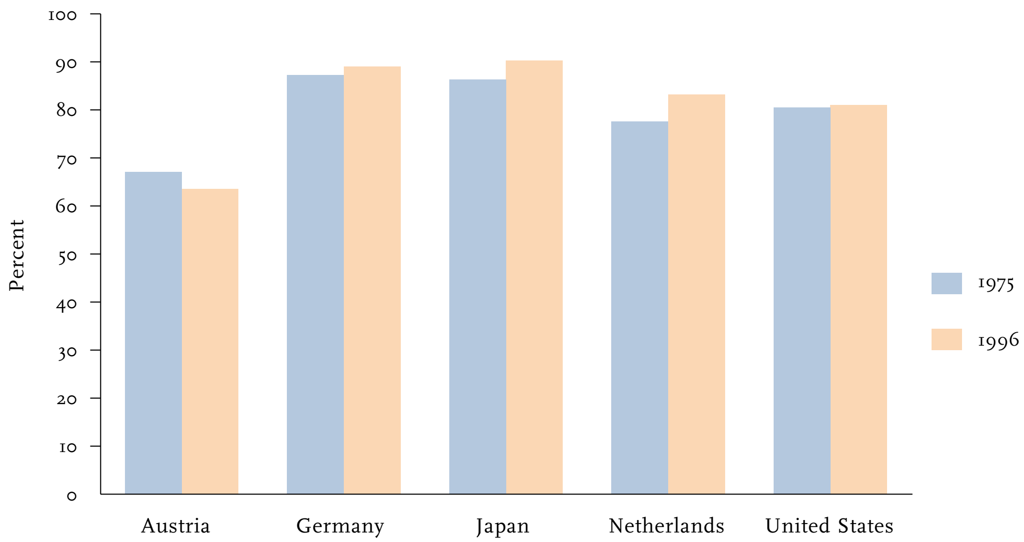
FIGURE 5a | CO_2 EMISSIONS FROM FOSSIL FUEL COMBUSTION AND INDUSTRIAL PROCESSES, 1975–1996 (INDEX)



Thus Japan, which experienced steady growth in DPO as a whole, but faster growth in energy consumption, saw the share of CO_2 in DPO rise by 4 percent. In the United States, energy consumption rose more rapidly than in Japan, but DPO grew more rapidly, too, and the net result was that the share of CO_2 in DPO barely changed. The point of these calculations is to highlight the fact that, despite improvements in energy efficiency and increased waste generation in other areas, fossil fuels have maintained their dominance in the material outflows of industrial economies. In the study countries, carbon dioxide from fossil fuel combustion and industrial processes accounted for, on average, 81 percent by weight of their entire domestic processed output in 1996, just one percent higher than in 1975. (*See Figure 5b.*)

In strong contrast to carbon dioxide emissions, all countries have experienced absolute declines in sulfur emissions to air, while combustion-related nitrogen emissions have broadly stabilized. These changes were forced by mandatory emission reductions and targets established in OECD countries, and aided by technological changes and market forces, which encouraged the switch to lower-sulfur fuels.

FIGURE 5b **CO_2 FROM FOSSIL FUEL COMBUSTION AND OTHER INDUSTRIAL PROCESSES AS A PERCENTAGE OF DPO, 1975 AND 1996**



Notes: These data do not include CO_2 from biomass combustion, which is assumed here to be carbon-neutral. Austria has implemented policies to encourage the use of biomass energy since the 1970s. If CO_2 emissions from biomass combustion were included, the share of CO_2 in Austrian DPO (1996) would be 15 percent higher than shown here.

BOX 3 **A NOTE ON ENERGY AND MATERIAL FLOWS IN NATIONAL PHYSICAL ACCOUNTS**

It is important to recognize the extent to which energy-related flows dominate physical accounts. Our 1997 report showed that fossil fuels and their associated hidden flows accounted for approximately 40 percent of total material requirement (TMR) in Germany, the Netherlands, and the United States in 1994, and a little less than 30 percent in Japan, thanks to relatively low per capita energy consumption in that country. (These data exclude the weight of oxygen drawn from the atmosphere during combustion.) On the output side, flows associated with energy use are equally dominant, and they appear more dominant in this report, because of our decision to include the weight of oxygen in combustion products, such as carbon dioxide. For example, coal mining wastes and fossil fuel combustion emissions together account for about 50 percent of total domestic output in the United States. If hidden flows are excluded, the picture is even more dramatic. Emissions from all fuel combustion account for between approximately 80 and 90 percent of domestic processed output in the study countries. Modern industrial economies, no matter how high-tech, are carbon-based economies, and their predominant activity is burning material. Processing materials into products requires energy; improvements in materials efficiency therefore bring improvements in energy efficiency as well.

The quantities of municipal and industrial wastes going to controlled landfill sites have declined significantly in most study countries, following the introduction of recycling targets for certain categories of municipal wastes, sometimes combined with landfill taxes. Since 1975, landfilling has declined by 34 percent in the Netherlands and by 31 percent in Austria. Dissipative flows show varying trends, generally reflecting the presence or absence of strong government intervention. For example, quantities of manure spread on fields and pesticide use fell in the Netherlands, as part of the government's effort to reduce nitrogen pollution and dispersion of hazardous materials from agriculture. Quantities of sewage sludge have risen in all countries, in line with population growth.

The more detailed nature of the U.S. database on material outflows permits examination of finer categories of material. For example, it appears that waste outputs of synthetic organic chemicals in plastics in the United States have more than doubled since 1975, as have outputs of waste medical chemicals. Annex 2 provides more detailed information on the composition of DPO in each of the study countries.

3.3 SECTOR INDICATORS: WHO GENERATES THE BIGGEST OUTPUT FLOWS?

In Germany and the United States, the mining sector (mineral fuels and metals) and the manufacturing sector dominate total domestic output. In countries without significant mining activity, the agriculture, construction, and manufacturing sectors generate the largest material flows. When hidden flows are excluded from consideration, the energy supply, manufacturing, transport, and household sectors all emerge as major sources of direct output flows to the environment. (In this study, we attribute overburden from coal mining to the mining and manufacturing sector, not the energy supply sector, which is defined as power plants and distribution systems.) The Netherlands is an exception, where the agriculture sector is the single largest contributor to DPO: animal manure flows in 1996 (dry weight) were more than four times greater than all landfilled wastes. It is also worth noting that most transport-related DPO takes the form of emissions from private vehicles, which arguably could be assigned to households.

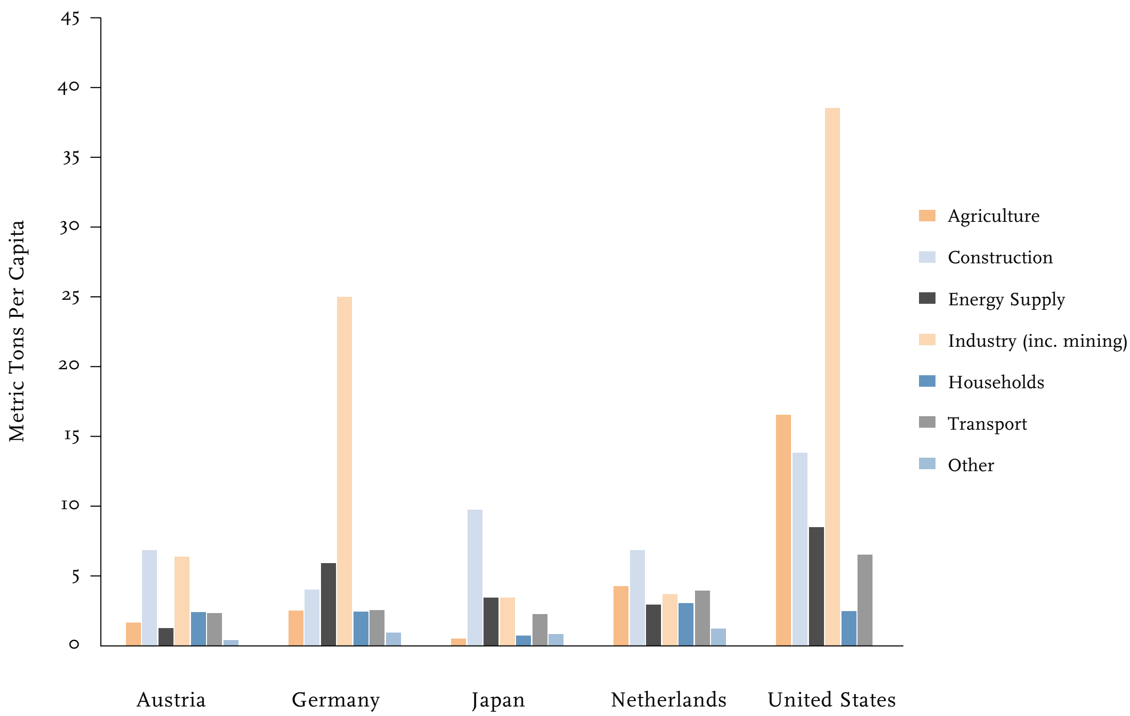
The national analyses presented here are not exactly comparable, because of methodological differences imposed by the organization of national statistics; data comparison is, therefore, limited to the coarse picture. (*See Figure 6.*) More detailed analysis of the physical accounts for each country reveals that, in all cases, economic sectors are interconnected by upstream and downstream product chains, and the question of who is directly "responsible" for output flows becomes almost irrelevant. The role of energy consumption is central, given the dominance of carbon dioxide emissions in DPO across virtually all sectors. Improved energy efficiency and faster progress toward a low-carbon fuel mix would dramatically reduce direct emissions to air from combustion. Such changes would also reduce other outflows associated with energy supply and distribution—coal mining wastes, toxic and hazardous outputs from oil refining and power generation, and fuel losses and spills that occur during energy transportation.

3.4 GATEWAY INDICATORS: WHERE DO MATERIAL OUTFLOWS GO?

In this study, we have disaggregated TDO and DPO by mode of first release—the first gateway by which materials enter the environment. Gateway indicators provide useful information given that many countries still organize environmental policy according to environmental media (air, water, and land) and track emissions or ambient quality in each medium separately. Poorly designed waste management policies can simply transfer wastes from one medium to another; for example, costly recycling requirements may encourage incineration. Comprehensive physical accounts track total outputs of each material, regardless of where it is deposited or whether or not it is regulated. Thus, they also provide a powerful tool to improve policies restricted to certain media.

Hidden flows remain largely on land, although an unknown fraction of earth from construction activities and eroded soil from cultivated fields enters river systems as sediment, and more than half of dredging wastes in the Netherlands is simply relocated within harbors or in deeper waters. The fate of materials constituting DPO is more complex. The share of outputs going to different gateways is influenced over time by changes in national economic structures, industries' choice of fuels and materials, consumer lifestyles and individual behavior, and policy decisions.

FIGURE 6 | CONTRIBUTION OF ECONOMIC SECTORS TO TDO, 1996



The study shows some shift between 1975 and 1996, from disposal on land to disposal in the atmosphere. As already discussed, increased fossil fuel combustion is the principal driver behind rising emissions to air; the shift has been dictated mostly by choices made on the input side of the economy. At the same time, some countries have reduced the amount of solid waste being disposed of on land. Regulation and public information campaigns have resulted in increased recycling rates for such materials as paper, glass and metals, and, more recently, for organic wastes. In Japan and Austria, the amount of waste going to controlled landfills has fallen in absolute and per capita terms since the 1980s, and in Germany and the Netherlands since 1990. In Germany, government and industry initiatives on packaging recycling and composting biowastes reduced the weight of household wastes by 30 percent between 1990 and 1993. Quantities of landfilled municipal wastes declined in the United States after 1987, following the widespread introduction of recycling and composting schemes. No trends could be discerned from the poor data on U.S. industrial landfilled wastes.

The waste management hierarchy espoused in some countries, which favors incineration over landfilling, has also encouraged the diversion of wastes from land to air. Incineration residues (which range from approximately 10 percent to 30 percent of original weight) are usually landfilled and the combustion products are emitted to air, where they may be transported over long distances. Unfortunately, some distortion arises from this study's accounting system, in that we recorded municipal waste as "wet weight," which exaggerates the reduction in solid waste quantities when incineration displaces landfilling. If municipal wastes are landfilled, this output is recorded as wet weight; if they are incinerated, the output is recorded as combustion emissions and ash, i.e., dry weight. Much of the difference between the two forms of output is actually due to water evaporation, which we did not include in our accounts.

It is a surprising fact that the atmosphere is now the biggest dumping ground for the processed output flows of industrial economies. In all study countries, regulatory efforts have focused on improving ambient air quality by reducing emissions of NO_x, SO_x, airborne lead, particulates, and other substances harmful to human health. These measures have met with considerable success, but the share of output flows going to air has increased in all study countries

TABLE 3 **PROPORTIONS OF DPO (PERCENT) GOING TO AIR, LAND AND WATER, 1975 AND 1996**

Country	To Air				To Land				To Water[1]	
	1975	1996	1975	1996	1975	1996	1975	1996	1975	1996
	Excluding Oxygen		Including Oxygen		Excluding Oxygen		Including Oxygen			
Austria	45	57	73	82	54	42	27	18	<1	<1
Germany	70	70	89	89	29	29	11	11	<1	<1
Japan	72	81	89	93	28	19	11	7	<1	<1
Netherlands	54	61	81	85	45	39	19	15	<1	<1
United States[2]	66	68	86	87	24	22	10	9	<1	<1

Notes:
1 Outputs to water are incomplete for all countries. The inclusion or exclusion of oxygen is, in any case, of minor relevance.
2 Approximately 10 percent (when oxygen excluded) or 4 percent (when oxygen included) of outputs in the United States could not reliably be allocated to any gateway, because of incomplete data. U.S. numbers, therefore, do not sum to 100 percent.
Numbers may not add due to rounding.

except Germany where, because of reduced dependence on lignite and hard coal and improved energy efficiency, carbon dioxide emissions have fallen.

Table 3 illustrates how the proportions of domestic processed output going to air, land, and water changed over the 21-year study period. The table presents the data in two forms: exclusive and inclusive of the weight of oxygen in emission compounds, such as carbon dioxide, oxides of nitrogen, and oxides of sulfur. It can be seen that the decision to exclude or include oxygen makes a substantial difference to the proportions of outflows to each environmental medium. As with economic accounts, the way in which system boundaries are drawn can strongly influence both data sets and the indicators they support.

These results also reveal, on the one hand, the inadequacy of available data on output flows to water in some countries, notably the United States, and, on the other hand, the effects of our methodological decision to exclude freshwater flows from the study. Emissions to water, for the most part, consist of wastewater and have not been estimated. The contaminant loading of these water flows is minor in quantity, but may have important environmental impacts. Mass flow analysis is not best suited to track these contaminants. Despite these problems, material flows do not simply stop, and a policy-relevant physical accounting system should attempt to capture at least some of the most environmentally significant cycles in their entirety. For this reason, a number of researchers have undertaken more detailed substance flow studies for such pollutants as nitrogen, sulfur, and some heavy metals, which include their transport in water.[21]

3.5 DISSIPATIVE FLOWS

Some materials are deliberately dissipated into the environment because dispersal is an inherent quality of product use or quality and cannot be avoided. Dissipative flows may take the form of dissipative *uses* or dissipative *losses*. Obvious examples of dissipative use flows are inorganic fertilizers, manure, compost, and sewage sludge that are spread on fields, partly to enrich soil, and partly (in the case of manure and sewage) as a disposal option. These flows are beneficial in appropriate quantities, and the use of manure, sewage and compost represents a necessary cycling of nutrients, but serious problems arise where dispersal loads exceed the absorptive capacity of the receiving environment.[22]

Available national level data do not support the accurate documentation of nutrients that are recycled through plant uptake or those that are lost into the environment through leaching and run-off. Also, the system boundaries that we chose for this study exclude the material exchanges involved in soil chemistry. However, nutrient losses to the environment are known to be large. Excessive nitrate levels in drinking water are now a widespread water quality problem in Europe and North America, and dispersive uses of nitrogen in agriculture are the leading source of contamination. Nutrient run-off also threatens estuaries and coastal areas worldwide.

Some other dissipative use flows are smaller in quantity but of comparable potential harm. They do not represent an intentional recycling loop. Pesticides and herbicides are sprayed over fields, but enter soil, water, and the air. Bio-accumulative agrichemicals are more controlled than in the past, but their use has not been eliminated. Salt, which has been linked to harmful impacts on wildlife, is still widely used as a de-icing agent on roads. Table 4 illustrates the significant differences in rates of some dissipative flows among the study countries.

Dissipative loss flows comprise numerous materials that are shed from products into the environment as an inevitable consequence of use or ageing. Examples of such dissipative losses include rubber worn from vehicle tires, asbestos (or substitute composites) from brake blocks and linings, paint flakes from buildings, and bitumen from road surfaces.

Governments do not officially record many of these flows. This study is the first attempt to estimate some of the less obvious, but potentially harmful, dissipative flows in five countries. (*See, for example, the German and U.S. country report data tables.*) It is important to know the quantities and nature of materials involved because once materials have been dispersed into the environment, if they are not captured and recycled by biological processes (such as plant growth), there is little opportunity for human action to recapture and recycle them. If dissipated materials are suspected of causing environmental or human health impacts, the only option is to reduce or substitute them with materials that are believed to be less harmful when dispersed into the environment.

3.6 NET ADDITIONS TO STOCK (NAS)

Physical accounts make it possible to track how much new material is added each year to a country's physical stock—the national

TABLE 4 SELECTED DISSIPATIVE USE FLOWS, 1996 (KILOGRAMMES PER CAPITA)

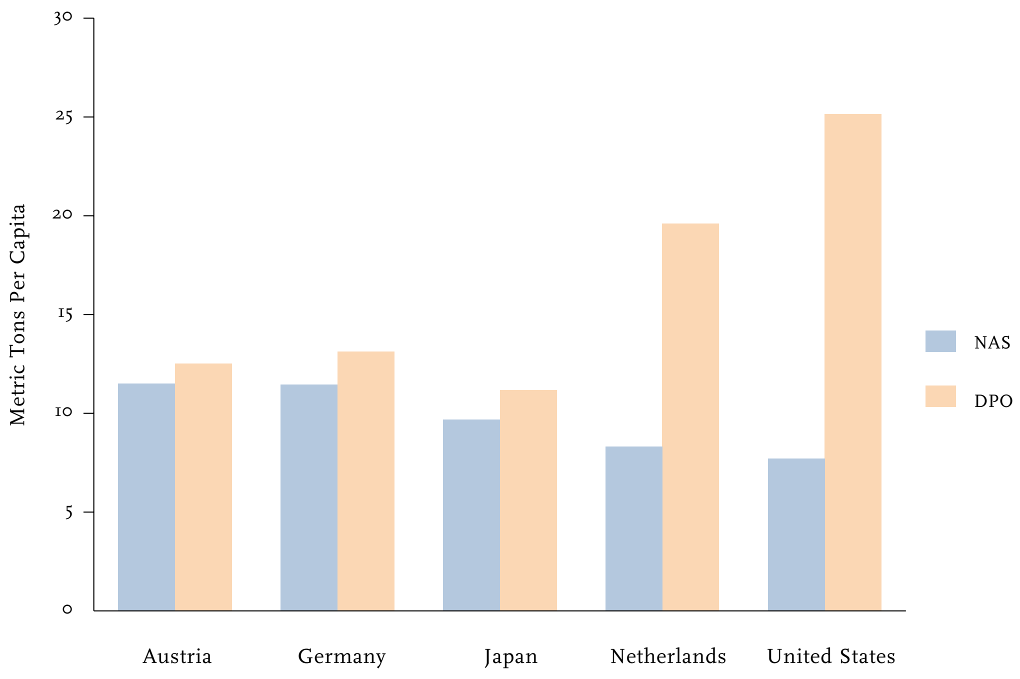
	Austria	Germany	Japan	Netherlands	United States
Inorganic Fertilizer	114	113	17	65	86
Spread Manure	454	334	105	2,282	298
Pesticides	3	0.4	0.5	0.7	..
Salt, Sand, and Gravel	134	26	..	..	60
Sewage Sludge	11	13	..	4	..

Notes:
Salt, sand, and gravel includes all grit materials spread on roads to improve tire traction. The Austrian data are high because of heavy use of grit materials on mountain roads in winter. Austrian data for inorganic fertilizer and pesticides are recorded as total weight, not active ingredients. Manure and sewage sludge are accounted in dry weight. Fuller accounts for dissipative use and dissipative loss flows are provided in the country reports.
.. Not estimated

material store represented by long-lived durable goods and physical infrastructure (roads, railways, airports, industrial plants, and residential, commercial, and public buildings). Each year, a small percentage of stock is decommissioned, as buildings are demolished, and durable goods discarded. These materials are subtracted from gross annual additions to stock to determine net additions.

The material flows added to stock each year are of comparable magnitude to DPO in three of the study countries—Austria, Germany and Japan—and they are around one-third to one-half of the size in the United States and the Netherlands. (*See Figure 7.*) In per capita terms, Austria and Germany add the greatest amount of material to stock each year, at 11.5 metric tons per person, and the United States appears to add the least, at just under 8 metric tons per person. This is a surprising finding, given the size of the country, its penchant for "building big," and its reputedly high levels of material consumption.

FIGURE 7 **NET ADDITIONS TO STOCK, AND DOMESTIC PROCESSED OUTPUT, 1996**



Two insights emerge from the data. One is that construction materials are overwhelmingly the largest constituent of net additions to stock. This has been deduced approximately by comparing quantities of construction materials required in each country (recorded as 1994 inputs in our earlier study) with NAS as calculated in this study. It appears that durable goods, such as cars, electronic goods, and household appliances, account for, at most, about one to two metric tons per capita of material added to stock each year. The decision whether or not to recycle construction materials emerges as important, given the huge quantities of material involved. Construction and demolition wastes generated when buildings are erected or demolished are recycled to a limited extent in all study countries, but data are not adequate to determine the quantities. (Construction and demolition wastes sent to landfill are recorded as part of DPO.) Recycling of materials in durable goods—notably metals from vehicles and large appliances—and material reuse as part of product maintenance and re-engineering are accounted for indirectly, in that these practices increase the residence time of materials in the economy. The materials are, at least temporarily, part of stock, not part of the waste stream.

The second insight is that the study countries, which are all mature industrial economies with their road, rail, and housing infrastructure relatively complete, do not yet show any sign of significantly reducing the quantities of new construction material required each year. Annual material enlargements of stock have remained remarkably constant over the past 25 years, rising broadly in line with population growth in the United States and at a somewhat lower rate in the other study countries. The continued physical growth of mature economies goes beyond maintenance. It is due to increased demand for transport infrastructure. It is also significantly influenced by demand for new housing associated with changing demographic structures and affluence. For example, the number of households is increasing faster than population growth, as more people live alone or in smaller family groupings. In the United States, increasing affluence has encouraged a taste for very large, low-density residences. If this trend continues, many millions of tons of minerals will continue to be dug from the land for the foreseeable future. The most damaging aspect of this trend will be an ongoing loss of productive land, degradation of scenic beauty, fragmentation and disturbance of habitats, and increased pressure on biodiversity.

A variety of economic, technological, topographic, and cultural factors affects flows of construction materials. When tracked over time, net additions to stock closely follow the economic cycle. Booms, recessions, and major building programs show up clearly in construction material flows. Transportation is a major element in national construction; the long distances in the United States necessitate a huge highway system, while mountainous terrain in Japan and Austria means that road building involves many bridges, tunnels, and embankments.[23] National building standards and traditions also appear to influence flows to stock significantly, although it is difficult to interpret the data. The relatively high NAS figures seen in parts of Europe might reflect a preference for building in stone and brick, rather than using the lighter wood-frame construction techniques still favored in much of the United States. Higher or lower levels of public investment in infrastructure maintenance will affect the quantity of annual flows to stock. In the case of Germany, it is interesting that heavy construction activities induced high per capita NAS even before reunification. Modernization of buildings and infrastructure, along with settlement expansion after reunification, has fostered the high rate of physical growth.

An important lesson is that as material stocks grow, so do the potential future waste volumes. Equally, so does the potential "mine" of materials for reuse. European countries have recently taken steps to encourage recycling of construction and demolition wastes. A forthcoming study by the U.S. Geological Survey aims to stimulate similar action by demonstrating the quantities of material that will be required as the country's infrastructure is largely replaced over the next 50 years.

4

POLICY APPLICATIONS

The environmental, social, and economic consequences of material outflows have become readily apparent over recent decades. Most industrialized countries have taken effective action to control a limited number of the more hazardous or objectionable outflows. OECD countries are also engaged in a program to test chemical materials produced in large volumes for toxicity. However, it is the contention of this study that the total quantities of outflows remain a mystery to most regulators and to the economic actors who produce them. For example, comprehensive data on discharges to surface water do not exist in any of the study countries. Definitional difficulties (and definition changes) applied to toxic and hazardous wastes preclude the development of reliable time-series data. Until the physical outflows of industrial economies are more accurately documented and assessed, it will be difficult to identify and prioritize remedial actions or design appropriate future policies.

The creation of indicators of material flows through industrial economies allows us to visualize those economies as physical as well as financial entities. Material flows into an economy in physical terms (metric tons) are a measure of that economy's dependence on resource extraction and potential associated environmental impacts. Material flows out of an economy are a measure of the effective loss of useful materials. Together with domestic hidden flows, they are an indicative measure of that economy's burden on the planet's assimilative capacity.

Like many macroindicators, aggregated material flows combine many different kinds of material in order to demonstrate the absolute and relative magnitudes of economic activity in terms of mass. The indicators are descriptors of a physical system, just as GDP, trade balances, and other economic indicators are descriptors of an economic system. Physical measures better approximate potential environmental burden than do the monetary indicators used by traditional economists. But just as GDP doesn't tell the whole story of the monetary economy, so the indicators we recommend do not tell the whole story of the physical economy. As in economic analyses, subaccounts, special analysis, and relevant weighting must be used to answer specific questions of economy and environment interactions, and to come up with specific management plans or policy interventions.

If the promise of the greening of national accounts is ever to be fulfilled, environmental economists must have these physical accounts—parallel to monetary accounts—to provide a basis for valuation and to calculate a green GDP. Given difficulties with valuing these physical accounts, however, it is likely that the indicators of the physical dimension of the economy, which we are recommending, will stand separate from monetary indicators for some time to come. We stress that both sets are necessary, along with those for labor and prices, to fully understand an economy and develop soundly based policy.

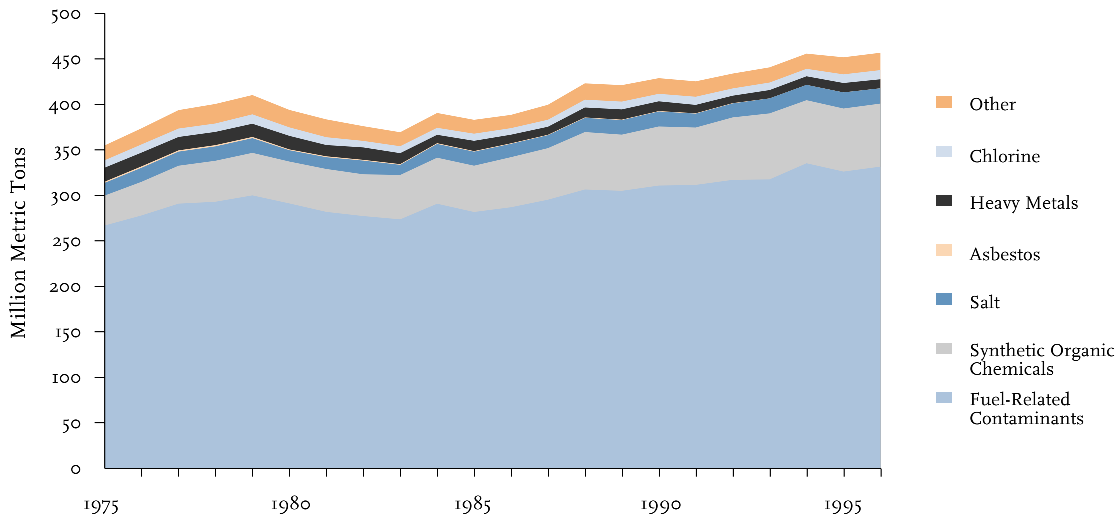
This section presents examples of how physical accounts and indicators at various levels of aggregation can be used in environmental policy-making.

Physical accounts can be used to track specific flows of concern over time and at every stage of the production-consumption chain.

Where time series are available, it is possible to analyze trends in the use of specific materials or categories of material, which are of concern either because of their impacts on human health or the environment or because of their economic or strategic interest. It is also possible to discern the influence of regulation, where controls have successfully

FIGURE 8

POTENTIALLY HAZARDOUS OUTPUT FLOWS IN THE UNITED STATES, 1975–1996



Note: Fuel-related contaminants include gangue (waste ore) from coal mining operations; fuel spills at the extraction, distribution, and use stages; methane leakage; and coal fly ash. Carbon dioxide is not included.

influenced material output flows in one or another application (for example, the use of lead in gasoline and mercury in batteries has declined), or where lack of regulation has allowed other outputs to grow (for example, lead uses in electrical products). Systematic accounting for such categories can highlight whole classes of materials currently outside the scope of environmental regulation. For example, in the United States, hazardous waste policy focuses on listed substances and releases to specific media. It does not cover most emissions from resource extraction, product use, or post-use disposal of products. Regulations are focused on the processing stage, but over half of toxic materials are embedded in products, where they may or may not receive appropriate treatment at the disposal stage. Figure 8 shows that when the entire material cycle is considered, output flows that are potentially toxic or hazardous in the environment have risen by nearly 30 percent in the United States since 1975. This increase appears to be primarily due to growing use of synthetic organics and increased outputs of the numerous contaminants associated with fossil fuels. This suggests the need for policy measures that focus more on resource extraction and the initial design and material components of products, in order to reduce the problems of managing hazardous substances later, when they enter the environment during use or disposal.

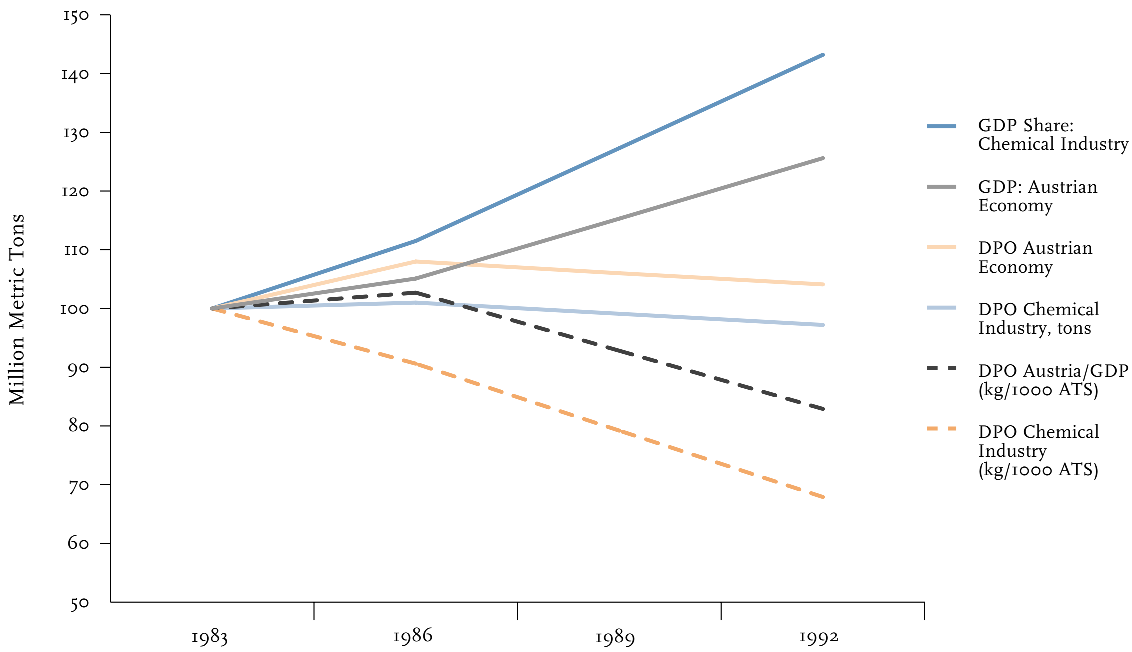
Detailed physical accounts can be developed and applied at the sector level.

This study provides preliminary data on the relative contributions of different economic sectors to national output flows in the five study countries. Sector level data are of interest to policy-makers concerned with energy and material efficiency and with waste prevention, both economy-wide, and in a sector-specific context. They are also relevant to companies interested in benchmarking their environmental performance against the industry sector as a whole or in comparing their sector's performance with that of other countries. Dupont, for example, has introduced a new measure that tracks resource throughput per unit of shareholder value as one of its performance indicators. Eco-efficiency is increasingly regarded as a key driver for corporate innovation and competitiveness. Physical accounts of inputs and outputs at the sector level, and their relation to economic performance, provide the basis for monitoring eco-efficiency. Figure 9 presents an illustrative case study. It records the results of a study that documented how the Austrian chemical sector improved its performance in the late 1980s and early 1990s.[24] Faced with rising resource costs, stricter waste disposal regulations, and increasing economic pressure from international competitors, the industry increased its economic output and reduced its waste outflows at faster rates than the economy as a whole.

At the national level, the indicators DPO and TDO, and their relationship to GDP, represent measures of the physical activity, and the energy and materials efficiency of an economy.

Definitions of sustainable development remain elusive. But we believe that decoupling economic growth and resource throughput is an essential objective in achieving long-term sustainability. When tracked over time, the physical indicators presented in our earlier resource flows report and in this study provide a means of tracking progress toward greater efficiency of resource use, and reduced waste intensity. Our reports

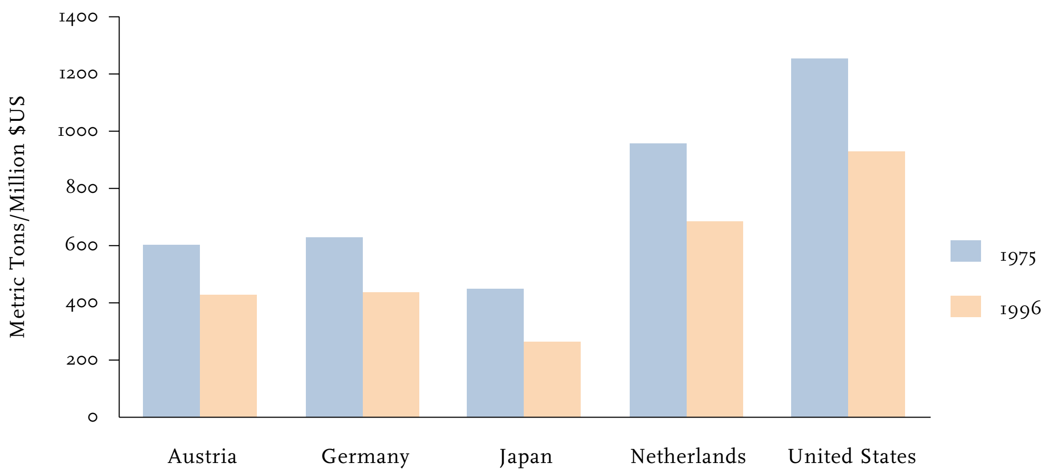
FIGURE 9 | DECOUPLING IN THE AUSTRIAN CHEMICAL SECTOR, 1982–1993



have shown that in all five countries materials efficiency has improved in recent decades, relative to economic growth, but that resource use and overall waste quantities have remained approximately steady on a per capita basis and have continued to grow in absolute terms. This is a finding of critical importance to economic and environmental decision-making in the years ahead. We have learned that efficiency gains brought by technology and new management practices have been offset by the scale of economic growth and consumer choices that favor energy- and material-intensive lifestyles.

The indicators also allow comparisons of eco-efficiency across countries, at both the national and sector levels. (*See Figure 10.*) This study shows the high energy and material intensity of the United States compared with other study countries, especially Japan. However, national economic structures vary, and interpretation of indicators requires care. For example, a national decline in U.S. gold mining would reduce hidden flows and "improve" apparent efficiency, but would not represent a contribution to global sustainability if equal quantities of gold continued to be imported from other countries.

FIGURE 10 **DPO PER CONSTANT UNIT OF GDP (U.S. DOLLARS) 1975 AND 1996**

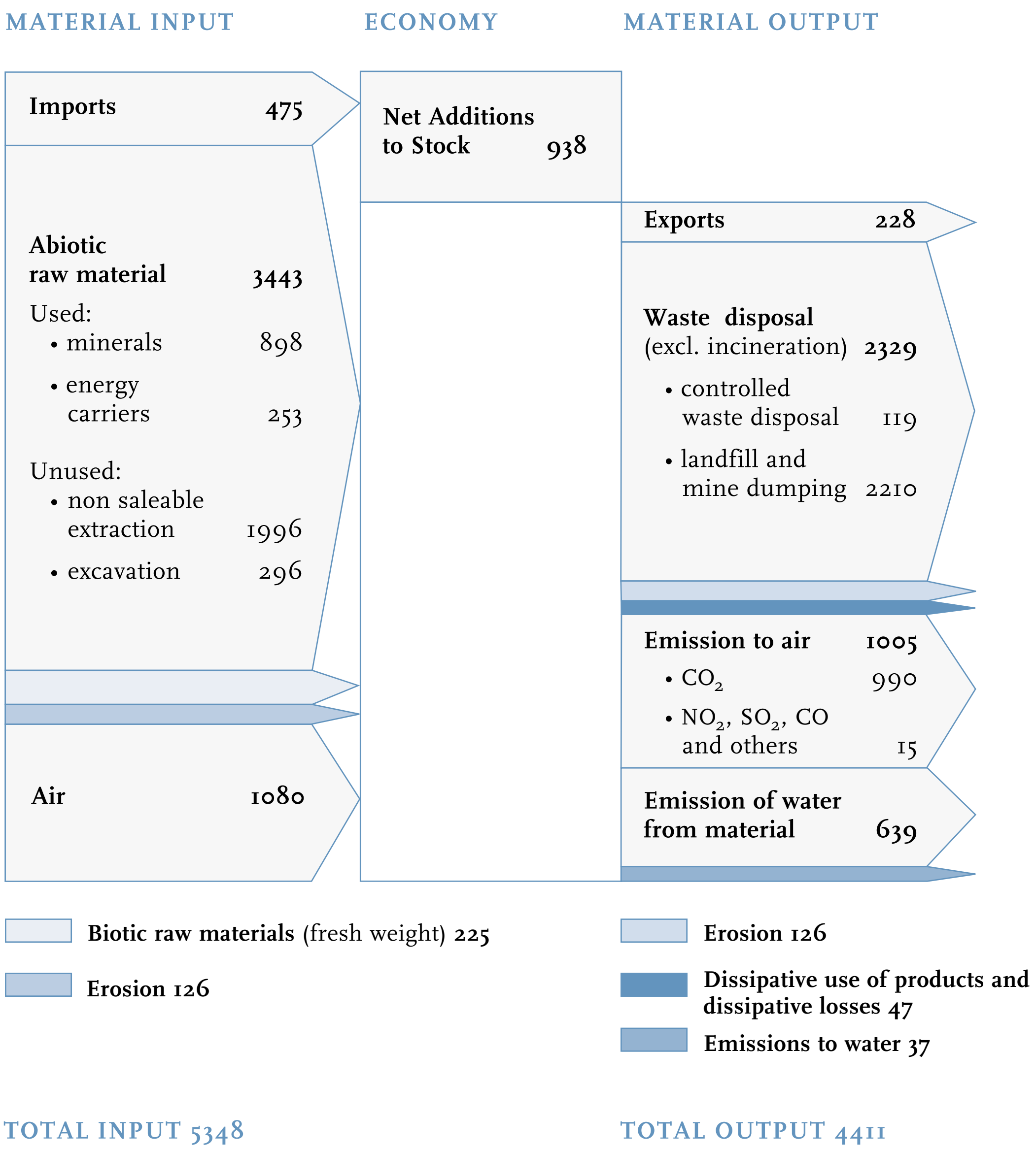


Note: National currencies expressed in U.S. dollars, based on data provided in *World Development Indicators, 1999* (Washington, D.C.: World Bank).

National physical accounts make it possible to organize flow data in an integrated framework, in order to see the big picture.

As an example, Figure 11 presents a sample material balance for Germany. The input side documents imported materials, materials harvested or extracted from the domestic economy, and inputs of oxygen required for fossil fuel combustion and human and animal respiration. Materials retained in the economy are shown as net additions to stock. On the output side, the figure shows exported materials, outflows to land, air, and water. Domestic hidden flows are accounted for on both sides of the system; because they do not enter the economy they are represented as a simultaneous input to, and output from the economic system. Such comprehensive frameworks show the composition of the material basis of an economy, its dependence on imports, the size of its infrastructure, and the quantities of material deposited into the environment. These frameworks allow setting of priorities based on knowledge of the whole system, as well as supporting indicators which track progress at the national level. German policy-makers have been influenced by the availability of material flow data for some years. The German Federal Statistical Office prepared a national material flow balance in 1995 and, partly as a result, Germany became one of the first countries to establish national targets for improving the efficiency of materials use.

FIGURE 11 | MATERIAL FLOW BALANCE OF GERMANY, 1996



5

NEXT STEPS

The goal of materials flow analysis is to develop new thinking, new metrics, and new management tools, which will facilitate the transition to more efficient and less environmentally harmful patterns of material use in industrialized and developing economies. The study findings and discussions with officials in the five study countries lead us to propose future activities that could enhance the usefulness of physical accounts and materials flow analysis in policy development and industrial decision-making.

Physical Accounts in Developing Countries

Published studies of material flows currently exist only for industrialized countries. Quantities and intensity of materials use are likely to vary substantially in developing countries, which employ different technologies and are still building their infrastructure. Greater understanding of material flows in these countries could help to answer questions critical to cost-effective and environmentally sound development policies. What and where are the key harmful flows? How efficiently are materials used? What are the hidden flows associated with producing materials for export? These questions are especially relevant in many developing countries because of their dependence on resource-intensive industries and the accelerating rates of resource use associated with high economic growth. OECD countries are currently developing some of the concepts and methodologies of materials flow analysis, but implementation of new patterns of materials use in highly industrialized countries could be slowed by "lock in" to existing infrastructure and established consumer behavior patterns. Faster application should be possible in developing economies, where opportunities to "leapfrog" Western technologies exist.

Weighting Material Flows

This report takes a step toward linking material flows to potential environmental impacts by characterizing flows according to their medium of entry, or mode of dispersion, into the environment. In the case of the U.S. dataset, we further characterize material flows according to a more detailed set of parameters, including physical and chemical properties of individual flows. However, the development of physical accounts for an economy provides the basis for far more detailed analysis than we have attempted.

Physical accounts do not in themselves provide information on environmental impacts. But they do provide the means for answering specific questions—if the accounts can be weighted appropriately. For example, if the individual flows in a set of physical accounts are weighted by relative toxicity, then assessments as to the relative toxicity of different sectoral activities could be calculated. If weighted by price, then the financial attributes of material flows in the system of national accounts could be calculated. If weighted by ozone-depleting potential, these flows would be relevant to understanding the causes of ozone layer depletion. Indeed, a universe of questions could be addressed if appropriate weighting schemes were applied. A crucial next step in refining physical accounting systems will be the development of such weighting schemes in order to demonstrate that specific material cycles can be linked to specific environmental impacts.

Improvement and Harmonization of Physical Accounting Methodology

This study made every effort to harmonize accounting methodologies used in the five study countries. The OECD is in the process of establishing a forum which will serve as an information clearing-house for countries interested in developing physical accounts and learning from each other's experience. However, further effort and continued collaboration will be required if governments and business are to adopt physical accounting as a practical management tool. Official statistics are still inadequate in many respects, as noted in section 2.5 of this report. Researchers in the field have more to do in establishing physical accounting practices and standardizing methods of data analysis, in order to develop a system of national physical accounts comparable to the internationally recognized System of National Accounts used in monetary accounting. Such national physical accounts will be increasingly necessary in tracking material flows across national borders and identifying the potential environmental impacts of growing world trade.

Integration of Materials Flow Data in National and Corporate Indicator Sets

Materials flow data have been used as the basis for resource efficiency indicators in a number of recent official reports, including *Sustainable Development in the United States: an Experimental Set of Indicators* (U.S. Interagency Working Group on Sustainable Development, December 1998), and *Quality of Life Counts: Indicators for a Strategy for Sustainable Development for the United Kingdom* (Department of the Environment, Transport and the Regions, United Kingdom, 1999). The OECD is currently consulting experts on how to expand its existing environmental indicator framework to make it more reflective of the wider objectives of sustainable development.

Industries in many countries are also developing performance measures and indicators to track their progress toward environmental or sustainable development goals. The indicators presented in this report and those developed in our previous report are intended to stimulate the widespread adoption of physical accounting methods, and appropriate indicators in government and business operations. The hope is that these actors will "institutionalize" materials flow accounting and track eco-efficiency as part of good practice.

Materials Flow Analysis at the Sector Level

Materials flow analysis is a powerful tool for understanding the role of economic sectors in resource use, waste generation, pollution, and landscape alteration. This study has disaggregated national output flows by major economic sectors. A next step is to further disaggregate specific material flows by sector, in order to understand patterns of resource consumption, efficiency of resource use, and generation of specific pollutants at the sector level. In Chapter 4, we presented the results of a study of mass flows in the chemical sector in Austria (*see p. 34*). The World Resources Institute is currently undertaking a more detailed study of input and output flows in the agriculture and forestry sectors of the United States.

At the global level, future studies could quantify environmentally and socially relevant material inputs and outputs associated with the production of specific products. As one example, analysis of the global agriculture sector could address questions that are fundamental to the long-term sustainability of food production systems: Where are some resource inputs high, relative to the economic or nutritional value of agricultural commodity outputs? Does modern agriculture disrupt the natural temporal and spatial patterns of nutrient cycling? Such an application of the techniques of materials flow accounting to agriculture could help determine the long-term productivity constraints to sustainable global food production.

Materials Flow Analysis at Different Scales

To date, most analyses of material flows have focused at the national level. Physical accounts developed at the regional or local level would allow more detailed analysis of flow sources, arrival pathways, sinks, and directional movement through actual environments. Geographic Information Systems (GIS) and material flow analysis could be combined to produce a visual representation of specific material flow patterns known to be adversely impacting the environment. As one example, analysis could focus on the size and spatial distribution of flows generated by mining and ore processing activities, which are major sources of hazardous flows. Studies at the scale of the administrative unit or of natural boundaries, such as watersheds, would allow decision-makers to monitor flows into and out of their area, to understand what is locally generated and what is imported from other regions. To help translate science into the policy and public arenas, researchers could identify the spatial sources and sinks of flows of environmental concern and develop visually powerful maps of material flows and environmental impacts.

Developing Scenarios of Material Flows

Scenario development is widely used in government and business to compare plausible futures under different assumptions about resource availability and prices or to estimate environmental quality given higher or lower emissions of specific pollutants. Decision-makers could apply scenario techniques to compare the economic and environmental implications of alternative future material flow patterns at national or international level. They might examine likely flows of specific commodities under different assumptions regarding economic growth rates, technologies, and recycling rates. Or they might compare alternative substitutions among materials that could, for example, achieve greater input efficiency (lower resource use per unit of economic output) or greater output efficiency (lower emissions to environment per unit of economic output). Scenarios could be used to improve industry's understanding of the environmental implications of choices regarding material use (for example, use of virgin versus recycled supplies). Scenarios could also help to influence policy reforms favoring material cycles that use resources efficiently and keep toxics out of the environment.

Conclusions

This report demonstrates that material outflows to the environment are still a cause for concern. Some toxic and hazardous flows have been controlled but many others have not. Numerous flows remain undocumented and outside the purview of environmental agencies. Fossil fuel combustion is the dominant activity of modern industrial economies and is the single largest contributor to material outflows to the air and on land. Most of these flows are hazardous to human health or the environment. Technological advances and economic restructuring have contributed to significant decoupling between rates of economic growth and material throughput but they have not achieved any overall reduction in resource use or waste volumes. Policies will therefore be needed to accelerate the trend toward dematerialization and to encourage substitution of benign materials for those that are environmentally harmful.

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11. A. Adriaanse, S. Bringezu, A. Hammond, Y. Moriguchi, E. Rodenburg, D. Rogich, and H. Schütz, 1997. *Resource Flows: The Material Basis of Industrial Economies.* (Washington, DC: World Resources Institute).

12. Water vapor from human and animal respiration has not been calculated for the United States.

13. Chemically toxic and biologically active materials that are hazardous in the environment may be aggregated in the U.S. material flow database. Other study countries also compiled data on toxic and hazardous material flows. However, no international comparisons have been made, nor do we present an indicator of toxic flows. Meaningful comparisons are not possible because of differing national definitions of "toxic" and "hazardous" materials.

14. Some hidden flows are captured indirectly by monetary accounts, in that the costs of managing them are included in GDP. Dredging,

highway construction, and landscape reclamation following mining are examples of activities that involve economic transactions. Indeed, these flow management costs have formed the starting point for some of our estimates of flow quantities. The point is that the total quantities of material involved cannot readily be determined from an examination of national financial accounts.

15. This methodology differs from that used in our 1997 report, in which hidden flows associated with imported resources were included in the calculation of total material requirement. Such an approach would have led to double-counting among countries linked by trade.

16. C.D. Keeling and T.P. Whorf, 1998. *Atmospheric CO_2 Concentrations (ppmv) Derived From In Situ Air Samples Collected at Mauna Loa Observatory, Hawaii*. (San Diego, California: Scripps Institute of Oceanography); A. Neftel et al., 1994. *Historical CO_2 Record from the Siple Station Ice Core*. (Bern, Switzerland: Physics Institute, University of Bern). Online at:http://cdiac.esd.ornl. gov/trends/co2/contents.htm

17. Peter M. Vitousek et al., 1997. "Human Alteration of the Global Nitrogen Cycle: Causes and Consequences." *Issues in Ecology*, No. 1: February.

18. An exception should be made for river sediment that is deposited on cultivated land downstream during floods, an important element in maintaining fertility in some parts of the world.

19. World Bank, 1999. *World Development Indicators 1999*. (Washington D.C.: World Bank).

20. The United States has recently revised the manner in which GDP is calculated to include software investment (Larry Moran, U.S. Bureau of Economic Affairs, private communication, March 24, 2000). U.S. Department of Commerce data show U.S. GDP rising by 93 percent between 1975 and 1996 (constant 1996 dollars). These new figures would substantially increase the decoupling observed between U.S. economic growth and material throughput. This report uses World Bank data, since its calculation of GDP offers greater comparability with the other study countries. U.S. Department of Commerce data are available online at: http://www.bea.doc.gov/bea/dn/gdplev.htm Accessed March 23, 2000.

21. See, for example, J. Maag, C. Lassen, and E. Hansen, *Substance Flow Analysis for Mercury* (Copenhagen: Danish EPA, Environmental Project no. 344, 1996); C. Lassen, E. Hansen, T. Kaas and J. Larsen, *Aluminium-Substance Flow Analysis and Loss Reduction Feasibility Study* (Copenhagen: Danish EPA, Environmental Project no. 484, 1999); L. Hoffmann, *Substance Flow Analysis for Phthalates* (Copenhagen: Danish EPA, Environmental Project no. 320); Central Bureau of Statistics, Department of the Natural Environment, *Mineralen in de landbouw*, 1970–1990 (CBS publications C-67 / 1970–1990); E. van der Voet, J.B. Guinée and H.A. Udo de Haes, eds., *Heavy Metals: a Problem Solved? Methods and Models to Evaluate Policy Strategies for Heavy Metals.* (Dordrecht, Boston, London: Kluwer Academic Publishers, series Environment and Policy vol. 22, 2000); B. Bergbäck, S. Anderberg and U. Lohm, 1992, "Lead Load: Historical Pattern of Lead Use in Sweden" *Ambio* 21:159–165; W. M. Stigliani, P.R. Jaffe, and S. Anderberg, 1993, "Heavy metal pollution in the Rhine Basin." *Environmental Science and Technology* 27: 786–793; P. Brunner and T. Lahner, *Materials Accounting as a Tool for Decision Making in Environmental Policy (MAc TEmPo)* (EC Programme Environment and Climate ENV4-CT96–0230, Final Report, 1998).

22. Though not a dissipative flow as defined here, the same principle applies to anthropogenic carbon dioxide emissions, which are partially captured and recycled by plant biomass and the oceans.

23. Because of limited data availability, road construction flows are not always adequately reflected in this report.

24. H. Schandl and H. Zangerl-Weisz, 1997. Materialbilanz Chemie. Methodik sektoraler Materialbilanzen. [A Material Balance for the Chemical Industry. Methods for Sectoral Material Flow Accounting]. (Vienna: IFF Social Ecology Papers No. 47).

ANNEX I

DATA SUMMARY: NATIONAL COMPARISONS

The following tables present the indicators that have been used as the basis of analysis throughout this report. They are drawn from the more detailed datasets presented in the country annexes. It should be noted that these indicators exclude the weight of water vapor from fossil fuel combustion and other industrial processes, and exclude the weight of water vapor and carbon dioxide from human and animal respiration. Information on these emissions can be found in the country datasets. For the purposes of comparison, however, the indicators are presented here in two forms: inclusive and exclusive of the weight of oxygen in emissions from fossil fuel combustion and other industrial processes.

SUMMARY INDICATORS, 1996 (thousand metric tons)

	Austria[1]	Germany	Japan	Netherlands[2]	United States
Indicators Including Weight of Oxygen					
Domestic Processed Output (DPO)	100,818	1,074,725	1,406,548	281,261	6,773,843
Domestic Hidden Flows (DHF)	70,530	2,417,427	1,225,538	99,862	16,487,220
Total Domestic Output (TDO)	171,348	3,492,153	2,632,086	381,122	23,261,063
Net Additions to Stock (NAS)	92,718	937,623	1,219,305	134,918	2,077,523
DPO by Gateway[3]					
Land	17,748	116,772	92,854	45,076	579,396
Air	82,964	954,495	1,311,982	235,509	5,918,616
Water	106	3,458	1,712	675	7,870
Uncertain	n/a	n/a	n/a	n/a	267,961
DPO by Sector[4]					
Agriculture	13,367	52,344	56,357	65,118	231,605
Construction	5,798	33,312	37,120	6,874	109,982
Energy Supply	10,202	484,221	431,265	45,399	2,248,362
Industry[5]	30,068	53,899	400,553	57,350	1,814,886
Household	19,373	163,597	92,120	46,953	661,827

	Austria[1]	Germany	Japan	Netherlands[2]	United States
Transport	18,739	207,332	285,359	61,088	1,707,201
Other	3,271	80,021	103,774	19,061	n/a
TDO by Sector[4]					
Agriculture	13,367	177,916	63,712	65,868	4,453,484
Construction	55,027	329,140	1,224,600	105,986	3,725,604
Energy Supply	10,202	484,221	431,265	45,399	2,285,397
Industry[5]	51,370	2,049,925	431,256	57,350	10,377,687
Household	19,373	163,597	92,120	46,953	661,854
Transport	18,739	207,332	285,359	61,088	1,757,037
Other	3,271	80,021	103,774	19,061	n/a

Indicators Excluding Weight of Oxygen

	Austria[1]	Germany	Japan	Netherlands[2]	United States
Domestic Processed Output (DPO)	41,910	386,293	496,254	110,482	2,667,736
Domestic Hidden Flows (DHF)	70,530	2,417,427	1,225,538	99,862	16,332,950
Total Domestic Output (TDO)	112,440	2,803,721	1,721,792	210,344	19,000,686
Net Additions to Stock (NAS)	92,718	937,623	1,219,305	134,918	2,077,523
DPO by Gateway[3]					
Land	17,748	116,772	92,854	45,076	579,396
Air	24,056	266,063	401,688	64,731	1,812,509
Water	106	3,458	1,712	675	7,870
Uncertain	n/a	n/a	n/a	n/a	267,961
DPO by Sector[4]					
Agriculture	9,466	44,754	30,643	44,643	231,605
Construction	5,365	26,206	25,414	3,006	109,982
Energy Supply	2,860	133,136	119,650	12,404	723,921
Industry[5]	10,993	35,301	171,294	18,122	652,964
Household	6,544	56,383	35,221	14,038	280,355
Transport	5,510	57,904	77,825	17,093	668,910
Other	1,172	32,608	36,206	5,864	n/a
TDO by Sector[4]					
Agriculture	9,466	170,326	37,998	45,393	4,338,650
Construction	54,594	322,034	1,212,894	102,118	3,686,169
Energy Supply	2,860	133,136	119,650	12,404	732,157
Industry[5]	32,294	2,031,328	201,998	18,122	9,235,265
Household	6,544	56,383	35,221	14,038	289,790
Transport	5,510	57,904	77,825	17,093	718,654
Other	1,172	32,608	36,206	5,864	n/a

Notes:
1 Austrian TDO data for agriculture do not include soil erosion or dredging waste flows, which were not estimated.
2 Dutch sector data do not sum to DPO and TDO due to use of data from different datasets; they differ by up to 10 percent.
3 Virtually all hidden flows go to land, so only DPO has been disaggregated by gateway; dissipative flows are embedded in flows of DPO to land, air, and water.
4 Energy flows have been attributed to utilities (energy supply) and other economic sectors based on location of emissions.
5 Industry sector data include the mining (including coal mining) and manufacturing sectors.
Numbers may not add due to rounding. n/a: not applicable.

SUMMARY INDICATORS, 1996 (metric tons per capita)

	Austria[1]	Germany	Japan	Netherlands[2]	United States
Indicators Including Weight of Oxygen					
Domestic Processed Output (DPO)	12.51	13.14	11.18	19.61	25.14
Domestic Hidden Flows (DHF)	8.75	29.55	9.74	6.45	61.19
Total Domestic Output (TDO)	21.26	42.68	20.91	26.05	86.33
Net Additions to Stock (NAS)	11.50	11.46	9.69	8.31	7.71
DPO by Gateway[3]					
Land	2.20	1.43	0.74	2.90	2.15
Air	10.29	11.67	10.42	16.65	21.97
Water	0.01	0.04	0.01	0.04	0.03
Uncertain	n/a	n/a	n/a	n/a	0.99
DPO by Sector[4]					
Agriculture	1.66	0.64	0.45	4.20	0.86
Construction	0.72	0.41	0.29	0.44	0.41
Energy Supply	1.27	5.92	3.43	2.93	8.34
Industry[5]	3.73	0.66	3.18	3.70	6.74
Household	2.40	2.00	0.73	3.03	2.46
Transport	2.33	2.53	2.27	3.94	6.34
Other	0.41	0.98	0.82	1.23	n/a
TDO by Sector[4]					
Agriculture	1.66	2.17	0.51	4.25	16.53
Construction	6.83	4.02	9.73	6.84	13.82
Energy Supply	1.27	5.92	3.43	2.93	8.48
Industry[5]	6.37	25.05	3.43	3.70	38.52
Household	2.40	2.00	0.73	3.03	2.46
Transport	2.33	2.53	2.27	3.94	6.52
Other	0.41	0.98	0.82	1.23	n/a
Indicators Excluding Weight of Oxygen					
Domestic Processed Output (DPO)	5.20	4.72	3.94	7.53	9.90
Domestic Hidden Flows (DHF)	8.75	29.55	9.74	6.45	60.62
Total Domestic Output (TDO)	13.95	34.27	13.68	13.97	70.52
Net Additions to Stock (NAS)	11.50	11.46	9.69	8.31	7.71
DPO by Gateway[3]					
Land	2.20	1.43	0.74	2.90	2.15
Air	2.98	3.25	3.19	4.57	6.73
Water	0.01	0.04	0.01	0.04	0.03
Uncertain	n/a	n/a	n/a	n/a	0.99

	Austria[1]	Germany	Japan	Netherlands[2]	United States
DPO by Sector[4]					
Agriculture	1.17	0.55	0.24	2.88	0.86
Construction	0.67	0.32	0.20	0.19	0.41
Energy Supply	0.35	1.63	0.95	0.80	2.69
Industry[5]	1.36	0.43	1.36	1.17	2.42
Household	0.81	0.69	0.28	0.91	1.04
Transport	0.68	0.71	0.62	1.10	2.48
Other	0.15	0.40	0.29	0.38	n/a
TDO by Sector[4]					
Agriculture	1.17	2.08	0.30	2.93	16.10
Construction	6.77	3.94	9.64	6.59	13.68
Energy Supply	0.35	1.63	0.95	0.80	2.72
Industry[5]	4.01	24.83	1.60	1.17	34.28
Household	0.81	0.69	0.28	0.91	1.08
Transport	0.68	0.71	0.62	1.10	2.67
Other	0.15	0.40	0.29	0.38	n/a

Notes:

1 Austrian TDO data for agriculture do not include soil erosion or dredging waste flows, which were not estimated.

2 Dutch sector data do not sum to DPO and TDO due to use of data from different datasets; they differ by up to 10 percent.

3 Virtually all hidden flows go to land, so only DPO has been disaggregated by gateway; dissipative flows are embedded in flows of DPO to land, air, and water.

4 Energy flows have been attributed to utilities (energy supply) and other economic sectors based on location of emissions.

5 Industry sector data include the mining (including coal mining) and manufacturing sectors.

Numbers may not add due to rounding.

N/a: not applicable.

ANNEX 2

COUNTRY REPORTS

MATERIAL FLOWS: AUSTRIA

Christof Amann, Marina Fischer-Kowalski, Walter Hüttler, Heinz Schandl, Helga Weisz

Input Flows

[Authors' note: This section on input flows is included, because Austria was not one of the original study countries in the 1997 report, which examined national inputs of material (Adriaanse et al., 1997).]

The direct material input (DMI) to the Austrian economy, encompassing both domestic extraction and imports, increased from 136 million metric tons in 1975 to 176 million metric tons in 1996. This 29 percent increase was fueled mostly by a 24 percent rise in domestic extraction of minerals and by an increase in imports, which have more than doubled since 1975. At the same time, domestic extraction of fossil fuels (mainly lignite) steadily decreased and biomass use remained more or less constant. (*See Figure A1.*) The DMI increase during this recent period was less dramatic than the 1960 to 1975 period, when it was more than 50 percent. Domestic extraction of minerals and imported materials accounted for most of the earlier increase. Austria's period of rapid material growth ended around the beginning of the 1980s.

Composition of Domestic Processed Output

In 1996, domestic processed output (DPO) amounted to 107 million metric tons in absolute terms and 13.3 metric tons on a per capita basis. (*See Figure A2.*) From 1975 to 1996, domestic processed output per capita increased by 10 percent. While Austria's population grew by about 6 percent during the study period, DPO increased by 17 percent in absolute terms. The most significant material flows within DPO in 1996 were CO_2 emissions from combustion of fossil fuels and industrial processes (almost 8 metric tons per capita), CO_2 emissions from combustion of biomass (1.9 metric tons per capita), waste deposited in controlled landfills (1.1 metric tons per capita), CO_2 emissions from human and livestock respiration (0.8 metric tons per capita)[1], and organic manure (0.7 metric tons per capita).

FIGURE A1 **DIRECT MATERIAL INPUT (DMI), AUSTRIA 1975–1996**

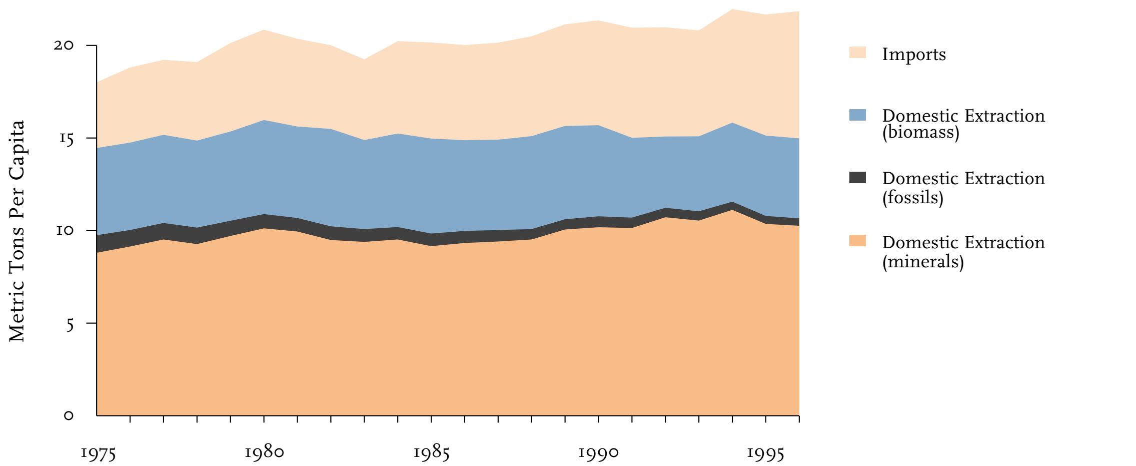
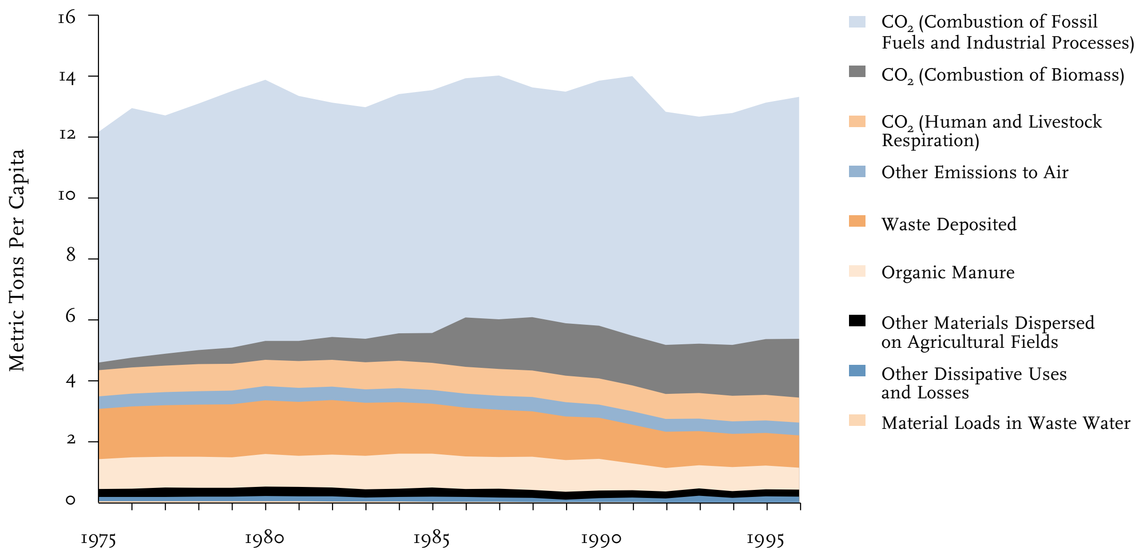


FIGURE A2 **COMPOSITION OF DOMESTIC PROCESSED OUTPUT (DPO), AUSTRIA 1975–1996**

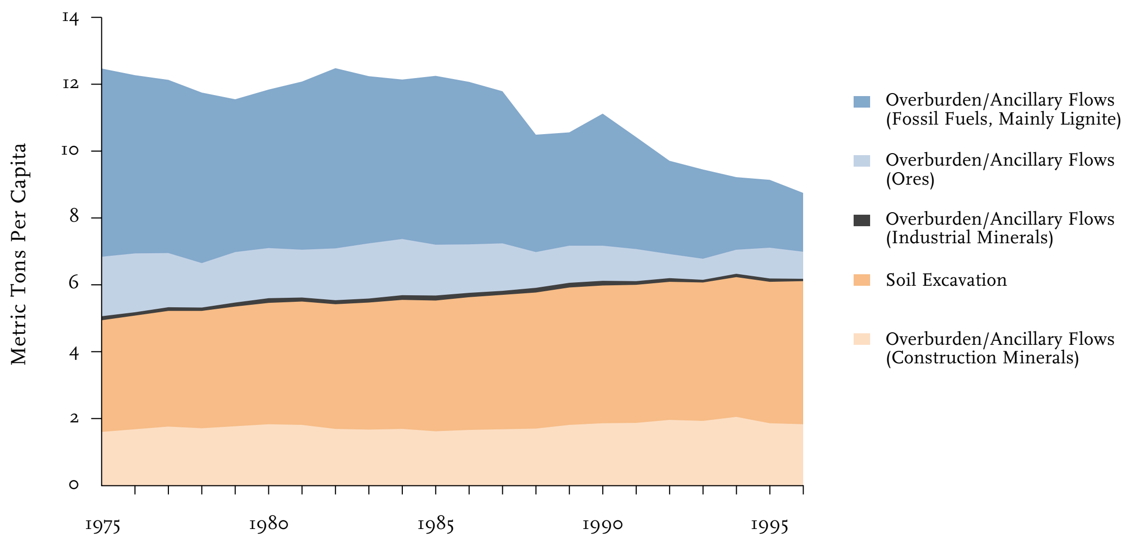


Overall, Austria has a lower DPO than most of the countries studied in this report (when CO_2 from human and animal respiration is excluded. (*See Note 1.*) This is due primarily to a significantly lower level of CO_2 emissions, a consequence of the structure of Austria's energy supply. Hydropower produces about 70 percent of electricity in Austria, and other renewable forms of energy (such as fuelwood) also play an important role. More than 20 percent of the nation's primary energy supply stems from these two sources. As a result, CO_2 emissions from combustion are comparatively low without Austria resorting to nuclear power. Quantities of dispersed materials such as organic manure are quite high, because of the importance of livestock in the agricultural sector.

Domestic Hidden Flows

Domestic hidden flows (DHF), including overburden and ancillary flows associated with the extraction of fossil fuels, ores, industrial minerals, and construction minerals, as well as soil excavation, amounted to a total of 71 million metric tons in 1996, or 8.8 metric tons per capita. (*See Figure A3.*) Hidden flows are dominated by soil excavation (4.3 metric tons per capita), overburden from the extraction of construction minerals (1.8 metric tons per capita), and fossil fuels such as lignite (1.7 metric tons per capita). Mining plays a small role in Austria compared to countries such as Germany. From 1975 to 1996, domestic hidden flows declined by about 25 percent, mainly because of the sharp decrease in lignite extraction. Furthermore,

FIGURE A3 | DOMESTIC HIDDEN FLOWS, AUSTRIA 1975–1996



hidden flows associated with ores were halved. However, hidden flows associated with construction activities increased significantly from 4.9 to 6.1 metric tons per capita.

Domestic Processed Output by Gateways

Domestic material outflows from economic processing (domestic processed output, or DPO) can enter the environment through the air, land, or water gateways. In 1996, more than 83 percent of DPO consisted of emissions to air. Land disposal of waste materials, and materials dispersed on land, accounted for only 17 percent of DPO. Outputs to water were quantitatively negligible. During the last two decades, there has been a shift from land outflows to air emissions. DPO to air consists mainly of CO_2, which is closely related to the use of energy sources (fossil fuels and biomass). In contrast to emissions of air pollutants such as SO_2 or NO_x, which were reduced significantly by regulatory policies, emissions of CO_2 from fossil fuel combustion and industrial processes increased by 12 percent between 1975 and 1996.

The decrease of DPO to land, by about 23 percent from 1975 to 1996, seems to be a result of intensified waste management policies implemented since the second half of the 1980s. These policies aimed to emphasize waste incineration over landfill disposal, reduce packaging materials, and encourage recycling. As a result, industry and commercial waste disposal on land decreased by one third. Dissipative use of mineral fertilizers declined by about 20 percent, partly because of a special tax, while the use of pesticides (measured in metric tons of the entire product, not active ingredients) increased by 50 percent.

DPO to water apparently declined by 73 percent from 1975 to 1996, amounting to just 0.1 percent of total DPO in 1996. This decline was primarily due to a reduction of organic carbon in wastewater emissions. Nitrogen (N) and phosphorus (P) discharges also show decreasing trends. During the last two decades, the capacity of municipal sewage treatment has tripled and the technical standards (N and P elimination) have improved significantly. At the same time, regulatory policies have forced particularly “dirty” industries like paper and pulp production to implement cleaner technologies and improve wastewater treatment facilities, resulting in considerable decreases in discharges to water.

Net Additions to Stock and Material Flows

We believe that, in addition to buildings, infrastructure, and durable goods, human beings and livestock must be considered part of the material stocks of a society. These material stocks require material flows for their development, reproduction, and maintenance. Humans need food just as livestock need fodder. They also need buildings, which require energy for heating, and construction materials for periodic renovation. Such material stocks have accumulated over long periods of time, and now they amount to several hundred metric tons for each inhabitant. Quantitatively, the most important of these material stocks are buildings and such infrastructure as road networks, railroads, and pipelines. The mass of human beings and livestock amounts to less than 0.1 percent of the total material stocks.

One surprising finding of this study is that material stocks in all five countries are still increasing.[2] In 1996, net additions to stock (NAS) amounted to 93 million metric tons (11.5 metric tons per capita) in Austria. While the Austrian population increased by only 6 percent over the past two decades, and livestock by only 4 percent, the mass of buildings and infrastructure increased by about one third. This shows that population growth is not the principal factor in increased material use. Other trends also point to the continuing growth of material stocks: between 1975 and 1996, the length of the Austrian public road network increased by 10 percent, and the number of buildings (as well as the floor space available) increased by more than 40 percent.

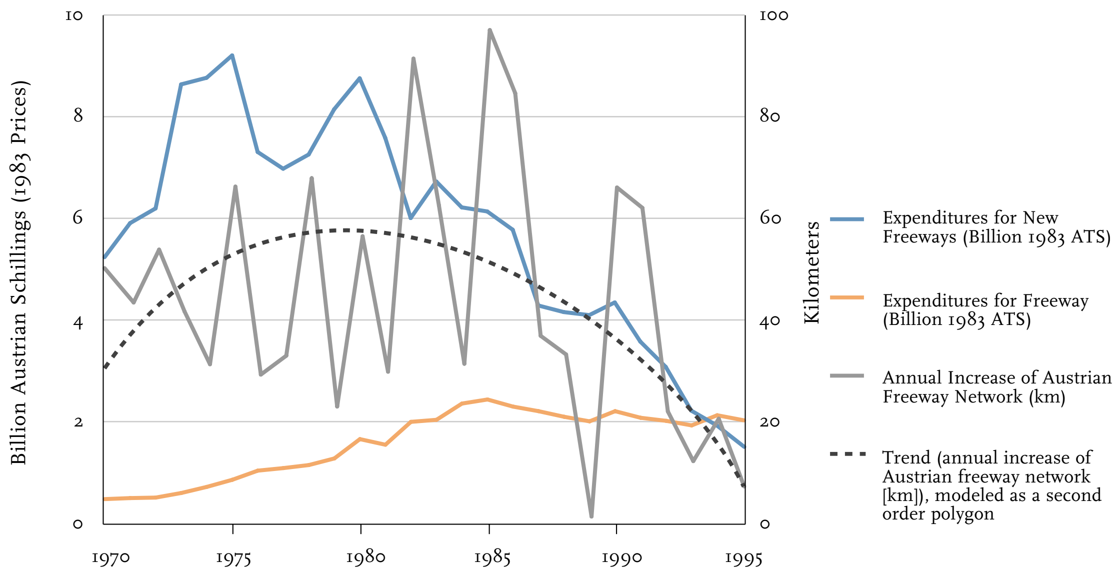
From a systemic point of view, there exist the following relationships between material stocks and flows. The input flow of materials produces stocks. If the input flow is larger than the output flow, material accumulates in stocks. Sooner or later stocks produce output flows such as demolition wastes that have to be recycled or deposited. In addition, stocks constantly induce material flows for use and maintenance. These flows comprise, for example, energy for heating buildings, and construction materials for maintaining roads. One can assume that, other things being equal, the larger the stocks, the larger the flows required for maintenance. This applies both to material flows and to costs, and it has consequences for material flow management. The continuous growth of infrastructure requires an increasing share of resources—both physical and economic—for its maintenance and, as a consequence, narrows the range of choices with regard to managing future resource flows.

The following example illustrates the dynamics of stock growth for the Austrian freeway network in physical and economic terms. Figure A4 shows maximum expenditures for new freeways in the mid-1970s. Within a decade, there followed a corresponding increase of the length of the freeway network. During the 1970–95 period, expenditures for maintenance of the network increased more or less steadily. By the 1990s, the expenditures for maintenance exceeded expenditures for new freeways. This means that, of the limited resources available for freeway construction, an increasing portion is used for maintenance. This example also indicates that certain infrastructure stocks such as freeways seem to have reached a level of saturation in Austria, although they continue to consume a large amount of materials and money for maintenance. Other stocks, such as buildings, are still increasing, but they may follow the course of the freeway network.

Decoupling Economic Growth and Material Flows

Environmental problems are not a direct result of the monetary scale of an economy, but rather of its physical scale. This, in contrast to the growth critique of the 1970s, is the core idea of the "dematerialization" hypothesis, which dominates the sustainability debate. This hypothesis argues that a decoupling between GDP growth and material and energy flows is feasible and has already taken place in highly industrialized economies (Malenbaum, 1978; Jänicke et al., 1989; World Bank, 1992). Environmental Kuznets Curves (EKC: for an overview see *Ecological Economics*, Vol. 25/2, 1998) provide a framework for the analysis of the linkage between the economy in monetary terms (economic growth) and the associated physical flows (physical growth).

FIGURE A4 **ANNUAL GROWTH OF THE AUSTRIAN FREEWAY NETWORK AND CORRESPONDING EXPENDITURES, AUSTRIA 1970–1995**



The EKC approach first was applied to the relationship between income and toxic emissions (Selden and Song, 1994) and later to aggregate resource indicators (de Bruyn and Opschoor, 1997). Here, for the first time, we test the "dematerialization" hypothesis using aggregate output data. We analyze the relationship between GDP and DPO in an EKC framework.

As Figure A5 illustrates, there is a fairly random relationship between overall DPO and GDP. Overall DPO does not increase consistently with an increase in GDP, nor does it decrease, as the decoupling hypothesis would suggest. Upon closer inspection, it becomes obvious that this seemingly "random" relationship is due to a non-relationship of GDP and CO_2 emissions from fossil fuel combustion and industrial processes, whereas DPO to water and locally hazardous emissions to air are clearly negatively related to GDP growth. These results mirror the successful implementation of end-of-pipe technologies in Austria. A similarly strong decoupling effect can be observed for DPO to land (*see Figure A6*), which is the result of policy strategies that fostered a structural change from deposition of wastes to waste incineration and recycling. This confirms previous studies claiming that decoupling should only be expected for outputs that can be reduced by end-of-pipe technologies.

FIGURE A5 ECONOMIC PROSPERITY (GDP) IN RELATION TO OVERALL DPO AND CO_2 EMISSIONS FROM COMBUSTION OF FOSSIL FUELS AND INDUSTRIAL PROCESSES, AUSTRIA 1975–1996

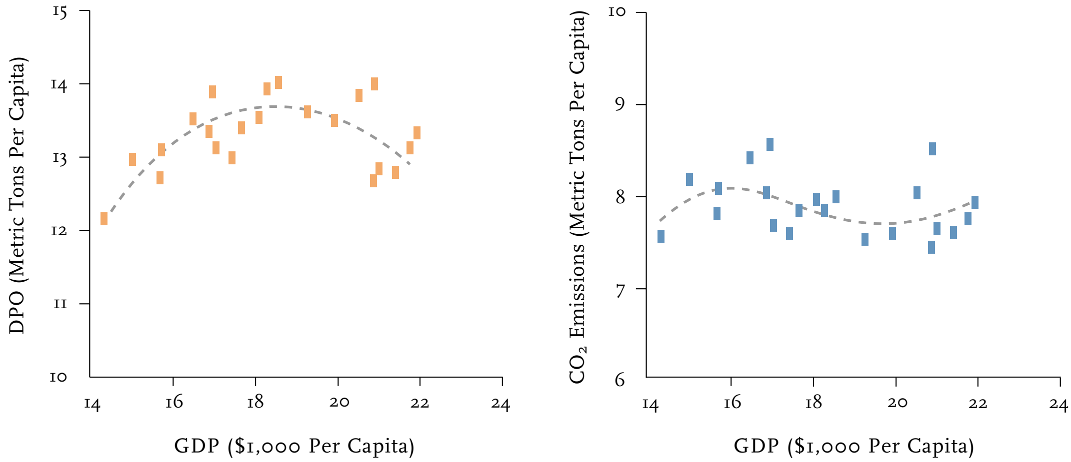
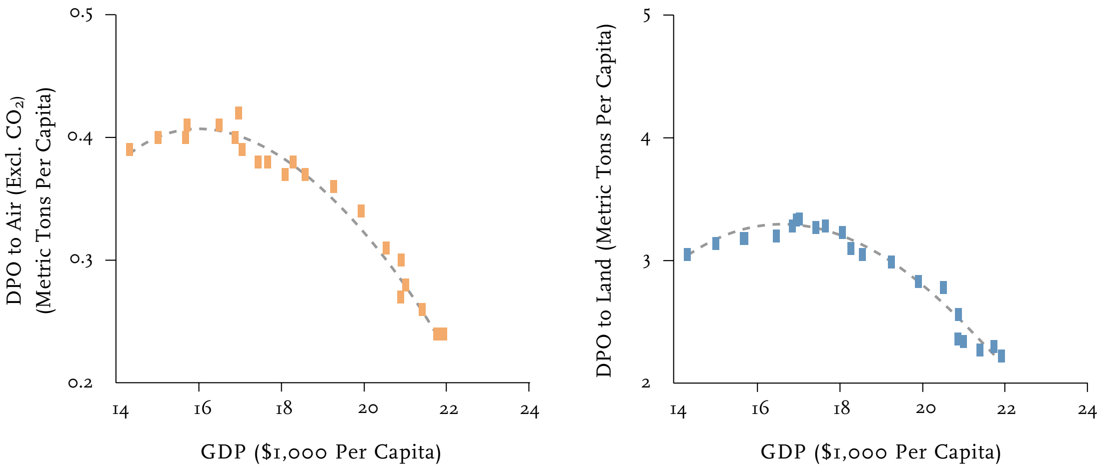


FIGURE A6 ECONOMIC PROSPERITY (GDP) IN RELATION TO DPO TO AIR (EXCLUDING CO_2) AND DPO TO LAND, AUSTRIA 1975–1996



Considering input and output flows of materials from an overall perspective, we can differentiate among three types of material flows. Each has a different logic with regard to decoupling and responds to different environmental policies:

1. *Outputs of toxic emissions*. These can be reduced by end-of-pipe technologies that shift the destination of output materials from one gateway to another. This was the first group of materials to be addressed by Austrian environmental policy. The policy has already led to the decoupling of DPO (to water, land, and air with the major exception of CO_2) from GDP growth.

2. *CO_2 emissions from fossil fuels*. These emissions are also strongly related to the input side, but end-of-pipe technologies have not yet been applied to them. CO_2 is not toxic, but the sheer volume of emissions is altering the earth's climate. Decoupling CO_2 output from GDP growth can probably be achieved only by reducing inputs. Environmental policies have recognized this problem, but have yet to implement successful strategies. Since decoupling has not taken place, the EKC shows no correlation.

3. *Bulk Input materials*. These are construction and other types of materials that are used in large quantities and are transformed into outputs after a long time lag. Although usually not toxic, they create environmental pressures because of their huge quantities, as well as positive feedback loops that may constrain future development. The goal for these materials must be resource management, but the government's environmental policy has not yet recognized this problem.

Political Responses to Material Flows

Over the past 30 years, Austrian environmental policy has sequentially addressed problems relating to specific environmental media, first concentrating on the quality of surface water, then on cleaner air and reduced emissions, and finally on land-based waste deposition (Amann and Fischer-Kowalski, forthcoming). Thus, the smallest material flows, namely material loads in wastewater, caused the first political response. It is surprising that the largest outflows did not become a policy focus until the 1990s, and even now the reduction of CO_2 seems to be beyond the capability of environmental policy.

The first environmental problem Austria tried to solve—even before the government established an environmental ministry—was the cleanup of lakes and rivers. Material loads in wastewater were (and still are) negligible compared to total DPO, amounting to 0.39 million metric tons in 1975 (0.05 metric tons per capita). Nevertheless the obvious impacts of water pollution negatively affected tourism, one of the most important economic sectors in Austria. Large investments in sewerage systems, wastewater treatment plants, and circular wastewater collection systems around lakes led to a substantial reduction in discharges of toxic and eutrophying substances into surface water. This policy was very expensive, but it has significantly improved the water quality of Austria's lakes and rivers. In 1996, DPO to water amounted to no more than 0.1 million metric tons (0.01 metric tons per capita).

In its second phase, Austrian environmental policy during the 1980s focused on air pollution. Acidifying substances like SO_2

were recognized as one of the main causes of forest dieback (Waldsterben). Forest owners feared for their trees, and municipal officials worried about both the effects of acid rain on historic buildings and major floods, which were expected to follow forest dieback. Through extensive regulations, Austrian policy-makers have made significant strides in reducing air pollutants. For instance, SO_2 emissions have been cut by more than 80 percent since the early 1980s.

For a long time, officials paid less attention to soil pollution and the problem of waste deposition. Dispersed materials such as sewage sludge, pesticides, and fertilizers, as well as leaking contaminated sites, threatened both soil quality and groundwater, the main source of drinking water in Austria. In 1990, the government enacted the Waste Management Act. The Act aimed to prevent waste generation and enforce recycling. Although the amount of waste generated in Austria is still increasing, waste deposition has generally decreased since the second half of the 1980s because of recycling activities and increased waste incineration. Incineration, however, has contributed to air emissions. In addition to regulatory policies, the government has used economic instruments effectively. For example, a tax on fertilizers led to a decrease in their use that continued even after the tax was abolished.

In the early 1990s, Austria emerged as a pioneer in international climate change policy. It accepted the "Toronto target" that called for a 20 percent reduction of CO_2 and other greenhouse gas emissions by 2005 (based on 1988 emissions). In 1998, the Kyoto Protocol set another goal: a 13 percent reduction by 2012, based on 1990 emissions. However, apart from some government measures to promote the use of renewable energy carriers and energy efficiency in buildings, climate change policy has been largely symbolic (Steurer, 1999). There is no indication that Austria will achieve its goals. Emissions of CO_2 have increased by 12 percent since 1988, with emissions continuing to trend upward in recent years.

How can material flow accounting help us to understand this sequence of environmental policy, and what are the advantages of such an approach in the future? The political system did not directly respond to the evidence of material flows in the first two phases, but to the likely consequences of ongoing environmental changes. Therefore it is necessary to take more factors into consideration. The effects of material flows are a result of their size, as well as the dimension and the quality of the receiving environment. (*See Table A1.*) For example, material loads in wastewater are small in quantitative terms, but lakes and rivers are very sensitive because of their physical and ecological characteristics. Other factors include the visibility of environmental changes and their effects on society. If powerful economic interests are adversely affected, the probability of a policy response increases. Pressure from the public, the media, or international communities may also lead to action.

In its first two phases, Austria's environmental policy focused on individual substances that could be regulated by end-of-pipe technology. The reduction of waste generation or emissions of CO_2 requires the application of more sophisticated instruments and a stronger degree of policy integration. Industrial economies increasingly will be faced with new types of environmental problems characterized by low visibility and long delays between socioeconomic activities and corresponding environmental impacts. Material flow analysis, as an overall information tool on environmental pressures, is the most promising instrument for future preventive environmental policies.

TABLE A1 POLITICAL RESPONSES TO MATERIAL FLOWS IN AUSTRIA

Environmental Policy Phase	**I**	**II**	**III**	**IV**
	1970s	1980s		1990s
Gateway	water	air/domestic	land	air/global atmosphere
Material flows	loads in waste water	air pollutants	waste and dispersed materials	greenhouse gases (CO_2 etc.)
Size of material flow	very small	small	medium	large
Affected environmental medium/issue	surface water	forests, historic buildings, human health	land (soil), groundwater, human health	global atmosphere, climate
Scale of environmental medium/issue	small	medium	medium	large
Direct visibility of effects	high	medium	low	very low
Economically interested environmental actors	tourism, construction industry	forest owners, municipalities, end-of-pipe technology industry	municipalities, waste management plants	agriculture, forestry, tourism
Environmental expenditure	high	medium	medium	low
Political responses	regulatory, end-of-pipe	regulatory, end-of-pipe	regulatory, (economic, societal)	mainly symbolic

Material Output Flows: Austria, 1975-1996

All units 1,000 metric tons unless otherwise stated

	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
Summary Data											
Population *(thousand capita)*	7,579	7,566	7,568	7,562	7,549	7,549	7,555	7,574	7,552	7,553	7,558
GDP	1,441	1,507	1,575	1,576	1,651	1,699	1,694	1,712	1,746	1,770	1,845
(constant 1996 billion Austrian schillings)											
Direct Material Input *(DMI)*	136,498	142,324	145,439	144,452	152,036	157,335	153,787	151,553	145,380	152,789	152,316
Domestic Extraction	109,619	111,622	114,801	112,384	115,946	120,510	117,939	117,306	112,473	115,132	113,078
Imports	26,879	30,701	30,638	32,068	36,090	36,825	35,848	34,248	32,906	37,657	39,238
Exports	10,428	11,956	11,730	12,819	14,564	15,085	15,317	15,299	16,505	18,198	18,279
Summary Indicators *(as presented in main report)*											
DPO *(including oxygen)*	85,710	91,586	89,694	92,352	95,439	98,373	94,224	92,828	91,415	94,411	95,594
DPO *(excluding oxygen)*	42,504	44,612	44,333	45,115	46,034	47,601	46,113	46,041	45,093	45,958	45,978
Domestic hidden flows	94,492	92,832	91,696	88,937	87,176	89,416	91,310	94,554	92,476	91,601	92,557
TDO *(including oxygen)*	180,202	184,417	181,390	181,289	182,615	187,789	185,534	187,383	183,891	186,012	188,151
TDO *(excluding oxygen)*	136,995	137,444	136,029	134,052	133,210	137,017	137,423	140,595	137,569	137,559	138,535
Net Additions to Stock	73,411	75,199	79,323	76,234	81,058	84,207	81,787	79,665	73,087	77,497	76,748
Summary Indicators *(metric tons per capita)*											
DPO *(including oxygen)*	11.31	12.10	11.85	12.21	12.64	13.03	12.47	12.26	12.10	12.50	12.65
DPO *(excluding oxygen)*	5.61	5.90	5.86	5.97	6.10	6.31	6.10	6.08	5.97	6.08	6.08
Domestic hidden flows	12.47	12.27	12.12	11.76	11.55	11.84	12.09	12.48	12.25	12.13	12.25
TDO *(including oxygen)*	23.78	24.37	23.97	23.97	24.19	24.88	24.56	24.74	24.35	24.63	24.89
TDO *(excluding oxygen)*	18.08	18.17	17.97	17.73	17.65	18.15	18.19	18.56	18.22	18.21	18.33
Net Additions to Stock	9.69	9.94	10.48	10.08	10.74	11.15	10.83	10.52	9.68	10.26	10.15
Summary Indicators including additional outputs *(not presented in main report)*											
DPO	92,195	98,107	96,260	99,059	102,089	104,891	100,867	99,484	98,137	101,195	102,335
(including carbon dioxide from respiration, excluding water vapor from all combustion & respiration)											
TDO	186,686	190,938	187,956	187,996	189,265	194,307	192,177	194,038	190,612	192,796	194,891
(including carbon dioxide from respiration, excluding water vapor from all combustion & respiration)											
Domestic Extraction	109,619	111,622	114,801	112,384	115,946	120,510	117,939	117,306	112,473	115,132	113,078
Fossils	7,220	6,769	6,726	6,694	6,218	5,782	5,487	5,590	5,229	5,070	5,109
Lignite & Hard Coal	3,397	3,215	3,127	3,076	2,741	2,865	3,061	3,297	3,041	2,901	3,081
Crude Oil	2,037	1,931	1,787	1,790	1,726	1,475	1,338	1,290	1,269	1,205	1,147
Natural Gas	1,786	1,624	1,812	1,828	1,751	1,441	1,088	1,003	919	963	881
Minerals	66,702	69,158	72,064	70,134	73,312	76,416	75,153	71,914	70,942	71,895	69,233
Ores & Industrial Minerals *(incl. salt)*	7,264	7,172	6,763	6,126	6,929	7,506	7,165	7,342	7,550	8,010	7,585
Construction Minerals *(incl. clay)*	59,437	61,986	65,301	64,008	66,383	68,910	67,988	64,572	63,392	63,885	61,649
Biomass	35,697	35,696	36,011	35,556	36,416	38,313	37,300	39,802	36,303	38,166	38,735
Agricultural Products	27,739	26,208	27,280	26,931	26,202	28,097	27,482	30,752	26,955	28,495	29,410
Wood	7,012	8,590	7,821	7,705	9,315	9,304	8,889	8,102	8,532	8,846	8,492
Grazing	946	898	909	920	899	912	929	947	816	825	833
Gateway Indicators											
DPO to Air	68,876	74,131	71,995	74,755	77,716	79,531	75,868	73,974	73,285	76,309	77,784
CO_2 from fossil fuel combustion											
& industrial processes	57,400	62,000	59,200	61,200	63,600	64,730	60,710	58,250	57,410	59,300	60,240
CO_2 from biomass combustion	1,902	2,435	2,968	3,500	4,033	4,710	5,020	5,700	5,830	6,760	7,370
CO_2 from respiration	6,484	6,521	6,566	6,707	6,650	6,517	6,643	6,656	6,721	6,784	6,740
(included in Austrian country report, not included in main report)											
SO_2	314	333	352	372	391	400	349	329	246	218	196
NO_x	204	209	215	220	225	234	226	224	223	222	225
NMVOC	511	513	514	516	518	519	519	517	520	527	526
CH_4	191	190	189	187	186	178	177	178	181	185	185
CO	1,589	1,600	1,612	1,623	1,635	1,691	1,625	1,564	1,529	1,583	1,530
N_2O	1	2	2	2	2	2	2	2	2	2	2
NH_3	84	84	84	83	83	80	80	81	82	83	83
Dust	72	73	75	76	77	79	76	73	70	64	58
Bunker Fuel Emissions											
CO_2 from bunkers	123	171	219	268	316	390	440	400	470	580	630

Material Output Flows: Austria, 1975-1996

All units 1,000 metric tons unless otherwise stated

1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	
											Summary Data
7,566	7,576	7,596	7,624	7,718	7,796	7,914	7,991	8,030	8,047	8,059	Population (thousand capita)
1,888	1,920	1,981	2,065	2,159	2,233	2,263	2,274	2,328	2,368	2,415	GDP
											(constant 1996 billion Austrian schillings)
151,551	152,704	155,676	161,190	164,838	163,372	166,081	166,259	176,292	174,299	176,084	Direct Material Input *(DMI)*
112,641	113,024	114,702	119,360	121,125	116,960	119,352	120,567	127,075	121,705	120,710	Domestic Extraction
38,910	39,680	40,974	41,829	43,713	46,411	46,730	45,692	49,217	52,594	55,375	Imports
18,050	18,718	20,038	20,980	22,259	21,808	22,222	22,638	25,283	28,107	28,742	Exports
											Summary Indicators *(as presented in main report)*
98,693	99,564	96,863	96,297	100,189	102,499	95,130	94,564	95,963	98,891	100,818	DPO *(including oxygen)*
46,161	46,029	44,949	43,859	44,676	44,158	40,991	41,022	40,944	41,858	41,910	DPO *(excluding oxygen)*
91,303	89,383	79,584	80,561	85,734	81,215	76,823	75,536	73,981	73,565	70,530	Domestic hidden flows
189,996	188,947	176,447	176,858	185,923	183,713	171,953	170,101	169,944	172,456	171,348	TDO *(including oxygen)*
137,464	135,412	124,533	124,421	130,410	125,372	117,814	116,558	114,925	115,423	112,440	TDO *(excluding oxygen)*
76,255	76,864	79,801	84,789	85,821	85,132	91,209	90,605	98,035	91,855	92,718	Net Additions to Stock
											Summary Indicators *(metric tons per capita)*
13.04	13.14	12.75	12.63	12.98	13.15	12.02	11.83	11.95	12.29	12.51	DPO *(including oxygen)*
6.10	6.08	5.92	5.75	5.79	5.66	5.18	5.13	5.10	5.20	5.20	DPO *(excluding oxygen)*
12.07	11.80	10.48	10.57	11.11	10.42	9.71	9.45	9.21	9.14	8.75	Domestic hidden flows
25.11	24.94	23.23	23.20	24.09	23.57	21.73	21.29	21.16	21.43	21.26	TDO *(including oxygen)*
18.17	17.87	16.39	16.32	16.90	16.08	14.89	14.59	14.31	14.34	13.95	TDO *(excluding oxygen)*
10.08	10.15	10.51	11.12	11.12	10.92	11.53	11.34	12.21	11.42	11.50	Net Additions to Stock
											Summary Indicators including additional outputs *(not presented in main report)*
105,377	106,240	103,440	102,910	106,824	109,117	101,642	101,305	102,680	105,617	107,448	DPO
											(including carbon dioxide from respiration, excluding water vapor from all combustion & respiration)
196,680	195,623	183,025	183,471	192,558	190,331	178,465	176,841	176,661	179,182	177,978	TDO
											(including carbon dioxide from respiration, excluding water vapor from all combustion & respiration)
112,641	113,024	114,702	119,360	121,125	116,960	119,352	120,567	127,075	121,705	120,710	**Domestic Extraction**
4,927	4,732	4,262	4,226	4,572	4,368	4,022	3,974	3,498	3,445	3,230	Fossils
2,969	2,786	2,129	2,066	2,448	2,081	1,751	1,692	1,372	1,289	1,108	Lignite & Hard Coal
1,117	1,063	1,175	1,158	1,149	1,280	1,180	1,155	1,100	1,035	992	Crude Oil
842	884	958	1,002	975	1,007	1,091	1,127	1,026	1,122	1,130	Natural Gas
70,612	71,324	72,298	76,711	78,589	79,011	84,870	84,266	89,282	83,365	82,669	Minerals
6,932	6,585	6,039	6,311	6,061	5,305	4,981	4,233	4,511	5,204	4,870	Ores & Industrial Minerals *(incl. salt)*
63,680	64,739	66,259	70,401	72,529	73,707	79,889	80,033	84,771	78,162	77,799	Construction Minerals *(incl. clay)*
37,102	36,967	38,142	38,423	37,963	33,581	30,460	32,327	34,295	34,894	34,811	Biomass
27,369	27,504	27,943	27,467	25,676	24,409	20,738	22,601	22,983	23,934	22,969	Agricultural Products
8,861	8,590	9,333	10,097	11,477	8,395	8,947	8,954	10,490	10,085	10,965	Wood
872	874	866	859	810	778	775	772	822	875	876	Grazing
											Gateway Indicators
81,819	83,115	80,681	81,331	85,369	89,179	83,155	82,509	84,486	87,126	89,594	**DPO to Air**
											CO_2 from fossil fuel combustion
59,360	60,640	57,250	57,970	62,040	66,440	60,530	59,530	61,070	62,430	64,030	& industrial processes
12,260	12,350	13,320	13,140	13,380	12,710	12,770	12,980	13,410	14,690	15,540	CO_2 from biomass combustion
6,685	6,676	6,577	6,614	6,635	6,618	6,512	6,741	6,717	6,726	6,630	CO_2 from respiration
											(included in Austrian country report, not included in main report)
177	160	115	102	91	83	64	60	56	52	52	SO_2
221	217	209	202	200	205	196	183	191	178	171	NO_x
539	542	545	534	516	488	462	450	439	435	426	NMVOC
187	184	184	176	171	161	160	164	167	168	167	CH_4
1,624	1,577	1,528	1,462	1,288	1,269	1,188	1,161	1,133	1,016	1,024	CO
3	3	3	3	3	4	4	4	4	4	4	N_2O
83	82	81	79	76	73	75	76	78	78	77	NH_3
51	45	40	39	39	38	35	32	30	27	24	Dust
											Bunker Fuel Emissions
630	640	830	1,010	930	1,090	1,160	1,130	1,190	1,320	1,450	CO_2 from bunkers

Material Output Flows: Austria, 1975-1996

All units 1,000 metric tons unless otherwise stated

	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
DPO to Land	22,932	23,591	23,881	23,922	23,992	24,979	24,642	25,177	24,544	24,602	24,292
Waste disposal to controlled landfills	12,493	12,645	12,797	12,949	13,101	13,256	13,411	13,566	13,143	12,775	12,422
Dissipative losses from roads & tyres	219	234	246	268	281	281	265	273	272	248	261
Dissipative uses *(agriculture)*	9,373	9,864	9,988	9,853	9,755	10,442	9,993	10,324	10,398	10,730	10,600
Mineral fertilizer *(total weight)*	1,134	1,196	1,468	1,305	1,321	1,487	1,433	1,268	1,151	1,143	1,312
Organic manure	7,398	7,825	7,651	7,688	7,566	8,079	7,669	8,157	8,331	8,678	8,369
(excrements, straw, ...)											
Pesticides *(total weight)*	17	17	19	18	20	18	19	18	23	25	27
Other	825	826	850	841	847	858	872	882	893	884	892
(sewage sludge, seeds, compost, ...)											
Dissipative uses	846	848	850	852	854	1,000	972	1,014	732	849	1,009
(thawing & grit materials)											
DPO to Water	387	385	383	382	381	380	357	333	308	283	259
Organic carbon in waste water	314	312	311	310	309	309	286	263	240	217	194
Nitrogen in waste water	35	35	35	36	36	36	36	36	35	35	34
Phosphorus in waste water	7	7	7	7	7	7	7	7	7	7	7
AO_x in waste water	30	30	30	29	29	28	28	27	26	25	24
Additional Inputs	80,778	86,827	84,691	88,130	91,030	90,936	88,102	86,211	85,969	89,482	90,807
(not presented in main report)											
Oxygen in combustion	62,249	67,939	65,940	68,614	71,731	72,300	68,738	66,950	66,703	69,844	71,604
Oxygen in respiration	5,671	5,703	5,740	5,864	5,815	5,696	5,804	5,816	5,876	5,934	5,896
Water	12,452	12,718	12,534	13,167	12,953	12,436	13,063	12,947	12,883	13,192	12,860
Nitrogen	406	467	477	485	531	504	498	498	507	512	446
(for the production of ammonia)											
Additional Outputs	23,182	25,564	24,650	25,588	26,738	26,063	25,200	24,708	25,029	26,437	27,180
(not presented in main report)											
Water vapor from combustion											
of fossil fuels & biomass	23,182	25,564	24,650	25,588	26,738	26,063	25,200	24,708	25,029	26,437	27,180
Water vapor from respiration	18,060	18,325	18,166	18,881	18,617	18,025	18,718	18,608	18,591	18,944	18,582
Domestic Hidden Flows	94,492	92,832	91,696	88,937	87,176	89,416	91,310	94,554	92,476	91,601	92,557
Excavated soil	25,312	25,732	26,154	26,577	27,002	27,428	27,856	28,286	28,717	29,150	29,584
Overburden/Ancillary flows	42,641	40,342	39,212	38,589	34,486	35,791	38,039	40,857	37,734	36,005	38,131
(fossil fuels)											
Overburden/Ancillary flows	14,396	14,052	13,020	10,815	12,342	12,370	11,715	12,641	13,394	13,717	12,617
(ores & industrial minerals)											
Overburden/Ancillary flows	12,142	12,705	13,311	12,955	13,346	13,826	13,700	12,770	12,630	12,729	12,224
(construction minerals)											

Material Output Flows: Austria, 1975-1996

All units 1,000 metric tons unless otherwise stated

1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	
23,329	22,926	22,588	21,426	21,318	19,818	18,369	18,682	18,082	18,382	17,748	**DPO to Land**
12,082	11,760	11,343	10,939	10,396	9,919	9,441	8,958	8,739	8,612	8,582	Waste disposal to controlled landfills
270	250	286	297	321	365	384	400	452	431	456	Dissipative losses from roads & tyres
10,044	10,079	10,194	9,876	9,942	8,734	7,909	8,003	8,146	8,161	7,632	Dissipative uses *(agriculture)*
1,030	1,281	1,056	1,088	1,067	994	919	995	860	938	915	Mineral fertilizer *(total weight)*
8,086	7,908	8,249	7,918	8,019	6,872	6,103	6,105	6,374	6,281	5,805	Organic manure *(excrements, straw, ...)*
22	25	25	25	25	26	22	20	24	49	27	Pesticides *(total weight)*
905	865	863	845	831	842	866	884	887	894	884	Other *(sewage sludge, seeds, compost, ...)*
933	837	765	315	659	799	635	1,320	746	1,177	1,078	Dissipative uses *(thawing & grit materials)*
229	200	171	153	136	120	118	114	112	109	106	**DPO to Water**
166	137	109	95	80	65	63	62	61	60	58	Organic carbon in waste water
34	33	34	32	32	31	33	31	30	29	29	Nitrogen in waste water
7	7	7	6	6	6	6	5	5	5	5	Phosphorus in waste water
23	22	22	20	19	18	17	16	15	14	14	AO_x in waste water
93,938	95,728	93,144	95,661	99,709	103,972	98,488	99,574	101,454	104,926	108,141	**Additional Inputs** *(not presented in main report)*
75,057	76,625	74,465	77,031	81,240	85,707	80,414	80,656	82,648	85,842	89,315	Oxygen in combustion
5,847	5,837	5,752	5,781	5,804	5,785	5,690	5,897	5,877	5,885	5,801	Oxygen in respiration
12,659	12,854	12,509	12,416	12,277	12,079	12,020	12,625	12,555	12,800	12,616	Water
375	411	419	432	389	401	364	396	375	399	409	Nitrogen *(for the production of ammonia)*
27,458	28,081	27,418	30,121	31,697	33,546	31,862	32,811	33,349	34,982	36,888	**Additional Outputs** *(not presented in main report)*
27,458	28,081	27,418	30,121	31,697	33,546	31,862	32,811	33,349	34,982	36,888	Water vapor from combustion of fossil fuels & biomass
18,349	18,530	18,122	18,050	17,947	17,740	17,635	18,474	18,399	18,665	18,429	Water vapor from respiration
91,303	89,383	79,584	80,561	85,734	81,215	76,823	75,536	73,981	73,565	70,530	**Domestic Hidden Flows**
30,020	30,458	30,897	31,338	31,780	32,224	32,669	33,116	33,565	34,015	34,467	Excavated soil
36,751	34,501	26,641	25,866	30,483	26,128	22,075	21,345	17,399	16,372	14,181	Overburden/Ancillary flows *(fossil fuels)*
11,970	11,681	9,120	9,556	9,149	8,301	6,551	5,665	6,590	8,229	7,121	Overburden/Ancillary flows *(ores & industrial minerals)*
12,562	12,744	12,927	13,801	14,322	14,563	15,528	15,410	16,427	14,949	14,762	Overburden/Ancillary flows *(construction minerals)*

Data Sources and Methodology: Technical Notes

General Notes on Quality of Data

Austrian official statistics do not provide comprehensive data on material outflows from economic activities and the quality of data varies widely, depending on the material category and the period of time. Data on hidden flows are not available at all. Except for some specific flows reported in official statistics, most data in this report derive from our own calculations. Nevertheless, the dataset provides a good overview for material trends between 1975 and 1996.

Domestic Processed Output to Air

Official data on emissions to air (including international bunkers according to Intergovernmental Panel on Climate Change [IPCC] format) are available for CO_2, SO_2, NO_x, NMVOC, CH_4, CO, N_2O, and NH_3 from 1980 to 1996 in time series (Ritter and Ahamer, 1999; Ritter and Raberger, 1999). CH_4 from agriculture (excluding enteric fermentation) and forestry, waste treatment and landfills, and N_2O from agriculture and forestry were subtracted to avoid double-counting. Time series from 1975 to 1979 were completed using trend estimations.

To balance inputs and outputs, we also estimated emissions of water vapor and CO_2 from respiration. Water vapor emissions from water and H-content in energy carriers were calculated using data from energy statistics (OESTAT) and factors according to Schütz (1999, personal communication). CO_2 and water vapor emissions from human and livestock metabolism were calculated using factors from Moll (1996) and Schütz (1999, personal communication).

Domestic Processed Output to Land

Reliable official data on the total amount of waste produced by households and similar institutions are available for 1989 to 1996 (BMUJF, 1992, 1995, 1998). For 1972, 1979, 1983, and 1987, the Austrian Federal Institute on Public Health conducted surveys on waste from households (OEBIG, 1974, 1981, 1985, 1989). We calculated a complete time series by using several assumptions and filling remaining data gaps by interpolation. A 1980s survey by the Austrian Federal Chamber of Commerce (Bundeskammer für gewerbliche Wirtschaft, 1991) was a major source for our estimates of the percentage of deposited waste that industry and commerce produces. The agricultural statistics (OESTAT) represent the most important source for dissipative flows (such as mineral fertilizer and organic manure).

Domestic Processed Output to Water

DPO to water includes emissions of organic carbon, nitrogen, phosphorus, and AOX from municipal sewage treatment plants, direct (dispersed) emissions from households, and emissions from industry. For these three categories, consistent data are available for 1991 and 1995 (BMLF, 1990 ff.; BMLF Wasserwirtschaftskataster, 1985, 1991, 1995, 1999). We calculated data for the other years by using statistics on households connected to municipal wastewater collection systems, as well as information on the capacity and the efficiency of the sewage treatment plants. Data for direct emissions from households were calculated and cross-checked with the results of a specific survey about nutrient flows in the Danube basin (Kroiss et al., 1998).

Input Flows

Most of the primary data incorporated in the calculation of the material input flows are periodically included in the official statistics by OESTAT and BMwA. For some aggregates, like sand, gravel, and crushed stone, or animal grazing, we had to rely on our own calculations and estimations (Hüttler et al., 1999; Schandl et al., 2000).

Domestic Hidden Flows

Domestic hidden flows were calculated using data on domestic extraction of minerals and fossils (Hüttler et al., 1999; Schandl et al., 2000) and factors according to Schütz/Bringezu (1998) with the exception of lignite, hard coal, iron ores, tungsten ores, lead and zinc ores, salt, and "magnesit" where specific Austrian factors were available or factors from other sources were used. The results should be viewed as a first approximation, because data transferability of factors calculated for countries other than Austria could not be checked in every single case. Soil excavation was calculated based on a time series of annual area covered by construction of new buildings (OESTAT). Soil erosion and dredging materials were not estimated due to a lack of sound data.

Additional Inputs

Additional oxygen in CO_2 from the combustion of fossil fuels and biomass was calculated using atomic weights. Oxygen for human and livestock respiration was estimated with factors by Moll (1996) and Schütz (personal communication, 1999). Some water had to be added on the input side to support an accurate balance of livestock metabolism. Data on additional inputs of nitrogen from air for the production of ammonia come from the chemical industry.

Economic Sector Indicators

Sectoral indicators could be calculated on the basis of NAMEA 1994 (Wolf et al., 1999) using several assumptions. Data for 1996 were extrapolated from 1994 data for emission to air and hazardous waste.

NOTES

1. In this country annex, DPO to air includes CO_2 from human and livestock respiration (Fischer-Kowalski and Hüttler, 1999). Consequently, some indicators differ slightly from those presented in the main report.

2. For the purposes of this study, stock changes are calculated as the difference between direct material input (DMI) plus additional inputs (such as oxygen) minus exports, domestic processed output (DPO), and additional outputs (water vapor). Stock changes therefore include statistical differences. Because of these additional inputs and outputs, DMI, DPO, and NAS cannot be compared directly.

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MATERIAL FLOWS: GERMANY

Stefan Bringezu, Helmut Schütz

Highlights

The following results, unless otherwise stated, refer to material outputs, excluding water vapor emissions from the combustion of energy carriers, human and animal livestock respiration, and evaporation from domestic biomass.

Time series for socioeconomic and material flow data in Germany reflect the reunification of Federal Republic of Germany with the former German Democratic Republic in 1990–91. Data presented here for 1975–1990 refer to Federal Republic of Germany only, data for 1991–1996 refer to reunified Germany. Population and GDP in the reunified Germany were 26 percent and GDP 24 percent higher, respectively, than in Federal Republic of Germany. In the Federal Republic of Germany, population had been relatively constant over the whole period from 1975 to 1990. Between 1991 and 1996, German population increased by another 2.6 percent.

FIGURE A1 | TDO AND DPO PER CAPITA, GERMANY 1975–1996

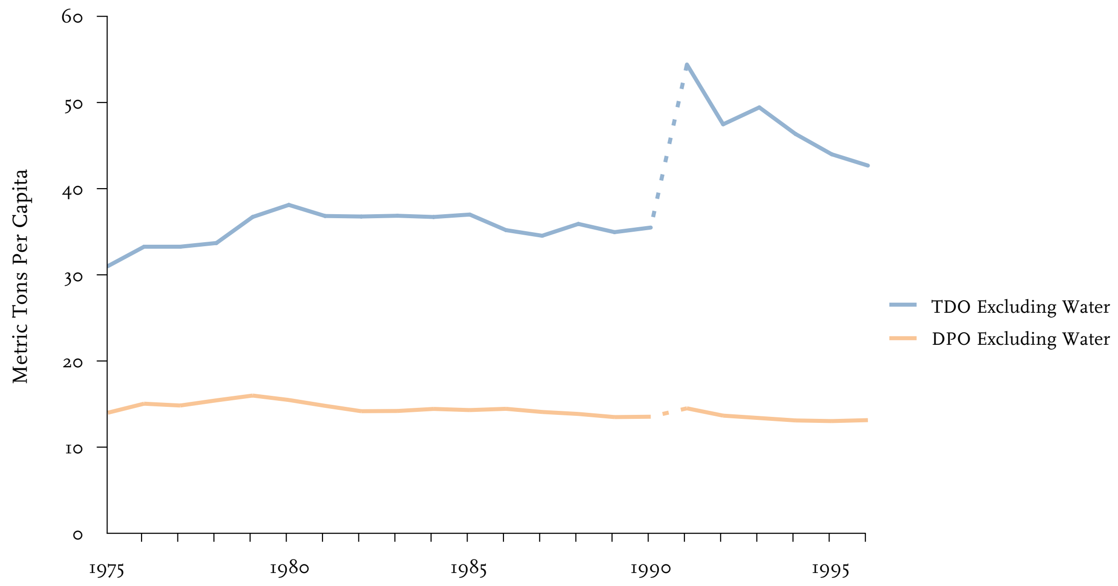
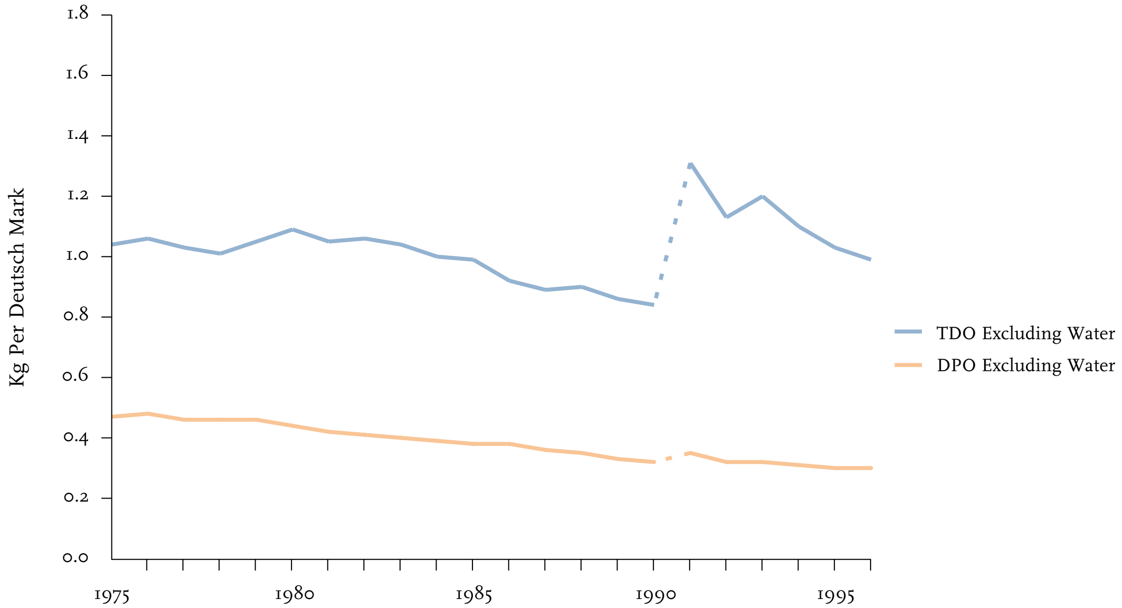


FIGURE A2 TDO AND DPO PER CONSTANT UNIT OF GDP, GERMANY 1975–1996



Domestic processed output (DPO) was almost constantly high in both the Federal Republic of Germany and reunited Germany with values around 15 metric tons per capita. (*See Figure A1.*) In contrast, total domestic output (TDO) increased significantly with reunification, rising to 54 metric tons per capita, compared to about 30 to 40 metric tons per capita in Federal Republic of Germany. This was due to the inclusion in the accounts of overburden from lignite mines in the eastern part of the country, some of which have been closed in recent years. However, lignite mining is still ongoing in Germany. Mining has been at the center of regional political debate because some villages have had to be abandoned to make way for mining excavation. Most of the hidden flows from mining are included in official German waste statistics.

During 1975–96, both DPO and TDO rose more slowly than economic growth. Thus, we can record a decoupling between physical throughput and economic performance. (*See Figure A2.*)

Despite the different levels of TDO in Federal Republic of Germany and reunited Germany, their composition, in terms of the main material constituents, was similar for both periods. Landfill and mine dumping,

CO_2 emissions to air, and excavation of soil for construction of infrastructure dominated outputs to the environment. (*See Figure A3.*) However, quantities of outputs from landfill and mine dumping accounted for a significantly higher proportion of TDO in reunited Germany.

With respect to environmental gateways, about 90 percent of DPO is emitted to the atmosphere. Dissipative outflows make up around 3 to 4 percent of DPO to air, the remainder being almost exclusively DPO to land. DPO to water is negligible in terms of flow volumes.

CO_2 dominates DPO to air throughout the study period, while such pollutants as SO_2 and NO_2, although important with respect to their environmental impacts, contribute little to the overall volume. (*See Table A1.*)

Mining wastes (mainly from open-pit lignite mining) and soil excavation for construction, to a much lesser extent in the reunited Germany, dominate domestic hidden flows, which account for a high proportion of TDO in Germany. (*See Figure A4.*) Soil erosion and dredging excavation contribute a significantly lower share to domestic hidden flows.

FIGURE A3 | COMPOSITION OF TDO, GERMANY 1975–1996

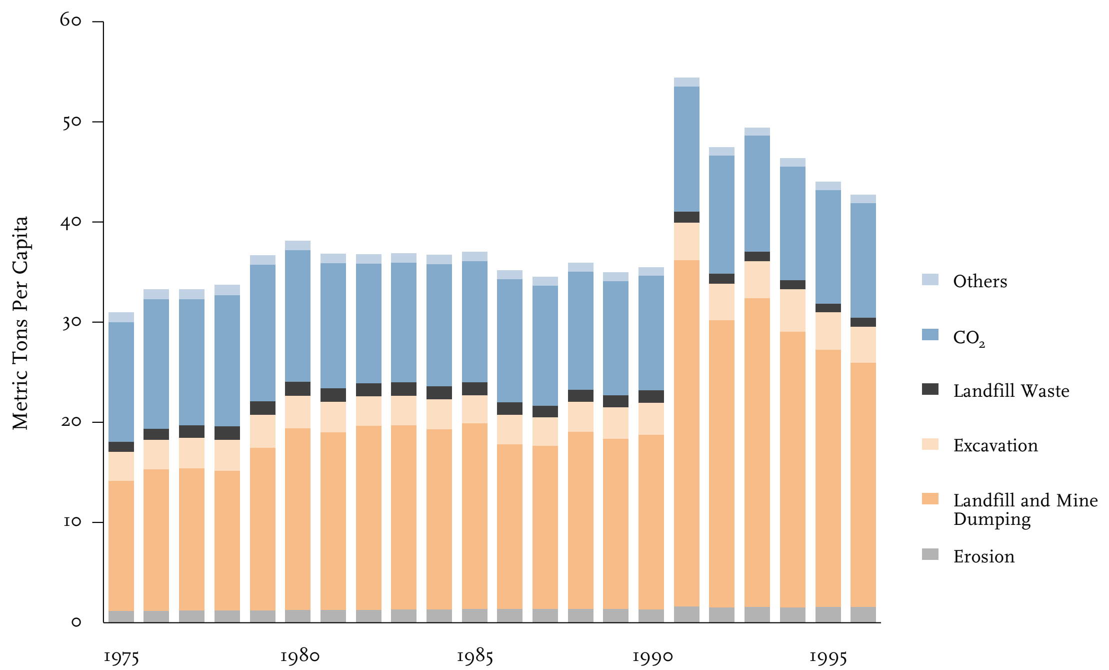


TABLE A1 | CO_2 AND OTHER EMISSIONS TO AIR, EXCLUDING WATER VAPOR, GERMANY 1975–1996

	Federal Republic of Germany		Reunified Germany	
	1975	1990	1991	1996
Million Metric Tons				
CO_2	741	726	995	938
Other emissions to air	26	17	24	16
TOTAL	767	743	1019	954
Metric Tons Per Capita				
CO_2	12.0	11.5	12.5	11.5
Other emissions to air	0.4	0.3	0.3	0.2
TOTAL	12.4	11.8	12.8	11.7

FIGURE A4 | COMPOSITION OF DOMESTIC HIDDEN FLOWS, GERMANY 1975–1996

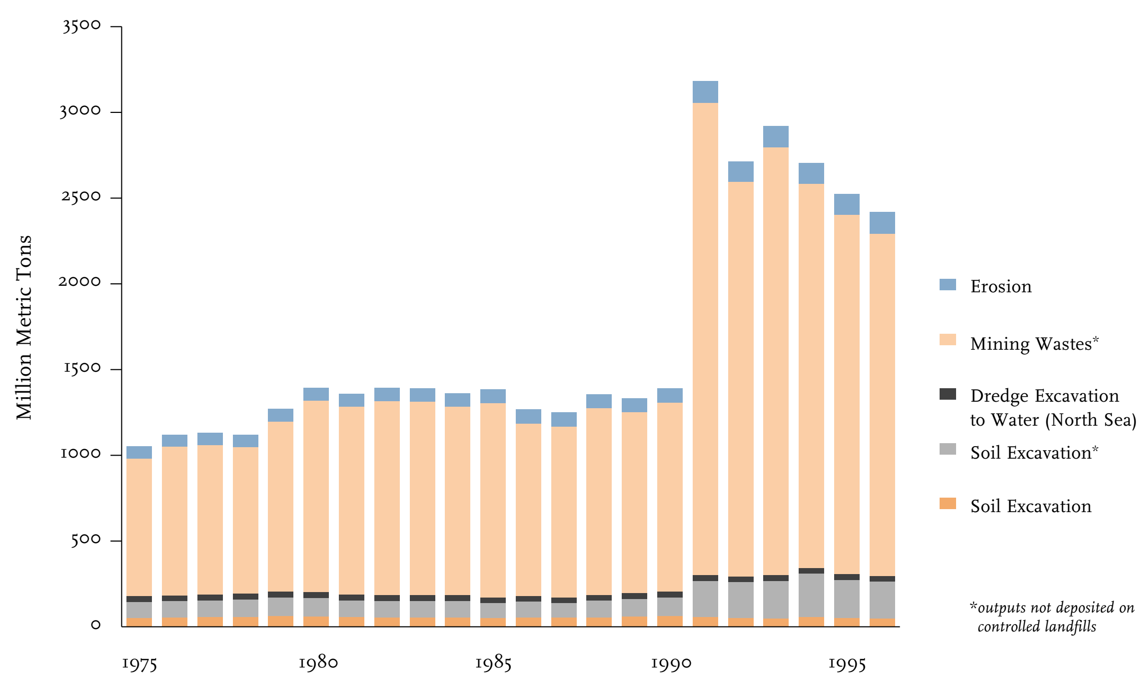


FIGURE A5

SELECTED MATERIAL OUTPUT FLOWS (INDEX), GERMANY 1995–1996

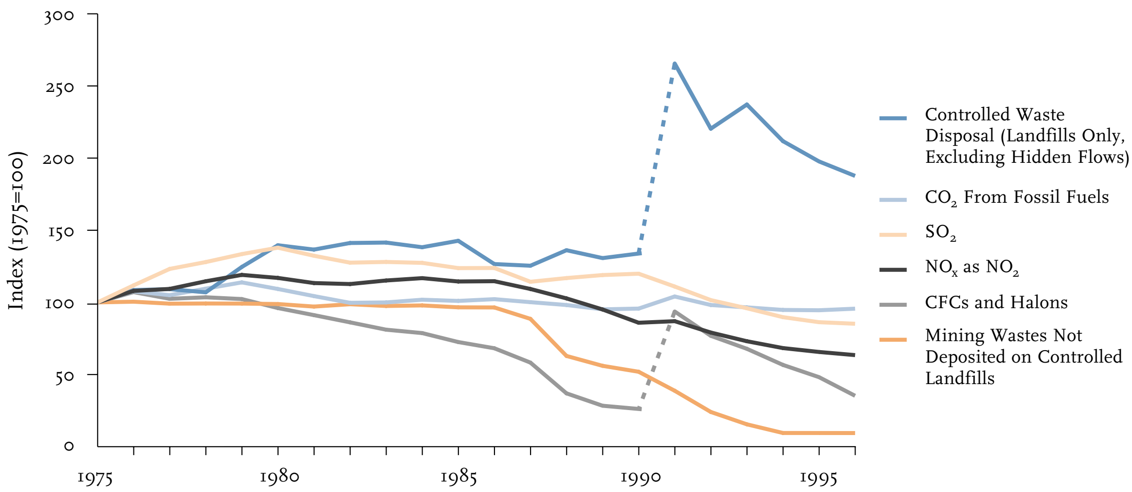
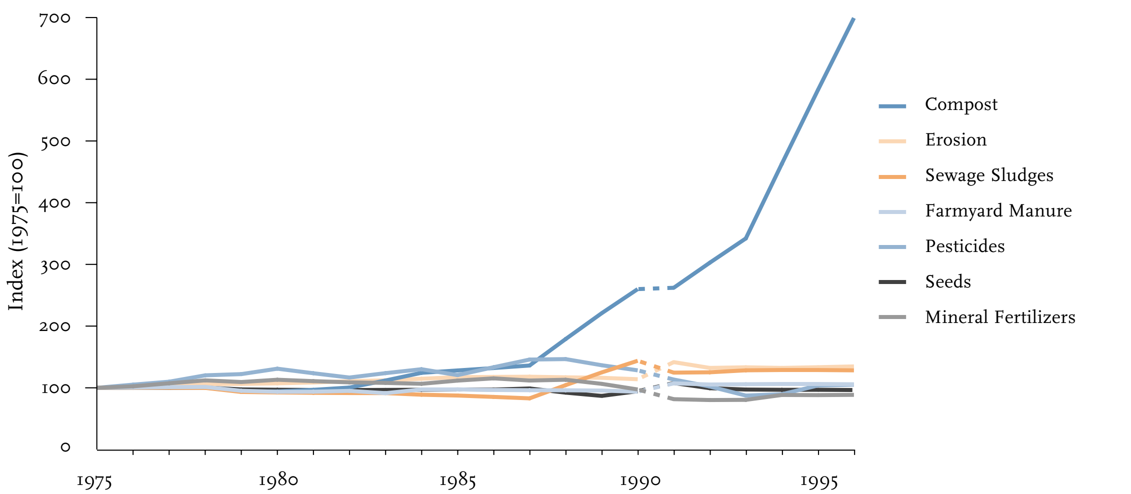


FIGURE A6

MATERIAL OUTPUT FLOWS TO AGRICULTURAL FIELDS (INDEX), GERMANY 1995–1996

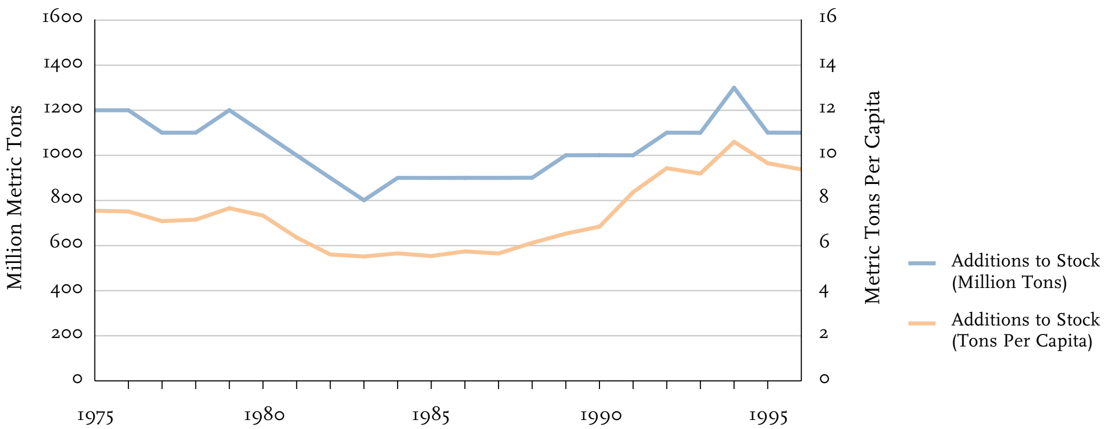


For selected material flows, we recorded some interesting temporal trends. (*See Figure A5.*) Mining wastes for landfills (not disposed of in controlled waste disposal sites) increased immediately after reunification and then decreased until 1996. This was due to the phase-out of lignite mining facilities in the eastern part of Germany. The decline of CFCs and halons is particularly obvious. As with SO_2 emissions, these are examples of material outputs declining because of effective policy regulations. Nevertheless, the overall increase in DPO and TDO indicates that these regulations did not reduce total output flows.

Among dissipative uses of products on agricultural fields, compost shows a significant increase over the study period. (*See Figure A6.*) The application of sewage sludge also reached a higher level in the reunited Germany in the 1990s compared to the level in the Federal Republic of Germany. The increase in the use of compost and sewage sludge should be interpreted as positive trends, indicating a higher recycling of nutrients via agriculture. These materials can be substituted for mineral fertilizer to a certain extent, thus contributing to reduced resource requirement.

Net additions to stock in the German economy exhibit an interesting trend. (*See Figure A7.*) After a period of heavy construction activities in Federal Republic of Germany from 1975 to 1980, net additions of material were lower between 1981 and 1987, then increased again in 1988 to 1990, but did not reach the high levels of the 1970s. After reunification, renovation and construction of new homes in the eastern part of Germany led to another increase. On a per capita basis, material additions to stock in the reunited Germany range from about 10 to 13 metric tons per capita. No continuously declining trend can be detected, which indicates that pressure on the environment associated with the physical growth of the technosphere is still increasing.

FIGURE A7 | NET ADDITIONS TO STOCK, GERMANY 1975–1996



Material Output Flows: Germany, 1975-1996

Data apply to Federal Republic of Germany 1975-1990, Reunited Germany 1991-1996
All units in 1,000 metric tons, unless otherwise stated

	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
Summary Data											
Population *(1,000)*	61,829	61,531	61,400	61,327	61,359	61,566	61,682	61,638	61,423	61,175	61,024
GDP *(constant 1996 million DM)*	1,838,508	1,936,705	1,991,827	2,051,473	2,135,862	2,158,780	2,162,542	2,142,072	2,175,513	2,236,058	2,278,334
Direct Material Input *(DMI)*	1,405,111	1,431,295	1,401,139	1,444,061	1,511,161	1,467,775	1,360,260	1,265,294	1,244,332	1,283,449	1,266,717
Domestic Extraction	1,089,418	1,086,488	1,063,563	1,088,454	1,125,245	1,093,525	1,019,062	940,004	920,348	946,572	923,626
Imports	315,693	344,807	337,576	355,607	385,916	374,250	341,198	325,290	323,984	336,877	343,091
Exports	130,143	133,475	141,896	161,575	164,285	162,270	161,030	152,643	155,398	167,749	166,161
Summary Indicators *(as presented in main report)*											
DPO *(including oxygen)*	865,312	925,639	910,647	946,433	980,993	952,674	912,738	873,559	872,103	883,203	872,771
DPO *(excluding oxygen)*	315,497	337,269	338,235	350,559	361,577	356,170	342,295	329,016	328,214	331,449	327,024
Domestic hidden flows	1,051,855	1,121,000	1,131,816	1,119,830	1,271,780	1,393,984	1,358,900	1,392,790	1,391,674	1,362,767	1,384,862
TDO *(including oxygen)*	1,917,167	2,046,639	2,042,464	2,066,263	2,252,773	2,346,659	2,271,638	2,266,349	2,263,776	2,245,970	2,257,633
TDO *(excluding oxygen)*	1,367,353	1,458,270	1,470,052	1,470,388	1,633,358	1,750,155	1,701,194	1,721,805	1,719,887	1,694,216	1,711,887
Net Additions to Stock	754,515	751,473	708,318	714,874	765,588	733,022	635,778	560,348	551,687	565,279	553,654
Summary Indicators *(metric tons per capita)*											
DPO *(including oxygen)*	14.00	15.04	14.83	15.43	15.99	15.47	14.80	14.17	14.20	14.44	14.30
DPO *(excluding oxygen)*	5.10	5.48	5.51	5.72	5.89	5.79	5.55	5.34	5.34	5.42	5.36
Domestic hidden flows	17.01	18.22	18.43	18.26	20.73	22.64	22.03	22.60	22.66	22.28	22.69
TDO *(including oxygen)*	31.01	33.26	33.26	33.69	36.71	38.12	36.83	36.77	36.86	36.71	37.00
TDO *(excluding oxygen)*	22.12	23.70	23.94	23.98	26.62	28.43	27.58	27.93	28.00	27.69	28.05
Summary Indicators including additional outputs *(not presented in main report)*											
DPO	910,203	970,544	956,019	992,270	1,026,927	998,671	958,596	919,665	918,911	929,989	919,598
(including carbon dioxide from respiration, excluding water vapor from all combustion & respiration)											
DPO	1,271,886	1,357,124	1,338,828	1,392,479	1,446,588	1,404,696	1,348,684	1,292,887	1,294,906	1,312,362	1,297,754
(including carbon dioxide from respiration, including water vapor from all combustion & respiration)											
TDO	1,962,058	2,091,544	2,087,835	2,112,100	2,298,707	2,392,656	2,317,495	2,312,455	2,310,585	2,292,755	2,304,460
(including carbon dioxide from respiration, excluding water vapor from all combustion & respiration)											
TDO	2,323,741	2,478,125	2,470,644	2,512,309	2,718,368	2,798,681	2,707,583	2,685,677	2,686,579	2,675,129	2,682,617
(including carbon dioxide from respiration, including water vapor from all combustion & respiration)											
Gateway Indicators											
DPO to Air	767,465	820,335	798,106	830,338	862,726	830,967	794,782	758,970	757,845	768,635	760,283
(including oxygen from all combustion, excluding oxygen from respiration, excluding all water vapor)											
CO_2 from fuel combustion	714,109	767,169	747,733	778,019	810,495	779,555	747,649	715,621	714,089	724,853	718,957
CO_2 from industrial processes *(not caused by energy use)*	27,000	27,000	25,000	27,000	27,000	27,000	24,000	21,000	22,000	22,000	20,000
SO_2	3,373	3,590	3,434	3,462	3,426	3,232	3,081	2,906	2,723	2,630	2,435
NO_x	2,382	2,549	2,581	2,699	2,804	2,767	2,703	2,675	2,716	2,739	2,703
Methane	3,544	3,459	3,397	3,402	3,440	3,377	3,401	3,423	3,341	3,295	3,357
Other air pollutants	15,918	15,442	14,846	14,650	14,440	13,901	12,804	12,190	11,836	11,992	11,716
Dissipative flows to air *(e.g. N_2O from product use)*	1,140	1,125	1,115	1,105	1,120	1,135	1,145	1,155	1,140	1,125	1,115
Bunker Fuel Emissions	19,142	19,255	20,064	20,519	21,214	21,308	22,908	21,445	20,698	20,394	23,430
CO_2 from bunkers	13,109	13,169	13,733	14,019	14,495	14,555	15,649	14,621	14,089	13,853	15,957
Other emissions from bunkers	6,033	6,086	6,331	6,499	6,719	6,753	7,259	6,824	6,609	6,540	7,473

Material Output Flows: Germany, 1975-1996

Data apply to Federal Republic of Germany 1975-1990, Reunited Germany 1991-1996

All units in 1,000 metric tons, unless otherwise stated

1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	
											Summary Data
61,066	61,077	61,450	62,063	63,254	79,753	80,275	80,975	81,338	81,539	81,818	Population *(1,000)*
2,329,057	2,362,185	2,449,948	2,533,450	2,662,376	3,308,569	3,381,382	3,341,381	3,432,165	3,494,311	3,541,500	GDP *(constant 1996 million DM)*
1,280,236	1,254,586	1,314,048	1,368,323	1,401,844	1,811,969	1,874,605	1,826,343	1,958,542	1,858,517	1,850,907	Direct Material Input *(DMI)*
935057	916,056	963,401	1,013,641	1,027,408	1,378,829	1,418,865	1,403,263	1,495,392	1,394,927	1,375,917	Domestic Extraction
345179	338,530	350,647	354,682	374,436	433,140	455,740	423,080	463,150	463,590	474,990	Imports
162027	165,835	175,025	189,174	189,279	201,608	205,868	191,016	212,579	214,276	227,830	Exports
											Summary Indicators *(as presented in main report)*
882,354	860,111	851,244	837,191	855,945	1,156,977	1,096,415	1,083,442	1,065,581	1,062,121	1,074,725	DPO *(including oxygen)*
329,833	319,003	318,098	315,532	321,836	423,830	400,990	394,347	386,522	383,461	386,293	DPO *(excluding oxygen)*
1,266,497	1,249,247	1,355,366	1,332,262	1,388,710	3,182,489	2,714,115	2,919,439	2,704,373	2,524,891	2,417,427	Domestic hidden flows
2,148,851	2,109,358	2,206,610	2,169,453	2,244,655	4,339,466	3,810,529	4,002,881	3,769,954	3,587,012	3,492,153	TDO *(including oxygen)*
1,596,330	1,568,251	1,673,464	1,647,794	1,710,546	3,606,320	3,115,104	3,313,786	3,090,895	2,908,351	2,803,721	TDO *(excluding oxygen)*
574,006	565,020	612,025	652,915	683,930	837,026	943,010	919,493	1,060,177	965,381	937,623	Net Additions to Stock
											Summary Indicators *(metric tons per capita)*
14.45	14.08	13.85	13.49	13.53	14.51	13.66	13.38	13.10	13.03	13.14	DPO *(including oxygen)*
5.40	5.22	5.18	5.08	5.09	5.31	5.00	4.87	4.75	4.70	4.72	DPO *(excluding oxygen)*
20.74	20.45	22.06	21.47	21.95	39.90	33.81	36.05	33.25	30.97	29.55	Domestic hidden flows
35.19	34.54	35.91	34.96	35.49	54.41	47.47	49.43	46.35	43.99	42.68	TDO *(including oxygen)*
26.14	25.68	27.23	26.55	27.04	45.22	38.81	40.92	38.00	35.67	34.27	TDO *(excluding oxygen)*
											Summary Indicators including additional outputs *(not presented in main report)*
928,652	905,663	896,456	882,432	899,345	1,210,046	1,148,230	1,134,999	1,117,195	1,113,605	1,126,189	DPO
											(including carbon dioxide from respiration, excluding water vapor from all combustion & respiration)
1,304,663	1,280,885	1,270,175	1,255,470	1,281,970	1,788,629	1,693,190	1,676,918	1,650,083	1,651,828	1,677,799	DPO
											(including carbon dioxide from respiration, including water vapor from all combustion & respiration)
2,195,149	2,154,910	2,251,822	2,214,694	2,288,055	4,392,536	3,862,345	4,054,438	3,821,569	3,638,496	3,543,617	TDO
											(including carbon dioxide from respiration, excluding water vapor from all combustion & respiration)
2,571,160	2,530,132	2,625,541	2,587,732	2,670,680	4,971,118	4,407,305	4,596,357	4,354,457	4,176,718	4,095,226	TDO
											(including carbon dioxide from respiration, including water vapor from all combustion & respiration)
											Gateway Indicators
769,493	753,396	741,932	725,844	742,655	1019,495	966,402	956,852	942,433	941,465	954,495	**DPO to Air**
											(including oxygen from all combustion, excluding oxygen from respiration, excluding all water vapor)
728,337	714,271	703,203	686,065	704,154	970,099	919,818	912,100	897,100	898,100	913,066	CO_2 from fuel combustion
20,000	19,000	20,000	22,000	21,500	25,000	25,000	25,000	27,000	26,000	25,000	CO_2 from industrial processes
											(not caused by energy use)
2,320	1,973	1,271	990	929	4,049	3,344	2,993	2,518	2,153	1,595	SO_2
2,744	2,603	2,462	2,310	2,140	2,707	2,475	2,312	2,181	2,107	2,083	NO_x
3,322	3,189	3,078	3,072	2,945	3,294	3,195	3,026	2,885	2,847	2,754	Methane
11,675	11,280	10,864	10,352	9,952	13,206	11,474	10,325	9,653	9,202	8,982	Other air pollutants
1,095	1,080	1,055	1,055	1,035	1,140	1,096	1,096	1,096	1,056	1,016	Dissipative flows to air
											(e.g. N_2O from product use)
28,294	25,410	23,942	23,821	23,769	26,848	25,878	28,940	29,196	29,212	28,327	Bunker Fuel Emissions
19,337	17,271	16,203	16,065	16,054	18,099	17,818	20,100	20,100	20,100	19,066	CO_2 from bunkers
8,956	8,140	7,739	7,756	7,715	8,749	8,060	8,840	9,096	9,112	9,261	Other emissions from bunkers

Material Output Flows: Germany, 1975-1996

Data apply to Federal Republic of Germany 1975-1990, Reunited Germany 1991-1996
All units in 1,000 metric tons, unless otherwise stated

	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
DPO to Land	95,123	102,593	109,836	113,393	115,563	118,995	115,238	111,874	111,552	111,873	109,799
Municipal landfill	10,147	10,098	10,077	10,283	10,506	10,761	10,068	9,349	9,371	9,389	9,429
Industrial landfill	50,713	57,828	64,802	67,394	70,587	73,326	70,531	68,057	67,815	66,841	64,120
Landfilled sewage sludge	1,864	1,864	1,864	1,926	1,989	2,052	2,198	2,345	2,591	2,838	3,065
Dissipative flows to land											
Fertilizers	7,899	8,051	8,420	8,781	8,574	8,894	8,732	8,571	8,472	8,325	8,706
Pesticides	25	26	28	30	31	33	31	29	31	33	30
Animal manure spread on fields	19,555	19,608	19,645	19,669	18,476	18,217	18,274	18,532	17,740	18,842	18,801
Sewage sludge spread on fields	612	610	608	606	566	563	561	558	555	537	528
Grit materials	1,660	1,660	1,447	1,660	1,660	1,932	1,660	1,243	1,660	1,660	1,660
Others	2,649	2,848	2,946	3,043	3,174	3,218	3,184	3,190	3,316	3,409	3,459
DPO to Water	2,724	2,711	2,705	2,702	2,704	2,712	2,717	2,715	2,706	2,696	2,689
N	316	315	314	314	314	315	315	315	314	313	313
P	35	35	35	35	35	35	35	35	35	35	35
Others	2,372	2,361	2,356	2,353	2,354	2,362	2,367	2,365	2,357	2,347	2,341
Additional Inputs *(not presented in main report)*											
Oxygen in combustion	782,282	837,439	822,418	859,797	896,626	859,530	818,203	779,852	781,629	795,098	789,383
Oxygen in respiration	32,648	32,658	32,997	33,336	33,407	33,452	33,351	33,532	34,042	34,026	34,056
Additional Outputs *(not presented in main report)*											
Water vapor from fossil combustion	331,239	356,206	352,312	369,574	388,986	375,276	359,357	342,420	345,011	351,459	347,266
Water vapor from respiration	30,444	30,374	30,497	30,635	30,676	30,748	30,731	30,803	30,984	30,915	30,891
CO_2 from respiration	44,891	44,905	45,371	45,837	45,934	45,997	45,858	46,106	46,808	46,785	46,826
Domestic Hidden Flows											
Excavated soil	143,802	147,634	153,307	158,935	170,044	167,526	153,307	149,955	149,780	149,660	137,429
Dredging wastes	33,794	33,794	33,794	33,794	33,794	33,794	33,794	33,794	33,794	33,794	33,794
Soil erosion	70,454	71,282	73,101	74,183	74,306	75,255	76,374	77,781	78,446	79,940	81,532
Mining overburden	803,807	868,291	871,615	852,918	993,637	1,117,409	1,095,426	1,131,260	1,129,654	1,099,373	1,132,107

Material Output Flows: Germany, 1975-1996

Data apply to Federal Republic of Germany 1975-1990, Reunited Germany 1991-1996

All units in 1,000 metric tons, unless otherwise stated

1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	
110,170	104,023	106,604	108,614	110,507	133,997	126,534	123,111	119,682	117,210	116,772	**DPO to Land**
9,500	9,565	9,949	10,376	10,910	13,985	13,008	12,043	12,097	12,127	12,168	Municipal landfill
63,934	57,729	59,469	61,165	62,755	69,657	65,313	64,101	59,319	56,588	55,890	Industrial landfill
3,293	3,521	3,435	3,349	3,263	6,158	4,407	2,657	2,657	2,657	2,657	Landfilled sewage sludge
											Dissipative flows to land
8,997	8,723	8,875	8,439	7,864	8,314	8,224	8,327	9,187	9,186	9,261	Fertilizers
33	36	37	35	33	37	33	29	30	35	35	Pesticides
18,638	18,570	18,656	18,759	18,731	27,047	26,753	27,088	27,318	27,375	27,361	Animal manure spread on fields
515	501	634	767	900	983	994	1,028	1,037	1,039	1,038	Sewage sludge spread on fields
1,660	1,660	1,660	1,660	1,660	2,110	2,110	2,110	2,110	2,110	2,110	Grit materials
3,600	3,718	3,890	4,065	4,391	5,706	5,691	5,729	5,927	6,093	6,251	Others
2,691	2,692	2,707	2,734	2,784	3,485	3,478	3,478	3,466	3,447	3,458	**DPO to Water**
313	313	314	317	321	381	360	338	317	295	296	N
35	35	35	36	36	44	39	34	28	23	23	P
2,343	2,343	2,358	2,381	2,427	3,060	3,080	3,107	3,121	3,129	3,139	Others
											Additional Inputs *(not presented in main report)*
799,655	791,173	781,249	767,475	789,318	1,061,705	1,014,175	1,016,769	1,006,013	1,018,161	1,042,593	Oxygen in combustion
33,672	33,129	32,881	32,903	31,564	38,596	37,684	37,496	37,538	37,443	37,428	Oxygen in respiration
											Additional Outputs *(not presented in main report)*
345,287	344,745	343,262	342,418	352,325	540,932	507,599	504,470	495,329	500,657	513,981	Water vapor from fossil combustion
30,725	30,477	30,457	30,619	30,300	37,651	37,361	37,449	37,559	37,566	37,628	Water vapor from respiration
46,299	45,552	45,212	45,241	43,400	53,070	51,815	51,557	51,615	51,484	51,464	CO_2 from respiration
											Domestic Hidden Flows
145,950	137,429	151,859	161,754	170,000	266,439	259,506	266,439	308,822	271,575	262,035	Excavated soil
33,794	33,794	33,794	33,794	33,794	33,794	33,794	33,794	33,794	33,794	33,794	Dredging wastes
81,892	82,118	81,940	82,192	82,098	128,704	120,964	122,954	122,586	123,926	125,572	Soil erosion
1,004,862	995,906	1,087,773	1,054,522	1,102,818	2,753,552	2,299,851	2,496,252	2,239,172	2,095,596	1,996,027	Mining overburden

Technical Notes and Sources

In general, outputs from the German economy comprise outputs to the domestic environment and outputs of materials to foreign countries as exports. The difference between material inputs, as accounted for in our earlier study (Adriaanse et al., 1997), and material outputs accounted for here represents the net amount of additional materials stocked within the technosphere.

Time series were established for Germany based on the period 1975 to 1990 (the territory of the former Federal Republic of Germany), then on the period 1991 to 1996 (the territory of the reunited Germany). Material outputs of the German economy to the environment comprise the following main groups:

(1) waste disposal in controlled landfills,
(2) dissipative uses and dissipative losses,
(3) emissions to air,
(4) emissions to water,
(5) domestic hidden flows.
Outputs 1 to 4 constitute the DPO. TDO comprises DPO plus hidden flows (No. 5).

Net additions to stocks were calculated by subtracting DPO and exports from direct material inputs to the German economy.

Please note that domestic material outputs were counted here at the system boundary between technosphere (economy) and environment, which was functionally defined: within the technosphere, humans control the quantity, quality, and locality of materials. Outside the technosphere, this is not the case. In spatial terms, the system boundary is at the end-of-pipe for industrial processes and at the surface of soil for agricultural and forestry processes. For example, the total amount of nitrogen in mineral fertilizers applied to agricultural land was counted under DPO, but the subsequent emissions of nitrogen oxides from these fertilizers were not counted under DPO (double-counting). These emissions were, however, still kept in the data base and might be used in further studies, for example, on qualitative aspects of DPO.

Three major data source types were differentiated: governmental statistics, non-governmental statistics, and specific studies. Because of limited space, detailed technical notes on data sources and formulae used in calculating outputs can be viewed at the homepage of the Wuppertal Institute (http://www.wupperinst.org/Projekte).

Waste Disposal in Controlled Landfills (Excluding Incineration)

This group comprises wastes disposed of in controlled landfills owned by industry or hospitals, as well as in public landfills and commercial landfills (the latter being used mainly by industry). To account for the contribution to DPO (to land), domestic hidden flows that are included in official waste data were subtracted and counted under the group of domestic hidden flows. This refers to soil excavation and mining wastes.

The basis for German data on waste disposal is official waste statistics published by FSOG (Federal Statistical Office Germany) in two volumes: waste disposal by industry and hospitals, and municipal waste disposal. In this study, the amount of waste disposed of in controlled landfills was estimated in time series based on official statistics and other sources.

Dissipative Use of Products and Dissipative Losses

These material outputs refer in general to dissipative uses of products on agricultural fields, on roads, and for other purposes, and to dissipative losses by erosion of infrastructure, abrasion of car tires, and leakages.

Data are provided by German agricultural statistics, the Federal Environmental Agency (FEA), and waste statistics of FSOG. They were supplemented by our own estimates.

Emissions to Air

Emissions to air were accounted for in the following major categories:

CO_2 total (from combustion of energy carriers, nonenergy sources, and from respiration; SO_2; NO_x as NO_2; VOC (NMVOC excluding emissions from use of solvents, and CH_4, excluding CH_4 from landfilled wastes); CO; dust; N_2O, excluding N from agriculture and wastes, and N_2O from use of products; NH_3 excluding emissions from fertilizer use; CFCs and halons; H_2O from combustion and respiration; and emissions of water from materials.

Except for CO_2 from respiration, water vapor from combustion and respiration, and water emissions from materials, all the data for categories listed above are available from FEA, starting in 1970. Respiration outputs in the form of carbon dioxide and water vapor were first estimated in the context of studies for the physical input-output table for the Federal Republic of Germany 1990 by FSO and Wuppertal Institute. The data for Federal Republic of Germany 1990 were used here and data for the remaining years were estimated on a per capita basis. Emissions to air also include those from international transport, that is, from bunker fuels.

Emissions to Water

Statistical information for emissions of materials to water were available for nitrogen and phosphorus from households and industry.

Domestic Hidden Flows

These material outputs were described in Adriaanse et al., 1997.

Exports

Official foreign trade statistics of FSO provide the data from which we subtracted the water content whose counterpart on the input side is the domestic water input and not the water content of other materials.

Sectoral Disaggregation of Material Outputs

The basic principle behind this attribution to activities was in line with the procedure used for the physical input-output table—PIOT—for Federal Republic of Germany 1990 by FSO.

MATERIAL FLOWS: JAPAN

Yuichi Moriguchi

Highlights

Domestic processed output in Japan grew 20 percent during the period 1975–1996, while the country's population grew by 12.4 percent. Total domestic output in Japan also grew about 20 percent during this period, because of an increase in both DPO and domestic hidden flows. (*See Figure A1.*) The growth in DPO and TDO occurred mainly after the late 1980s. Before then, DPO was almost constant and TDO decreased slightly.

On a per capita basis, there was a downward trend in TDO from the late 1970s to the mid–1980s; DPO per capita also decreased slightly in this period. Growth in DPO per capita and TDO per capita were particularly evident in the late 1980s, when the country experienced the so-called "bubble-economy." (*See Figure A2.*) The absolute level of DPO per capita in Japan is about 4 metric tons without oxygen and 11 metric tons with oxygen. These values are relatively small among the countries studied.

When DPO is calculated excluding oxygen, the data show a smaller increase than when DPO is calculated including oxygen. (*See Figure A3.*) In 1990–1996, the former was almost constant, whereas the latter was increasing. This is because CO_2 emissions

FIGURE A1 | TOTAL DOMESTIC OUTPUT, JAPAN 1975–1996

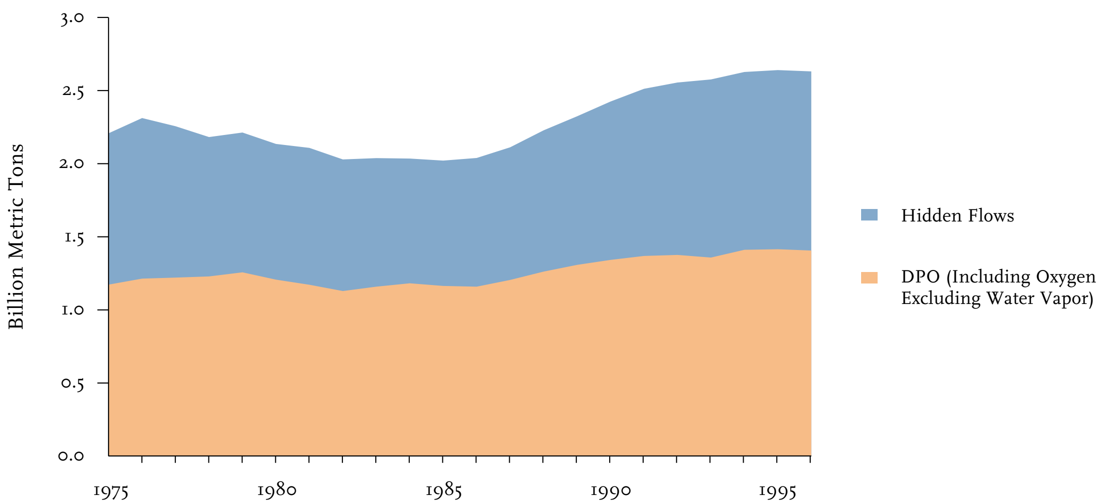


FIGURE A2 | TDO, DPO, AND NAS PER CAPITA, JAPAN 1975–1996

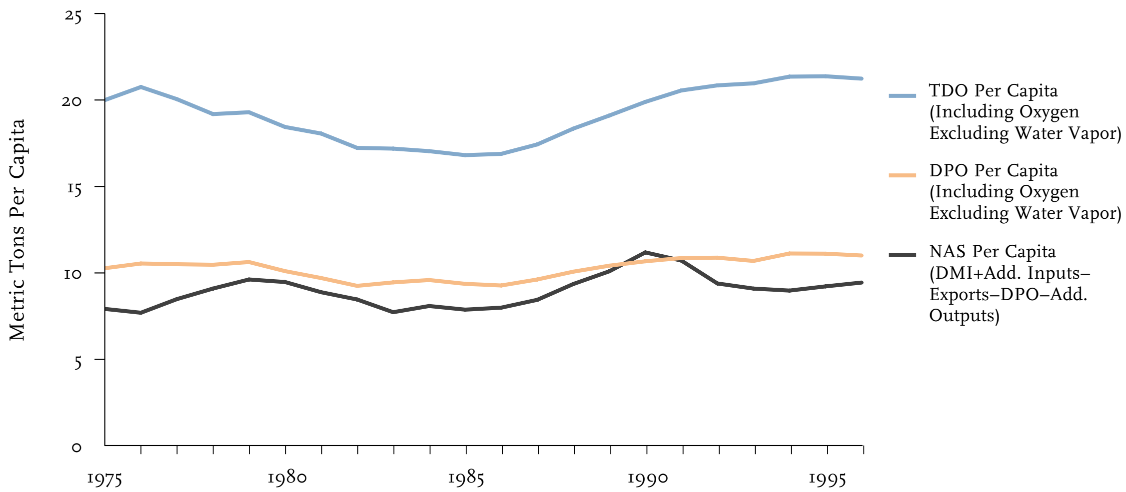


FIGURE A3 | TRENDS IN MATERIAL FLOW INDICATORS (INDEX), JAPAN 1975–1996

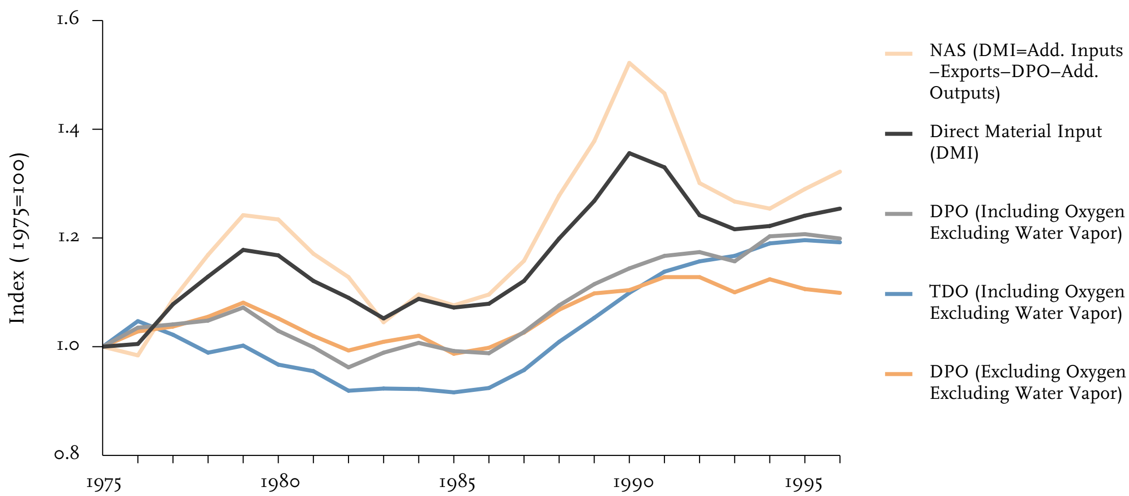


FIGURE A4

MATERIAL OUTPUT INTENSITY, DENOMINATED BY POPULATION AND GDP (INDEX), JAPAN 1975–1996

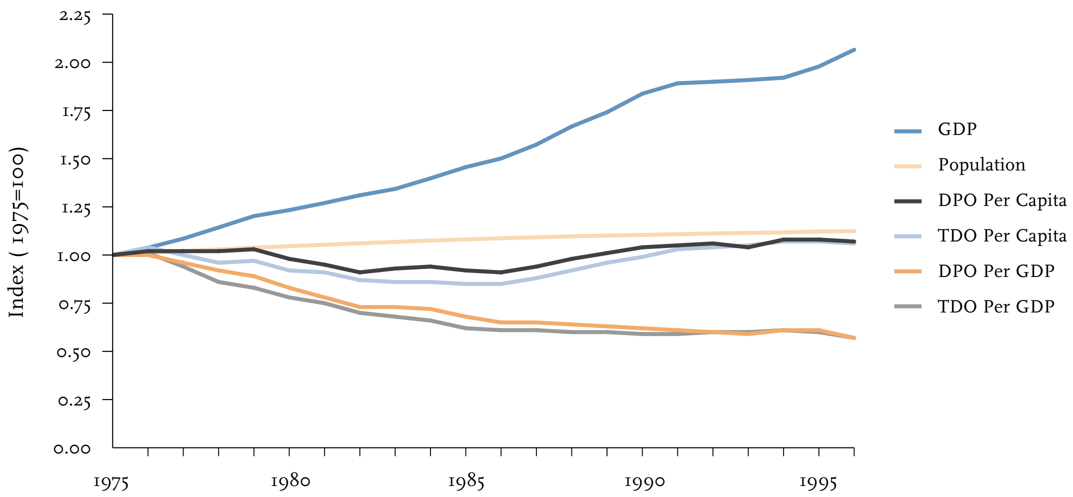
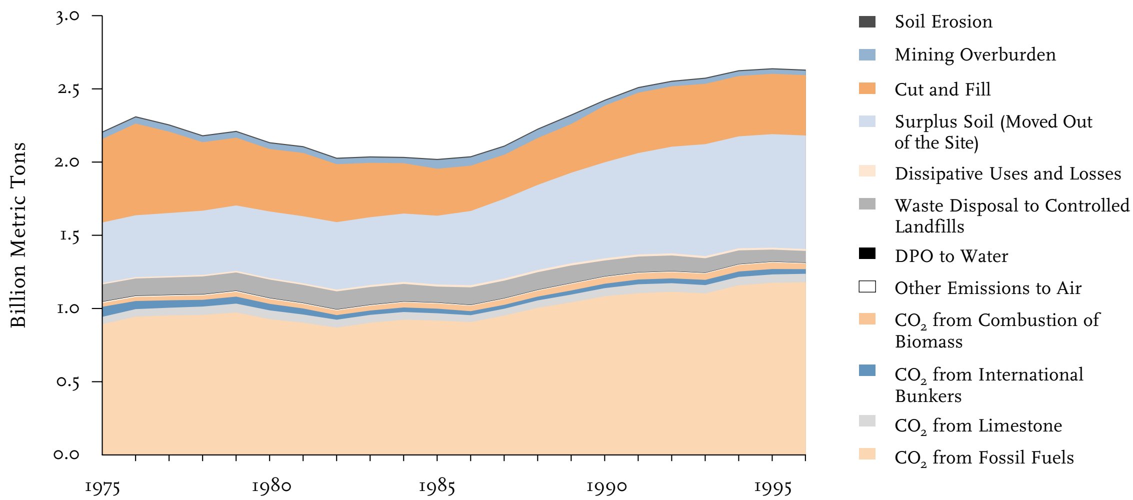


FIGURE A5

COMPOSITION OF TDO, JAPAN 1975–1996



from fossil fuel combustion, which dominate DPO increased, whereas some other outputs, such as final disposal of solid wastes to land, decreased. In the same period, the direct material input (DMI) of Japan was actually decreasing, mainly because of reduced construction activity following the collapse of the bubble-economy. Net additions to stock (NAS), mainly reflected fluctuations in construction activity. A steep increase in NAS occurred in the late 1980s, the period of the bubble-economy. NAS and DMI show parallel fluctuations. This is because construction materials that are dominant elements of DMI went almost exclusively to stock.

Figure A4 shows that material output intensity, that is, DPO or TDO per constant unit of GDP, and DPO or TDO per capita, declined until 1990 because of larger growth in the monetary economy than in physical throughput (the physical economy). However, since 1990, decoupling between economic growth and material throughput has not improved, because DPO and TDO have continued to increase, while economic growth has slowed down. This recent trend can be explained by structural changes in energy consumption: thanks to relatively cheap oil prices, household energy consumption (including gasoline consumption by private cars) has increased as a proportion of total energy consumption and has contributed to higher CO_2 emissions, but this trend has contributed little to GDP growth.

As shown in Figure A5, TDO is dominated by CO_2 emissions, particularly from combustion of fossil fuels. CO_2 emissions were roughly constant from 1975 to the mid-1980s, then increased from the late 1980s to the 1990s. A steep increase in CO_2 emissions, roughly proportional to GDP growth, took place before 1973, that is, before the first oil crisis. These trends are closely related to fluctuations in energy price.

After CO_2, waste disposal to controlled landfill sites is the next major component of DPO. This is of greater environmental significance than the nominal weight implies because Japan has a shortage of landfill sites for waste disposal. Reclaiming coastal areas for this purpose has sometimes decreased habitat for wildlife. The weight of waste disposed of in landfill sites is much smaller than that of waste generated. Waste statistics report that 50 million metric tons of municipal solid wastes (MSW) and 400 million metric tons of industrial wastes (both of them measured as wet weight) were generated in 1995. The difference between the amount generated and the amount sent to landfill is the amount recycled or reduced by incineration and drying. Three quarters of MSW is incinerated to reduce waste volumes, but this practice unfortunately generates undesirable byproducts such as air emissions, including dioxins. The amount of landfilled wastes was almost constant until 1990, but is now declining, thanks to waste minimization and recycling measures.

Dissipative use is another important category of output flows. Dissipative flows are dominated by applications of animal manure to fields. Japan classes animal excreta as industrial wastes in waste statistics, but animal excreta used as manure is classed as recycling. Reduction of final disposal of this industrial waste is, thus, offset by dissipative use. Fertilizers and pesticides are intensively used in Japanese agriculture to enhance productivity and compensate for the limited area of available farmland.

Estimates of output flows to water are rough and incomplete, but they are relatively small as far as the quantity of solid materials is concerned. Nevertheless, wastewater flows should be analyzed carefully, because they are an important issue in Japanese environmental policy.

DPO to air accounts for about 90 percent of total DPO. DPO to land is decreasing not only in terms of its relative share of total DPO, but also in absolute amounts.

Soils excavated during construction activities dominate domestic hidden flows. Some portion of excavated soil is moved out of the construction site, then dumped into landfills or used for other purposes, while another portion remains within the same site (cut and fill). Only "surplus soil," which means the soil excavated then moved out of the construction site to landfill or other sites for application, is quantified by official surveys. The total quantity of soil excavation by construction activities is much greater, because excavation work is usually designed to balance cut and fill, to use excavated soil on site, and minimize the generation of surplus soil. The total size of excavations may be a better indicator of landscape alteration. However, as an indicator of output flows, we may differentiate the surplus soil from the excavated soil for on-site application. The former has greater environmental significance. For this reason, these two types of soil are separately shown in the data sheet and Figure A5.

Hidden flows associated with mining activities are trivial in quantity, because of the limited resources of fossil fuels and metal ores in Japan. Consequently, the contribution of domestic hidden flows to TDO is relatively small, compared with more resource-rich countries. It should be borne in mind that the small size of domestic hidden flows is counterbalanced by imported hidden flows associated with imported metals and energy carriers; this represents the transfer of Japan's environmental burden to its trade partners, which the study by Adriaanse et al., 1997 emphasized.

When disaggregated by economic activities, different sectors contribute to different types of output flows. For DPO, the energy supply sector and the manufacturing sector are large contributors because of their high levels of CO_2 emissions. In the case of TDO, the construction sector surpasses these two sectors, because of large amounts of excavated soil. (*See Figure A6, Figure A7.*)

Net additions of materials to stock (NAS) in the Japanese technosphere have fluctuated in accordance with patterns of governmental and private investment. NAS increased significantly in the late 1980s, then stabilized at a lower level in 1990. Because Japan has a shorter history of industrialization than other Western countries, construction work is still active and significantly contributes to the country's overall picture of material flows. As much as 60 percent of direct material input (DMI) is added to the stock. This figure also has a close relation with inputs of construction materials as well as with soil excavation. Increasing quantities of stock imply that demolition wastes will also increase in the future. Currently, the government is attempting to encourage recycling of demolition wastes.

FIGURE A6 | **DPO BY ECONOMIC SECTOR, JAPAN 1975–1996**

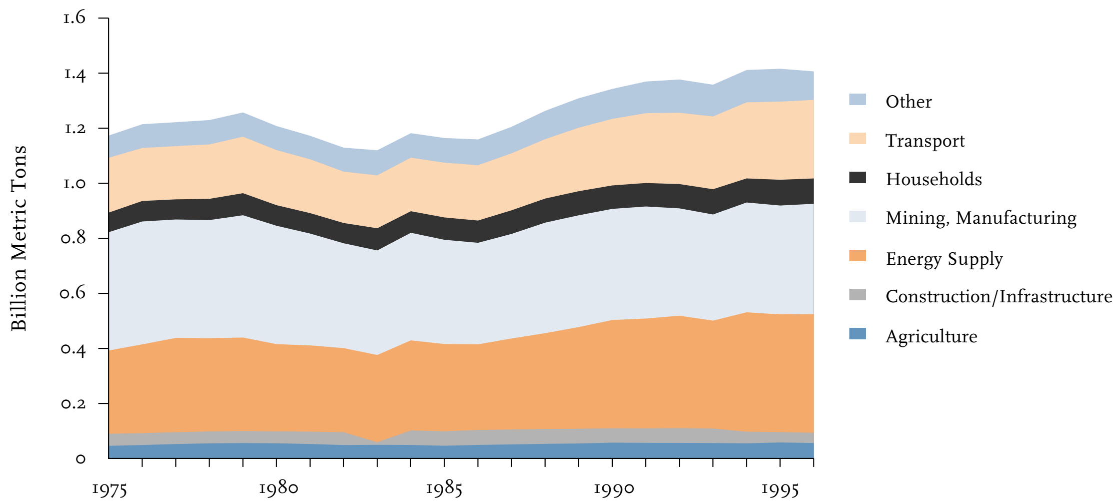
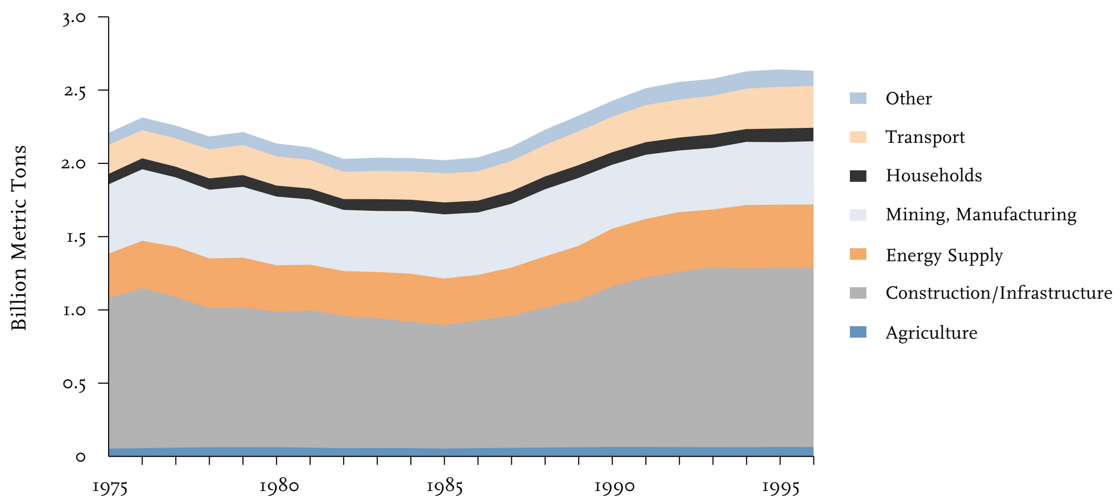


FIGURE A7 | **TDO BY ECONOMIC SECTOR, JAPAN 1975–1996**



Material Output Flows: Japan, 1975-1996

All units 1,000 metric tons unless otherwise stated

	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
Summary Data											
Population *(1,000)*	111,940	113,089	114,154	115,190	116,155	117,060	117,902	118,728	119,536	120,305	121,049
GDP *(constant 1996 billion Yen)*	244,291	253,485	264,962	279,308	293,689	301,324	310,333	319,943	328,037	341,485	355,578
Direct Material Inputs *(DMI)*	1,606,827	1,615,133	1,731,611	1,814,777	1,893,402	1,876,801	1,801,146	1,750,743	1,690,602	1,748,064	1,721,813
Domestic Extraction	1,057,244	1,042,953	1,141,952	1,254,627	1,282,480	1,272,136	1,235,600	1,192,844	1,145,634	1,150,915	1,128,236
Imports	549,583	572,179	589,659	560,149	610,921	604,665	565,546	557,898	544,968	597,149	593,578
Exports	66,404	72,895	84,601	80,589	75,128	81,303	78,921	77,634	85,457	85,851	90,265
Summary Indicators *(as presented in main report)*											
DPO *(including Oxygen)*	1,173,248	1,214,487	1,221,840	1,229,516	1,257,203	1,207,858	1,172,354	1,129,212	1,159,912	1,182,004	1,164,346
DPO *(excluding Oxygen)*	451,507	464,037	468,201	476,459	488,174	475,024	460,754	448,424	455,687	460,398	445,822
Domestic hidden flows	1,035,239	1,098,663	1,035,788	953,969	956,304	928,239	936,756	900,864	879,325	853,752	857,527
TDO *(including Oxygen)*	2,208,487	2,313,150	2,257,627	2,183,484	2,213,507	2,136,097	2,109,109	2,030,076	2,039,237	2,035,757	2,021,874
TDO *(excluding Oxygen)*	1,486,746	1,562,701	1,503,988	1,430,428	1,444,479	1,403,263	1,397,510	1,349,288	1,335,012	1,314,150	1,303,350
Net Additions to Stock	922,408	908,016	1,002,246	1,078,176	1,145,300	1,138,233	1,079,684	1,040,332	963,664	1,010,948	992,607
(DMI + Add'l Inputs - Exports - DPO - Add'l outputs)											
Summary Indicators *(metric tons per capita)*											
DPO *(including Oxygen)*	10.48	10.74	10.70	10.67	10.82	10.32	9.94	9.51	9.70	9.83	9.62
DPO *(excluding Oxygen)*	4.03	4.10	4.10	4.14	4.20	4.06	3.91	3.78	3.81	3.83	3.68
Domestic hidden flows	9.25	9.72	9.07	8.28	8.23	7.93	7.95	7.59	7.36	7.10	7.08
TDO *(including Oxygen)*	19.73	20.45	19.78	18.96	19.06	18.25	17.89	17.10	17.06	16.92	16.70
TDO *(excluding Oxygen)*	13.28	13.82	13.18	12.42	12.44	11.99	11.85	11.36	11.17	10.92	10.77
Net Additions to Stock	8.24	8.03	8.78	9.36	9.86	9.72	9.16	8.76	8.06	8.40	8.20
(DMI + Add'l Inputs - Exports - DPO - Add'l outputs)											
Summary Indicators including additional outputs *(not presented in main report)*											
DPO	1,226,827	1,268,763	1,277,492	1,286,560	1,315,464	1,266,903	1,232,133	1,189,611	1,221,164	1,244,143	1,227,073
(including carbon dioxide from respiration, excluding water vapor from all combustion & respiration)											
DPO	1,643,877	1,702,293	1,722,093	1,738,854	1,778,475	1,709,445	1,665,566	1,613,775	1,657,524	1,694,175	1,677,665
(including carbon dioxide from respiration, including water vapor from all combustion & respiration)											
TDO	2,262,067	2,367,427	2,313,279	2,240,529	2,271,768	2,195,142	2,168,888	2,090,475	2,100,488	2,097,896	2,084,600
(including carbon dioxide from respiration, excluding water vapor from all combustion & respiration)											
TDO	2,679,116	2,800,957	2,757,880	2,692,822	2,734,780	2,637,684	2,602,322	2,514,639	2,536,848	2,547,927	2,535,192
(including carbon dioxide from respiration, including water vapor from all combustion & respiration)											
Gateway Indicators											
DPO to Air	1,045,306	1,086,022	1,091,417	1,095,450	1,120,275	1,070,118	1,036,819	992,547	1,024,370	1,046,838	1,039,495
(including oxygen from all combustion, excluding oxygen from respiration, excluding all water vapor)											
Total CO_2	1,038,199	1,079,353	1,085,186	1,089,339	1,114,285	1,064,248	1,031,147	987,073	1,019,093	1,041,754	1,034,603
(from non-biological activities)											
CO_2 from fossil fuels	961,878	999,951	1,003,827	1,002,123	1,021,092	972,034	944,338	900,944	932,591	954,983	949,651
(incl. Bunkers)											
CO_2 from limestone	49,770	51,153	52,304	57,178	60,084	59,735	55,721	53,903	53,588	52,243	49,224
(cement making)											
CO_2 from combustion of biomass	26,551	28,249	29,055	30,039	33,109	32,480	31,088	32,226	32,914	34,528	35,728
SO_x	2,586	2,134	1,682	1,547	1,412	1,277	1,201	1,125	1,049	978	906
NO_x	2,286	2,300	2,315	2,329	2,344	2,358	2,298	2,238	2,178	2,118	2,058
VOC	2,234	2,234	2,234	2,234	2,234	2,234	2,173	2,111	2,050	1,989	1,927
Bunker Fuel Emissions											
CO_2 from international bunkers	68,688	55,235	50,714	45,921	47,717	44,397	41,199	31,191	29,589	31,095	31,315
DPO to Land	125,588	126,142	128,133	131,812	134,710	135,560	133,393	134,563	133,479	133,143	122,850
Municipal solid wastes											
to controlled landfill	21,017	19,093	18,709	19,900	20,357	19,718	17,257	18,174	16,769	16,192	16,031
Industrial wastes											
to controlled landfill	95,583	97,560	99,538	101,515	103,492	105,469	104,848	104,226	103,604	102,983	92,269
Dissipative flows to land	8,987	9,489	9,887	10,397	10,860	10,373	11,289	12,163	13,105	13,969	14,550
Animal manure spread on fields	6,551	6,662	7,037	7,439	7,770	7,929	8,735	9,464	10,269	11,097	11,801
(dry weight)											
Mineral fertilizers	2,343	2,733	2,756	2,864	2,996	2,354	2,465	2,612	2,75	2,788	2,666
Pesticides	94	94	94	94	94	90	88	87	86	84	83

Material Output Flows: Japan, 1975-1996

All units 1,000 metric tons unless otherwise stated

1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	
											Summary Data
121,660	122,239	122,745	123,205	123,611	124,043	124,452	124,764	125,034	125,570	125,864	Population *(1,000)*
366,737	384,181	407,133	425,238	448,834	462,070	463,823	466,038	469,056	483,150	504,391	GDP *(constant 1996 billion Yen)*
1,733,928	1,800,867	1,927,167	2,037,678	2,178,946	2,136,390	1,994,923	1,953,262	1,964,128	1,993,803	2,014,507	Direct Material Inputs *(DMI)*
1,154,166	1,204,430	1,273,743	1,358,063	1,478,469	1,424,593	1,330,753	1,285,835	1,272,303	1,247,113	1,259,685	Domestic Extraction
579,762	596,438	653,424	679,615	700,477	711,797	664,170	667,427	691,825	746,691	754,822	Imports
78,125	71,456	66,250	66,562	70,044	69,417	78,008	85,300	90,071	94,708	93,903	Exports
											Summary Indicators *(as presented in main report)*
1,159,296	1,205,142	1,262,996	1,308,752	1,342,746	1,369,576	1,376,895	1,358,031	1,411,440	1,415,875	1,406,548	DPO *(including Oxygen)*
450,608	463,371	482,035	495,894	498,512	509,322	509,271	496,541	507,560	499,566	496,254	DPO *(excluding Oxygen)*
880,985	907,883	966,159	1,016,797	1,083,518	1,143,305	1,179,083	1,218,958	1,216,468	1,225,538	1,225,538	Domestic hidden flows
2,040,282	2,113,025	2,229,155	2,325,549	2,426,264	2,512,881	2,555,979	2,576,989	2,627,908	2,641,413	2,632,086	TDO *(including Oxygen)*
1,331,593	1,371,254	1,448,194	1,512,691	1,582,030	1,652,627	1,688,355	1,715,500	1,724,028	1,725,105	1,721,792	TDO *(excluding Oxygen)*
1,010,751	1,068,144	1,178,999	1,270,782	1,403,571	1,351,889	1,200,056	1,168,324	1,156,832	1,190,357	1,219,305	Net Additions to Stock *(DMI + Add'l Inputs - Exports - DPO - Add'l outputs)*
											Summary Indicators *(metric tons per capita)*
9.53	9.86	10.29	10.62	10.86	11.04	11.06	10.88	11.29	11.28	11.18	DPO *(including Oxygen)*
3.70	3.79	3.93	4.02	4.03	4.11	4.09	3.98	4.06	3.98	3.94	DPO *(excluding Oxygen)*
7.24	7.43	7.87	8.25	8.77	9.22	9.47	9.77	9.73	9.76	9.74	Domestic hidden flows
16.77	17.29	18.16	18.88	19.63	20.26	20.54	20.65	21.02	21.04	20.91	TDO *(including Oxygen)*
10.95	11.22	11.80	12.28	12.80	13.32	13.57	13.75	13.79	13.74	13.68	TDO *(excluding Oxygen)*
8.31	8.74	9.61	10.31	11.35	10.90	9.64	9.36	9.25	9.48	9.69	Net Additions to Stock *(DMI + Add'l Inputs - Exports - DPO - Add'l outputs)*
											Summary Indicators including additional outputs *(not presented in main report)*
1,222,694	1,268,843	1,326,952	1,372,888	1,407,058	1,434,020	1,441,744	1,423,016	1,476,101	1,480,059	1,470,366	DPO *(including carbon dioxide from respiration, excluding water vapor from all combustion & respiration)*
1,673,752	1,735,939	1,811,254	1,874,758	1,926,544	1,961,361	1,975,023	1,948,739	2,025,759	2,034,452	2,020,362	DPO *(including carbon dioxide from respiration, including water vapor from all combustion & respiration)*
2,103,679	2,176,726	2,293,111	2,389,685	2,490,577	2,577,325	2,620,827	2,641,974	2,692,569	2,705,597	2,695,904	TDO *(including carbon dioxide from respiration, excluding water vapor from all combustion & respiration)*
2,554,737	2,643,822	2,777,413	2,891,555	3,010,063	3,104,666	3,154,107	3,167,697	3,242,227	3,259,990	3,245,901	TDO *(including carbon dioxide from respiration, including water vapor from all combustion & respiration)*
											Gateway Indicators
1,023,626	1,068,896	1,126,752	1,172,620	1,218,338	1,246,213	1,253,655	1,243,336	1,301,992	1,319,113	1,311,982	**DPO to Air** *(including oxygen from all combustion, excluding oxygen from respiration, excluding all water vapor)*
11,018,768	,063,985	1,121,789	1,167,605	1,213,194	1,241,072	1,248,673	1,238,536	1,297,035	1,314,176	1,307,247	Total CO_2 *(from non-biological activities)*
935,010	978,460	1,030,789	1,070,648	1,114,181	1,136,910	1,147,209	1,139,252	1,196,053	1,212,703	1,210,793	CO_2 from fossil fuels *(incl. Bunkers)*
46,893	46,662	50,617	52,614	55,152	61,065	58,431	56,617	56,923	56,960	58,087	CO_2 from limestone *(cement making)*
36,865	38,863	40,383	44,342	43,860	43,096	43,034	42,667	44,060	44,513	38,368	CO_2 from combustion of biomass
835	849	862	876	966	976	895	814	847	827	805	SO_x
2,089	2,120	2,150	2,181	2,212	2,271	2,222	2,163	2,237	2,237	2,029	NO_x
1,935	1,943	1,951	1,958	1,966	1,894	1,865	1,823	1,873	1,873	1,901	VOC
											Bunker Fuel Emissions
27,432	26,496	25,955	27,973	29,986	32,189	32,668	35,839	37,053	36,817	31,587	CO_2 from international bunkers
133,691	134,290	134,313	134,226	122,531	121,514	121,419	112,903	107,684	95,021	92,854	**DPO to Land**
16,023	16,490	16,900	17,490	16,809	16,379	15,296	14,959	14,142	13,602	13,093	Municipal solid wastes to controlled landfill
102,872	102,979	102,680	101,975	91,145	90,601	91,503	83,324	79,207	68,035	66,554	Industrial wastes to controlled landfill
14,795	14,822	14,733	14,760	14,577	14,534	14,619	14,619	14,335	13,384	13,207	Dissipative flows to land
11,994	12,049	12,088	12,083	12,043	12,091	12,159	12,139	11,899	11,115	11,018	Animal manure spread on fields *(dry weight)*
2,722	2,697	2,575	2,609	2,466	2,377	2,395	2,415	2,371	2,205	2,124	Mineral fertilizers
79	76	70	69	68	66	65	65	65	65	65	Pesticides

Material Output Flows: Japan, 1975-1996

All units 1,000 metric tons unless otherwise stated

	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
DPO to Water	2,355	2,323	2,289	2,254	2,218	2,181	2,142	2,103	2,063	2,023	2,002
Organic load *(as COD)*	1,339	1,316	1,293	1,269	1,244	1,218	1,191	1,165	1,138	1,111	1,093
T-N	914	908	902	894	887	878	870	861	852	842	841
T-P	102	98	95	91	88	84	81	77	73	70	68
Additional Inputs	1,025,861	1,068,072	1,077,329	1,082,842	1,105,501	1,052,180	1,023,026	980,998	1,016,042	1,042,909	1,038,724
(not presented in main report)											
Oxygen in combustion	986,894	1,028,598	1,036,855	1,041,355	1,063,129	1,009,239	979,550	937,071	971,496	997,717	993,105
Oxygen in respiration	38,967	39,474	40,474	41,487	42,372	42,942	43,475	43,927	44,547	45,192	45,619
Additional Outputs	470,629	487,807	500,253	509,338	521,273	501,587	493,213	484,562	497,611	512,170	513,318
(not presented in main report)											
Water vapor											
from fossil combustion	321,384	336,431	341,632	346,737	354,318	335,419	325,369	311,102	324,325	335,666	334,263
Water vapor											
from biomass combustion	9,051	9,630	9,905	10,241	11,287	11,073	10,598	10,986	11,221	11,771	12,180
Water vapor from respiration	21,919	22,204	22,767	23,336	23,834	24,155	24,455	24,709	25,057	25,420	25,661
Water included in DMI											
as water contents of food & feed	64,695	65,265	70,297	71,980	73,571	71,897	73,012	77,366	75,757	77,174	78,489
CO_2 from respiration	53,580	54,276	55,652	57,044	58,262	59,045	59,779	60,399	61,252	62,139	62,726
Domestic Hidden Flows	1,035,239	1,098,663	1,035,788	953,969	956,304	928,239	936,756	900,864	879,325	853,752	857,527
Excavated soil											
by construction activities	984,388	1,048,942	986,430	906,699	909,487	881,809	890,430	856,652	835,279	810,620	790,518
Surplus soil	414,358	422,507	430,655	438,803	446,951	455,100	458,008	460,917	463,826	466,735	469,644
(moved out of the site)											
Cut & Fill	570,029	626,435	555,776	467,896	462,536	426,710	432,422	395,735	371,453	343,886	320,875
Soil erosion	7,682	7,575	7,438	7,367	7,355	7,384	7,396	7,420	7,444	7,450	7,492
Mining overburden	43,169	42,146	41,919	39,903	39,463	39,045	38,929	36,792	36,601	35,682	59,517

Material Output Flows: Japan, 1975-1996

All units 1,000 metric tons unless otherwise stated

	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
DPO to Water	1,979	1,955	1,931	1,905	1,877	1,849	1,821	1,792	1,763	1,741	1,712
Organic load *(as COD)*	1,073	1,054	1,034	1,014	988	962	936	909	883	859	833
T-N	839	836	833	829	828	827	826	824	822	824	822
T-P	67	65	64	62	61	61	60	59	58	57	57
Additional Inputs	1,028,700	1,074,672	1,129,336	1,174,424	1,221,213	1,246,276	1,258,165	1,249,101	1,308,534	1,325,713	1,319,063
(not presented in main report)											
Oxygen in combustion	982,592	1,028,344	1,082,823	1,127,780	1,174,441	1,199,408	1,211,002	1,201,839	1,261,507	1,279,034	1,272,650
Oxygen in respiration	46,108	46,328	46,514	46,645	46,773	46,868	47,162	47,262	47,027	46,680	46,413
Additional Outputs	514,456	530,798	548,258	566,007	583,799	591,785	598,128	590,708	614,319	618,577	613,814
(not presented in main report)											
Water vapor from fossil combustion	332,408	347,688	366,000	381,825	398,932	410,016	415,084	412,224	433,310	439,705	439,754
Water vapor from biomass combustion	12,568	13,249	13,767	15,117	14,952	14,692	14,671	14,546	15,020	15,175	13,080
Water vapor from respiration	25,936	26,060	26,164	26,238	26,310	26,364	26,529	26,585	26,452	26,257	26,107
Water included in DMI as water contents of food & feed	80,147	80,099	78,371	78,691	79,292	76,269	76,997	72,368	74,874	73,255	71,055
CO_2 from respiration	63,398	63,702	63,956	64,136	64,313	64,444	64,848	64,985	64,662	64,184	63,818
Domestic Hidden Flows	880,985	907,883	966,159	1,016,797	1,083,518	1,143,305	1,179,083	1,218,958	1,216,468	1,225,538	1,225,538
Excavated soil by construction activities	816,720	845,300	901,947	951,758	1,043,621	1,104,647	1,140,813	1,176,980	1,176,980	1,187,480	1,187,480
Surplus soil *(moved out of the site)*	506,965	544,286	581,607	618,929	656,250	692,417	728,583	764,750	764,750	775,250	775,250
Cut & Fill	309,755	301,014	320,339	332,829	387,371	412,230	412,230	412,230	412,230	412,230	412,230
Soil erosion	7,527	7,587	7,629	7,641	7,599	7,545	7,474	7,408	7,355	7,355	7,355
Mining overburden	56,738	54,995	56,583	57,398	32,298	31,113	30,796	34,570	32,134	30,704	30,704

Data Sources and Methodology: Technical Notes

Japanese data were drawn from official statistical sources of various ministries and agencies as well as from academic literature and personal communications with experts. Official sources include Environment Agency (EA), Ministry of Agriculture, Forestry and Fisheries (MAFF), Ministry of International Trade and Industry (MITI), Ministry of Health and Welfare (MHW), and Ministry of Construction (MOC). Most of the Japanese data are presented on a fiscal year basis rather than calendar year.

DMO to Air

Carbon Dioxide and Water Vapor Emissions, and Oxygen Input

Inventories of CO_2 emissions have been officially reported based on the United Nations Framework Convention for Climate Change (UNFCCC) using Intergovernmental Panel on Climate Change (IPCC) guidelines for greenhouse gas (GHG) emissions and Japanese country-specific methodologies. However, this official inventory is not enough to provide a complete balance of CO_2, oxygen, and water vapor. The official inventories do not cover CO_2 that is not contributing to the greenhouse effect, namely, from digestion of food or feed by animals (including human beings). Therefore, emissions of CO_2, water, and extra inputs of oxygen for oxidation of carbon and hydrogen were newly estimated for this study. Results were compared with official inventories to prove that both data sets coincide with each other within acceptable margins of error (less than a few percent). The outline of our estimation method is as follows: for fossil fuels, carbon and hydrogen, contents were assumed by type of fuels; for example, 0.85, 0.12 for crude oil; 0.865, 0.125 for petroleum products; 0.76, 0.055 for coking coal; 0.645, 0.05 for fuel coal; 0.75, 0.25 for natural gas. Using such fractions, CO_2 and water produced and oxygen taken in by combustion of fuels were estimated stochiometrically.

Emissions from incinerating fuels used for international transport (heavy oil for navigation, and jet fuel for aviation) were included as a part of the transport sector's activities. CO_2 and water from biofuels (as in the case of the paper and pulp industry) as well as those from waste incineration, were estimated by applying the same procedure and listed in the dataset separately. CO_2 originating from limestone for cement and other industrial activities was estimated by applying the same methodology as the official inventory, namely as a product of the carbon fraction of limestone and apparent consumption of limestone for various activities.

Human respiration was calculated on the basis of an average CO_2 production of 0.3 metric tons per capita per year. The respiration of livestock was calculated on the basis of the number of cattle, pigs, poultry, and other animals (MAFF) and exhalation factors for each animal (Wuppertal Institute, except for cattle data). Factors applied in tons of CO_2 per year were as follows: cattle 1.6, pigs 0.327, poultry 0.027, sheep/goats 0.254, and horses 1.33. Material balances among feed intake, exhalation, and excreta validate these estimates. For example, as much as one third of feed intake by cattle is not digested but voided as excreta. To cross check, the amount of excreta estimated from feed inputs was compared with the amount of animal manure in industrial wastes.

Sulfur Dioxide, Oxides of Nitrogen, and Non-Methane Volatile Organic Compounds

The data for SO_2, NO_x, and NMVOC to air since 1990 were drawn from official GHG inventories. Before 1990, emissions of SO_2 and NO_x were reported only in international literature (OECD) or documents covering only short time intervals. Emissions of NMVOC before 1990 were not published; only unofficial estimates are available. Although certain inconsistencies exist among data before and after 1990, no correction was applied, time-series data were simply quoted from multiple data sources. Moreover, although a considerable percentage of NMVOC originates from dissipative use of products (e.g., solvents and paints), they are not categorized in the Japanese dataset as dissipative uses, but as outputs to air.

Another problem is that these inventories cover only emissions from sources on land and from navigation along Japanese coastal areas, even though Japan's heavy dependence on resource imports is accompanied by emissions from vessels far from Japanese territory. Given that the emission factors of SO_x and NO_2 per unit fuel consumption for ocean-going vessels are high (IPCC), the figures in this report are certainly underestimates. SO_2 and NO_x originating from international bunker oil will have to be added in future analyses, which will result in significant changes to the data presented here.

DMO to Land

Waste Disposal to Controlled Landfills

Data on wastes generated, treated, recycled or disposed at landfill sites were available for municipal solid wastes and industrial wastes respectively, from MHW. Industrial wastes are subdivided into 19 types: embers; sludge; waste oil; waste acid; waste alkali; waste plastics; waste paper; wood debris; waste fiber; animal and plant residues; waste rubber; metal scrap; glass and ceramic debris; slag; construction scrap wood; livestock excreta; animal corpses; soot and dust; and others. The total amounts of each type of wastes from all industries and the total amounts of all wastes from each type of industries are available in time series. However, cross tabulation between the waste type and the industry type is available only for 1993. The structure of this year was extrapolated to estimate all time series, assuming that the proportion of each industry's contribution to the generation of a specific type of industrial wastes is constant for all time series.

DMO to Water

Discharges of organic loads (COD) and nutrients (N, P) have been surveyed only for the drainage areas of three major closed waters (Tokyo Bay, Ise Bay, and Seto Inland Sea), where an area-wide total pollutant load control scheme has been applied. Although surveys of nutrients (N, P) were also applied to basins of major lakes and reservoirs, there is no nationwide survey. Therefore, results from these limited surveys were extrapolated, assuming that discharges per capita in nonsurveyed areas are the same as those in surveyed areas. Although population within the above-mentioned three major surveyed areas covers about 53 percent of the national total, there are considerable differences in land use, industrial structure, and discharge management between surveyed areas and nonsurveyed areas. Therefore, these results should be considered rough estimates.

Dissipative Use

Animal Manure

Data on livestock excreta are available from a survey of industrial wastes, in which generation amounts as well as reuse amounts are reported. The quantities reused can be inferred as manure application, although they are reported on a fresh (wet) weight basis. On the other hand, amounts of faeces and urine from typical livestock categories are estimated both on a dry and wet weight basis by applying their emission factors per animal head. The dry to wet ratio calculated from this estimate was combined with the above statistics on reused amounts to estimate manure application in dry weight.

Fertilizers and Pesticides

Time series of used amounts of N, P, and K fertilizers were taken from the statistics of MAFF, in which figures are expressed as P_2O_5, N, and K_2O. In addition, used amounts of lime were estimated, using the consumption data of lime-containing fertilizers. Limited time series for data pesticides use in Japan are available from international sources (OECD). Interpolation was applied when necessary.

Domestic Hidden Flows

All data for hidden flows were taken from our previous report (Adriaanse et al., 1997) and updated when necessary by applying the same methodology. MOC officially surveyed only excavated soils removed from construction sites (surplus soils). The total size of the excavation was estimated based on various studies in the literature including environmental impact assessment statements, land development statistics, excavation volumes announced for highway construction work contractors, among others, resulting in very rough and preliminary estimates. Soil excavated and used within the same site (cut and fill) was estimated only for new residential area development, by multiplying the factor of soil excavation works per unit area (average of several recent cases) by total area of new residential area development.

Contribution of Economic Sectors

DPO was attributed to seven economic activity categories (sectors): construction and infrastructure; mining and manufacturing; energy supply; households; agriculture; transport, and other. Other generally refers to service industries. Emissions of CO_2 to air from fuel combustion were attributed by energy balance tables. CO_2 from oil consumption for international navigation and aviation was included in the transport sector. CO_2 from waste incineration was attributed to other. Because of the limited data availability in time series, all of SO_2 and NO_x emissions were attributed to the energy sector. VOC emissions were included in the manufacturing sector, although they could have been attributed to other sectors, given more sophisticated data handling.

Municipal solid wastes were attributed to households, although they sometimes include wastes from small-sized service industries. Industrial wastes were attributed to the sector corresponding to the type of wastes, using sector versus waste type cross tabulation. Such a cross tabulation is available only for a single year (1993); the proportion of this year was extrapolated to all time series.

Discharges to water were originally reported as arising from three source categories:

municipal, industrial, and others. They were assumed to correspond respectively to households, industry, and agriculture in this study. Dissipative uses of manure, fertilizers, and pesticides were included in the agriculture sector. In terms of hidden flows for calculating TDO by sector, soil excavation was attributed to the construction/infrastructure sector, mining overburden was attributed to the mining and manufacturing sector, and soil erosion to the agriculture sector.

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ACKNOWLEDGMENT

The author would like to acknowledge the valuable assistance of Mr. Masaya Yoshida in preparing this country report.

MATERIAL FLOWS: THE NETHERLANDS

René Kleijn, Ester van der Voet

Highlights

Figure A1 shows domestic processed output (DPO) and total domestic output (TDO) for the Netherlands. Figure A2 shows DPO and TDO per capita, and Figure A3 shows DPO and TDO per constant units of GDP. All indicators are presented exclusive of water vapor, unless otherwise indicated.

From 1975 to 1996, the changes in both DPO and TDO were minor. DPO per capita remained relatively constant, while the Dutch population grew slightly, which is the reason for the slight increase in overall DPO. Due to a reduction in hidden flows, TDO per capita has decreased slightly, resulting in a roughly constant TDO.

Figure A3 shows that the stream of waste and emissions remained relatively constant, while per capita income grew significantly. Therefore, TDO and DPO per constant unit of GDP decreased steadily between 1975 and 1996. Figure A4 specifies the contribution of various output flows to TDO.

It appears that TDO can effectively be characterized by a limited number of key output flows. As is the case in the other countries,

FIGURE A1 | DPO AND TDO, NETHERLANDS 1975–1996

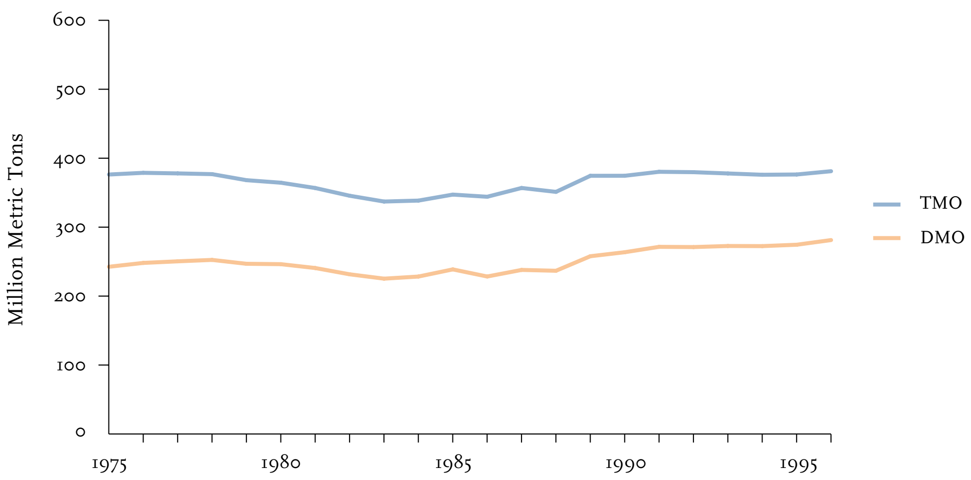


FIGURE A2

DPO AND TDO PER CAPITA, NETHERLANDS 1975–1996

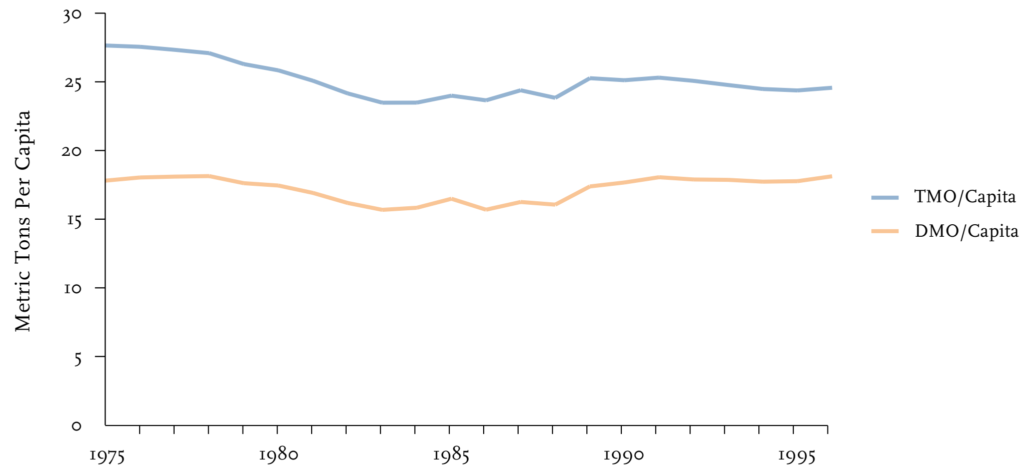


FIGURE A3

DPO AND TDO PER CONSTANT UNIT OF GDP, NETHERLANDS 1975–1996

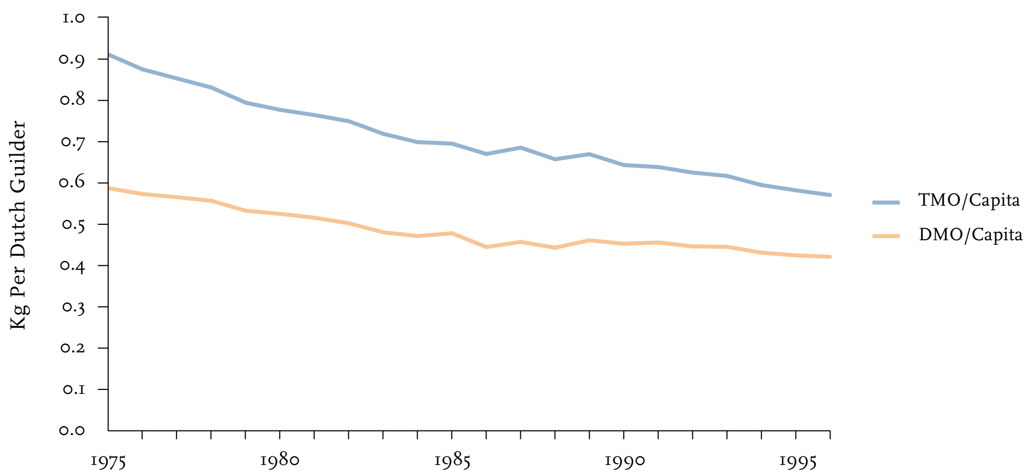
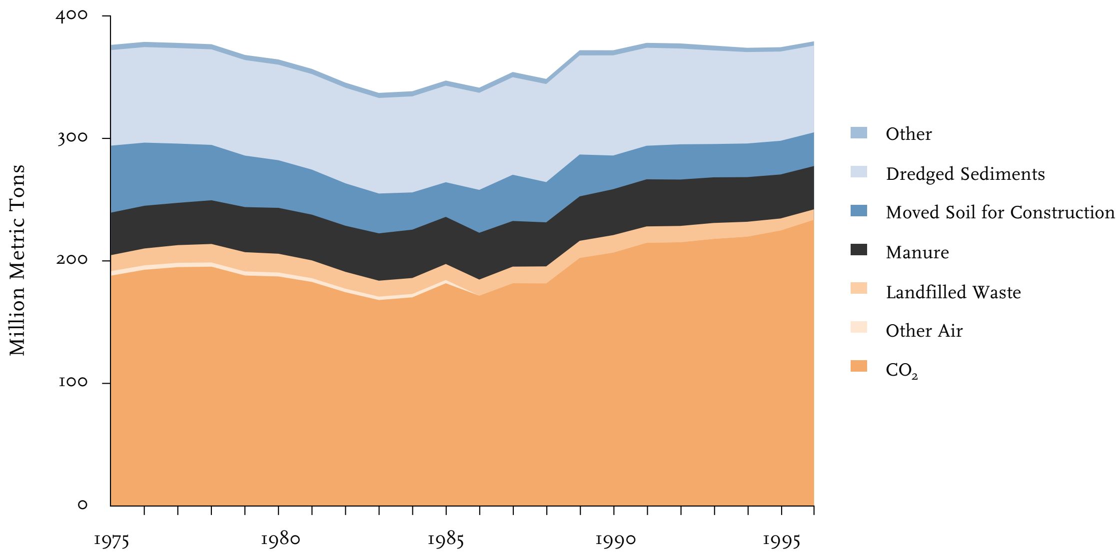


FIGURE A4 TOTAL DOMESTIC OUTPUT, NETHERLANDS 1975–1996



TDO in the Netherlands is dominated by emissions to air. The largest contributor to TDO is carbon dioxide (CO_2). The contribution of CO_2 emissions to TDO has increased. This is counterbalanced by a decrease of other outputs, keeping the total TDO more or less constant. DPO to land, of which the main component is landfill of final waste, has decreased steadily over the years. DPO to water is negligible compared to the other outflows. Another large flow in the category of dissipative use is spread manure. This is a typically Dutch problem, associated with the intensive stock breeding practiced in the Netherlands, and this issue is treated later in more detail. Domestic hidden flows constitute roughly one third of total TDO and they appear to have decreased during the study period. Reductions in two major flows are largely responsible for this decrease: dredged sediments and soil excavation for construction activities. The flow associated with dredging of sediments, which is another typically Dutch problem, will be addressed later. The soil excavation hidden flow dropped significantly from 1975 to 1996. This can be explained by the level of road building: construction of the highway network was still in full progress in 1975, but had slowed significantly by 1996.

Dredged Sediments

The country's location in the Rhine and Meuse delta has shaped the Dutch economy as an important transportation center.

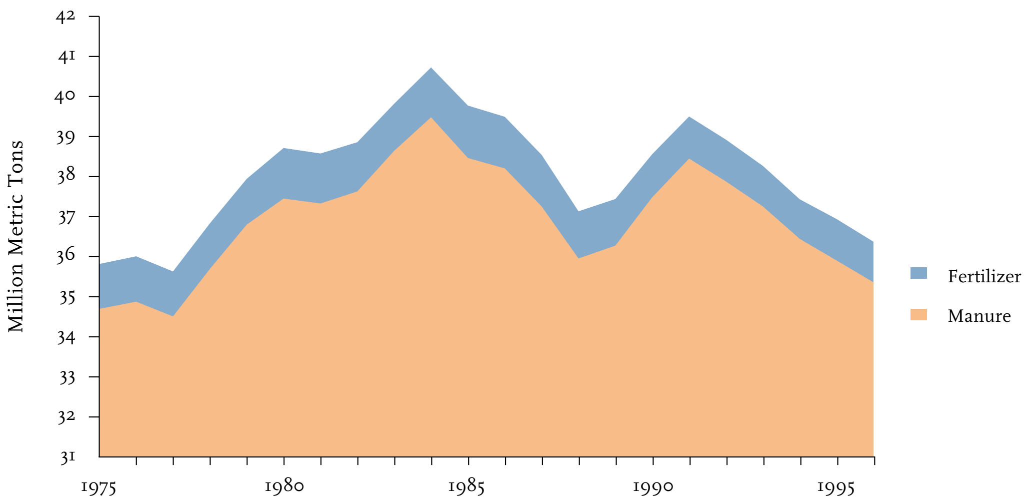
However, maintaining the waterways and harbors for use by heavy ships requires extensive dredging of sediments. This very large material flow then must be disposed of. Because a portion of this sediment is polluted by either Dutch or foreign sources (clay, sand, and toxic pollutants such as heavy metals find their way from other countries to the Netherlands by water), it cannot be used for soil improvement or construction sites, nor is it acceptable to dump it at sea. Therefore, an increasing portion of the sediment is disposed of in specified controlled landfill sites. The total amount of sediments being dredged each year has remained relatively constant over the years. Their destination, however, has changed significantly: the percentage that is disposed of at controlled sites increased from zero in 1975 to almost half in 1996.

Manure

Dutch agriculture is famous for its intensive production methods. Figure A5 presents the Dutch use of manure and fertilizer. The average amount equals roughly 2,500 kg (dry weight) per person and 500 kg per hectare of arable land per year. The amount of fertilizer used is dwarfed by the amount of manure, and it constitutes only 2 to 3 percent of the total.

Although the use of fertilizer decreased slightly from 1975 to 1996, the use of manure fluctuated. Manure use is directly related to the size and composition of the livestock population. It peaked in about 1984. In that year, the government enacted its first (interim) legislation regarding pig and

FIGURE A5 MANURE AND FERTILIZER OUTFLOWS, NETHERLANDS 1975–1996



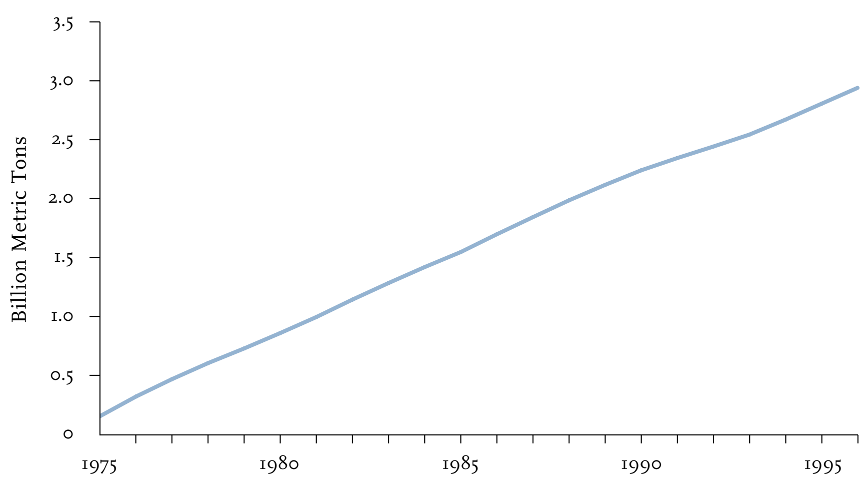
poultry farming because of a growing awareness of the environmental consequences of overnutrification. Manure use subsequently decreased. After 1989, manure use rose again, then declined after 1992, possibly because of changes in European Union agricultural policy. In 1996, it was back to the level of the late 1970s.

Net Additions to Stock, and Material Accumulation in the Netherlands

An analysis of DPO, combined with direct material input (DMI) and data on exports, can produce an overall picture of total material inflows and outflows. In addition to being exported and being emitted to the environment, materials accumulate in economic stocks of materials and products. On average, these three destinations were roughly equal in 1975: one third of DMI was exported, one third was emitted into the environment, and one third was added to stock. By 1996, exports had become more important, while annual net additions to stock decreased. Figure A6 shows the increase in the stock from 1975 to 1996.

As Figure A6 illustrates, the amount of material stockpiled in the economy increased by about 3 billion metric tons during the 21-year study period. This increase has yet to show any signs of slowing down. At present, we do not know which products or materials caused this accumulation, or what the size of the stock was in 1975. Despite that, this phenomenon is something to consider in formulating future waste management policies, since all stockpiled materials will eventually become wastes.

FIGURE A6 | MATERIAL ACCUMULATION IN STOCKS, NETHERLANDS 1975–1996



The Contribution of Economic Sectors

Table A1 shows the contributions of the six main economic sectors to Dutch TDO and DPO. Construction and infrastructure appear to be the odd ones out. Their contribution to TDO is large, but to DPO minor. Comparing the accounts with and without oxygen, the difference is much less for this sector than for the others; construction and infrastructure activity appears to be oxygen-extensive. Both phenomena are due to the large but hidden flows (in which oxygen plays only a small role), which are allocated almost entirely to this activity. With oxygen, the contribution of the remaining sectors (apart from "others") is in the same order of magnitude. Without oxygen, agriculture appears as the largest contributor to DPO and the second largest to TDO.

TABLE A1 **CONTRIBUTION OF MAJOR ECONOMIC SECTORS TO TDO AND DPO IN THE NETHERLANDS, 1996**

Sector	TDO (Incl. Oxygen) Metric tons	DPO (Incl. Oxygen) Metric tons
Construction/infrastructure	105,986,018	6,874,200
Manufacturing/Industry	57,350,171	57,350,171
Energy Utilities	45,398,689	45,398,689
Household	46,952,636	46,952,636
Agriculture	65,867,555	65,117,555
Transport	61,087,801	61,087,801
Other	19,060,552	19,060,552
	TDO (Exc. Oxygen) Metric tons	**DPO (Exc. Oxygen)** Metric tons
Construction/infrastructure	102,117,948	3,006,130
Manufacturing/Industry	18,122,478	18,122,478
Energy Utilities	12,404,351	12,404,351
Household	14,038,112	14,038,112
Agriculture	45,392,927	44,642,927
Transport	17,093,404	17,093,404
Other	5,864,219	5,864,219

Notes: These data do not sum to DPO and TDO as presented in the Dutch data table (*see page 98*) because of use of data from other datasets, DPO totals differ by up to 10 percent.

Material Output Flows: The Netherlands, 1975-1996

All units in metric tons unless otherwise stated

	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
Summary Data											
Population	13,599,000	13,734,000	13,814,000	13,898,000	13,986,000	14,091,000	14,209,000	14,286,000	14,340,000	14,395,000	14,454,000
GDP *(constant 1996 thousand Guilders)*	412,996,404	432,820,232	442,775,097	453,401,699	463,376,537	468,937,055	466,592,370	460,993,261	468,830,147	484,301,542	499,314,889
Direct Material Input *(DMI)*	405,146,844	404,619,658	404,092,472	403,565,286	403,038,100	402,510,914	397,881,022	397,353,836	396,826,650	396,299,464	395,772,278
DMI *(Adriaanse et al, 1997)*	521,653,000					550,459,000					559,214,000
Domestic Extraction	197,021,789					199,724,857					190,417,857
Imports	197,381,055	161,305,820	187,932,687	186,157,731	198,917,055	192,364,757	175,532,589	174,896,932	178,172,043	185,815,165	195,362,821
Exports	138,005,129	120,172,078	138,507,258	147,668,642	158,937,263	152,800,676	146,272,778	137,274,571	145,644,317	148,567,223	153,366,251
Summary Indicators *(as presented in main report)*											
DPO *(including oxygen)*	242,553,233	248,124,689	250,429,355	252,481,452	246,858,430	246,311,538	240,710,505	231,610,546	225,297,832	228,352,275	238,731,789
DPO *(excluding oxygen)*	104,105,673	106,248,827	107,034,205	108,879,460	108,538,010	108,619,470	106,363,720	103,435,734	101,807,205	103,275,678	105,339,832
Domestic hidden flows	133,790,000	130,658,600	127,527,200	124,395,800	121,264,400	118,133,000	116,039,000	113,945,000	111,851,000	110,166,091	108,481,182
TDO *(including oxygen)*	376,343,233	378,783,289	377,956,555	376,877,252	368,122,830	364,444,538	356,749,505	345,555,546	337,148,832	338,518,366	347,212,971
TDO *(excluding oxygen)*	237,895,673	236,907,427	234,561,405	233,275,260	229,802,410	226,752,470	222,402,720	217,380,734	213,658,205	213,441,769	213,821,014
Net Additions to Stock	152,996,503	167,139,985	147,915,906	136,143,459	124,245,750	130,724,985	135,789,569	147,906,128	140,526,829	135,127,323	127,518,295
Summary Indicators *(metric tons per capita)*											
DPO *(including oxygen)*	17.84	18.07	18.13	18.17	17.65	17.48	16.94	16.21	15.71	15.86	16.52
DPO *(excluding oxygen)*	7.66	7.74	7.75	7.83	7.76	7.71	7.49	7.24	7.10	7.17	7.29
Domestic hidden flows	9.84	9.51	9.23	8.95	8.67	8.38	8.17	7.98	7.80	7.65	7.51
TDO *(including oxygen)*	27.67	27.58	27.36	27.12	26.32	25.86	25.11	24.19	23.51	23.52	24.02
TDO *(excluding oxygen)*	17.49	17.25	16.98	16.78	16.43	16.09	15.65	15.22	14.90	14.83	14.79
Net Additions to Stock	11.25	12.17	10.71	9.80	8.88	9.28	9.56	10.35	9.80	9.39	8.82
Summary Indicators including additional outputs *(not presented in main report)*											
DPO *(including carbon dioxide from respiration, excluding water vapor from all combustion & respiration)*	264,130,776	269,835,261	271,985,269	274,648,228	269,600,284	269,408,916	263,785,950	254,859,685	249,064,829	252,550,118	262,447,316
DPO *(including carbon dioxide from respiration, including water vapor from all combustion & respiration)*	354,486,632	369,364,169	367,701,194	372,511,752	371,453,985	362,700,958	348,880,546	333,496,317	328,699,518	336,513,276	348,378,419
TDO *(including carbon dioxide from respiration, excluding water vapor from all combustion & respiration)*	397,920,776	400,493,861	399,512,469	399,044,028	390,864,684	387,541,916	379,824,950	368,804,685	360,915,829	362,716,209	370,928,498
TDO *(including carbon dioxide from respiration, including water vapor from all combustion & respiration)*	488,276,632	500,022,769	495,228,394	496,907,552	492,718,385	480,833,958	464,919,546	447,441,317	440,550,518	446,679,367	456,859,601
Gateway Indicators											
DPO to Air *(including oxygen from all combustion, excluding oxygen from respiration, excluding all water vapor)*	191,692,277	196,382,145	198,447,121	198,707,482	191,421,276	190,549,724	185,885,453	177,350,682	170,864,746	173,039,243	184,439,190
CO_2 from fossil fuel combustion	187,975,145	192,761,843	194,923,648	195,280,838	188,091,461	187,300,261	182,813,898	174,423,759	168,059,145	170,240,335	181,730,754
SO_2	402,219	421,713	441,207	460,701	480,195	499,689	473,779	400,985	305,982	273,904	243,059
NO_x	467,179	488,630	510,081	531,532	552,983	574,434	567,215	553,808	546,589	566,184	569,278
NMVOC	612,364	601,395	590,427	579,459	568,491	574,000	545,000	543,250	541,500	542,750	534,000
CO	2,173,840	2,040,440	1,907,040	1,773,640	1,640,240	1,506,840	1,393,160	1,349,080	1,343,280	1,349,080	1,300,360
Fine particles	61,530	68,124	74,718	81,312	87,906	94,500	92,400	79,800	68,250	66,990	61,740
Bunker Fuel Emissions											
CO_2 from bunkers	38,635,145	40,685,843	40,111,648	37,732,838	27,807,461	24,280,261	23,213,898	22,803,759	20,999,145	18,620,335	19,850,754
DPO to Land	49,067,057	49,995,182	50,281,411	52,119,684	53,829,406	54,200,605	53,310,381	52,791,731	53,011,491	53,937,976	53,032,599
Municipal landfill	13,038,925	13,774,982	14,443,739	15,101,900	15,706,998	15,302,826	14,544,915	13,728,275	12,984,841	12,997,466	13,040,855
Landfilled sewage sludge	90,000	90,000	90,113	62,467	60,409	61,204	62,000	63,000	61,000	66,000	54,000
Dissipative flows to land	35,938,131	36,130,200	35,747,559	36,955,317	38,061,999	38,836,575	38,703,466	39,000,457	39,965,650	40,874,510	39,937,744
Fertilizers	1,120,714	1,132,817	1,121,627	1,137,778	1,142,341	1,261,944	1,247,976	1,227,897	1,174,762	1,243,413	1,309,325
Pesticides	21,178	21,305	21,431	21,558	21,685	21,812	21,938	22,065	22,192	22,319	23,042
Animal manure spread on fields	34,698,289	34,878,127	34,511,199	35,694,022	36,801,612	37,452,638	37,329,552	37,630,495	38,644,696	39,481,779	38,464,377
Sewage sludge spread on fields	97,950	97,950	93,302	101,958	96,361	100,181	104,000	120,000	124,000	127,000	141,000

Material Output Flows: The Netherlands, 1975-1996

All units in metric tons unless otherwise stated

1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	
											Summary Data
14,529,000	14,615,000	14,715,000	14,805,000	14,893,000	15,010,000	15,129,000	15,239,000	15,342,000	15,424,000	15,494,000	Population
513,295,706	520,481,846	534,014,374	559,113,050	582,036,685	595,423,529	607,331,999	612,190,655	631,780,756	646,311,713	667,640,000	GDP *(constant 1996 thousand Guilders)*
416,893,058	416,365,872	415,838,686	415,311,500	414,784,314	402,252,532	400,258,402	423,011,737	449,477,182	452,514,075	475,754,498	Direct Material Input *(DMI)*
				600,235,000	626,533,000	637,926,000	603,523,000	615,903,000			DMI *(Adriaanse et al, 1997)*
				192,698,619	182,679,714	183,211,762	183,330,143	193,457,381	193,457,381	193,457,381	Domestic Extraction
198,517,791	203,274,546	215,443,750	212,505,773	209,567,795	206,629,818	203,691,840	225,716,094	242,535,901	245,152,394	267,990,917	Imports
153,784,967	156,242,952	159,747,154	163,906,577	168,066,000	172,722,522	177,379,043	196,998,134	199,371,534	195,861,286	218,066,845	Exports
											Summary Indicators *(as presented in main report)*
228,408,022	237,957,446	236,744,591	257,819,071	263,640,198	271,435,080	271,114,529	272,666,389	272,495,245	274,503,911	281,260,671	DPO *(including oxygen)*
102,404,376	104,610,067	103,465,436	109,485,740	112,111,537	114,214,490	113,586,396	113,176,963	111,736,171	110,091,082	110,482,156	DPO *(excluding oxygen)*
115,676,873	118,858,564	114,423,255	116,656,945	110,879,636	108,845,394	108,623,152	105,197,909	103,484,667	101,877,424	99,861,818	Domestic hidden flows
344,084,894	356,816,009	351,167,845	374,476,016	374,519,834	380,280,474	379,737,680	377,864,298	375,979,912	376,381,335	381,122,489	TDO *(including oxygen)*
218,081,248	223,468,631	217,888,690	226,142,685	222,991,174	223,059,884	222,209,548	218,374,872	215,220,837	211,968,507	210,343,974	TDO *(excluding oxygen)*
150,856,366	145,295,196	142,707,468	131,072,856	123,774,369	103,791,037	97,882,780	101,380,461	126,860,192	135,025,990	134,918,063	Net Additions to Stock
											Summary Indicators *(metric tons per capita)*
15.72	16.28	16.09	17.41	17.70	18.08	17.92	17.89	17.76	17.80	18.15	DPO *(including oxygen)*
7.05	7.16	7.03	7.40	7.53	7.61	7.51	7.43	7.28	7.14	7.13	DPO *(excluding oxygen)*
7.96	8.13	7.78	7.88	7.45	7.25	7.18	6.90	6.75	6.61	6.45	Domestic hidden flows
23.68	24.41	23.86	25.29	25.15	25.34	25.10	24.80	24.51	24.40	24.60	TDO *(including oxygen)*
15.01	15.29	14.81	15.27	14.97	14.86	14.69	14.33	14.03	13.74	13.58	TDO *(excluding oxygen)*
10.38	9.94	9.70	8.85	8.31	6.91	6.47	6.65	8.27	8.75	8.71	Net Additions to Stock
											Summary Indicators including additional outputs *(not presented in main report)*
252,020,870	261,130,035	259,309,417	280,571,545	287,016,671	295,325,782	294,763,249	296,044,299	295,507,882	297,276,511	303,788,725	DPO *(including carbon dioxide from respiration, excluding water vapor from all combustion & respiration)*
340,647,018	353,088,951	348,577,078	378,188,494	384,508,345	399,046,131	397,454,890	399,149,915	399,091,442	401,097,952	414,375,627	DPO *(including carbon dioxide from respiration, including water vapor from all combustion & respiration)*
367,697,743	379,988,599	373,732,672	397,228,491	397,896,308	404,171,176	403,386,400	401,242,208	398,992,549	399,153,936	403,650,543	TDO *(including carbon dioxide from respiration, excluding water vapor from all combustion & respiration)*
456,323,891	471,947,515	463,000,333	494,845,439	495,387,981	507,891,525	506,078,042	504,347,824	502,576,109	502,975,377	514,237,446	TDO *(including carbon dioxide from respiration, including water vapor from all combustion & respiration)*
											Gateway Indicators
174,267,125	184,354,755	184,260,889	204,930,037	209,329,978	217,050,133	217,431,251	220,084,227	221,789,797	226,780,819	235,509,174	**DPO to Air** *(including oxygen from all combustion, excluding oxygen from respiration, excluding all water vapor)*
171,609,638	181,749,005	181,665,229	202,441,927	206,768,708	214,763,183	215,233,601	217,966,327	219,787,797	224,834,299	233,628,774	CO_2 from fossil fuel combustion
247,994	253,000	241,500	204,900	202,520	172,700	171,900	163,100	145,900	145,720	134,700	SO_2
581,653	596,800	603,800	591,100	579,750	567,250	554,750	534,800	510,100	497,800	485,700	NO_x
532,600	534,200	535,800	532,400	515,000	460,000	434,000	404,000	387,000	363,000	348,000	NMVOC
1,234,240	1,160,000	1,149,560	1,097,360	1,197,000	1,023,000	977,000	961,000	907,000	892,000	862,000	CO
61,000	61,750	65,000	62,350	67,000	64,000	60,000	55,000	52,000	48,000	50,000	Fine particles
											Bunker Fuel Emissions
16,569,638	20,589,005	21,245,229	40,931,927	43,228,708	44,623,183	45,853,601	47,986,327	46,427,797	47,904,299	49,298,774	CO_2 from bunkers
52,903,117	52,387,130	51,290,362	51,717,914	53,161,319	53,243,747	52,549,777	51,589,962	49,854,548	47,013,492	45,076,317	**DPO to Land**
13,157,330	13,581,352	13,862,363	13,956,156	14,282,735	13,400,000	13,300,000	13,000,000	12,150,000	9,800,000	8,450,000	Municipal landfill
92,000	119,000	151,000	143,000	152,000	170,000	176,000	210,000	161,000	179,000	174,000	Landfilled sewage sludge
39,653,787	38,686,779	37,276,999	37,618,759	38,726,584	39,673,747	39,073,777	38,379,962	37,543,548	37,034,492	36,452,317	Dissipative flows to land
1,287,976	1,287,103	1,177,341	1,163,413	1,075,794	1,051,825	1,043,730	1,011,944	987,222	1,035,873	1,012,183	Fertilizers
24,621	20,588	20,683	21,792	21,438	19,698	16,817	13,249	12,917	12,610	10,680	Pesticides
38,206,189	37,256,088	35,956,975	36,277,554	37,484,353	38,449,224	37,879,230	37,256,769	36,447,409	35,906,008	35,363,455	Animal manure spread on fields
135,000	123,000	122,000	156,000	145,000	153,000	134,000	98,000	96,000	80,000	66,000	Sewage sludge spread on fields

Material Output Flows: The Netherlands, 1975-1996

All units in metric tons unless otherwise stated

	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
DPO to Water	1,793,900	1,747,362	1,700,824	1,654,285	1,607,747	1,561,209	1,514,671	1,468,133	1,421,595	1,375,056	1,260,000
N	213,182	211,770	210,358	208,945	207,533	206,121	204,709	203,297	201,885	200,473	200,000
P	45,059	43,732	42,404	41,076	39,749	38,421	37,094	35,766	34,438	33,111	30,000
Others *(Chloride)*	1,535,659	1,491,861	1,448,062	1,404,264	1,360,465	1,316,667	1,272,868	1,229,070	1,185,271	1,141,473	1,030,000
Additional Inputs *(not presented in main report)*											
Oxygen in combustion	218,763,877	230,346,002	228,475,972	230,591,791	228,857,043	220,618,328	209,986,425	198,074,040	194,277,017	199,710,515	209,775,159
Oxygen in respiration	15,692,758	15,789,507	15,677,028	16,121,292	16,539,530	16,798,093	16,782,142	16,908,465	17,285,088	17,598,431	17,247,656
Additional Outputs *(not presented in main report)*											
Water vapor from fossil combustion	90,355,856	99,528,908	95,715,925	97,863,524	101,853,701	93,292,042	85,094,596	78,636,631	79,634,689	83,963,158	85,931,102
Water vapor from respiration	8,827,177	8,881,597	8,818,328	9,068,227	9,303,486	9,448,927	9,439,955	9,511,011	9,722,862	9,899,118	9,701,807
CO_2 from respiration	21,577,543	21,710,571	21,555,913	22,166,776	22,741,854	23,097,378	23,075,445	23,249,139	23,766,997	24,197,843	23,715,527
Domestic Hidden Flows	133,790,000	130,658,600	127,527,200	124,395,800	121,264,400	118,133,000	116,039,000	113,945,000	111,851,000	110,166,091	108,481,182
Excavated soil	54,667,000	51,509,200	48,351,400	45,193,600	42,035,800	38,878,000	36,758,400	34,638,800	32,519,200	30,399,600	28,280,000
Dredging wastes	78,000,000	78,000,000	78,000,000	78,000,000	78,000,000	78,000,000	78,000,000	78,000,000	78,000,000	78,409,091	78,818,182
Soil erosion	1,123,000	1,149,400	1,175,800	1,202,200	1,228,600	1,255,000	1,280,600	1,306,200	1,331,800	1,357,400	1,383,000

Material Output Flows: The Netherlands, 1975-1996

All units in metric tons unless otherwise stated

1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	
1,237,780	1,215,560	1,193,340	1,171,120	1,148,900	1,141,200	1,133,500	992,200	850,900	709,600	675,180	**DPO to Water**
196,400	192,800	189,200	185,600	182,000	202,000	222,000	201,333	180,667	160,000	171,867	N
29,380	28,760	28,140	27,520	26,900	25,700	24,500	21,533	18,567	15,600	14,047	P
1,012,000	994,000	976,000	958,000	940,000	913,500	887,000	769,333	651,667	534,000	489,267	Others *(Chloride)*
											Additional Inputs *(not presented in main report)*
204,782,444	215,088,636	212,628,187	235,103,953	238,187,926	249,416,456	248,809,591	251,138,863	252,833,350	256,698,554	269,077,984	Oxygen in combustion
17,172,981	16,852,793	16,410,783	16,547,254	17,001,072	17,375,056	17,199,069	17,002,116	16,736,463	16,561,891	16,384,039	Oxygen in respiration
											Additional Outputs *(not presented in main report)*
88,626,148	91,958,916	89,267,661	97,616,949	97,491,674	103,720,349	102,691,641	103,105,617	103,583,560	103,821,441	110,586,903	Water vapor from fossil combustion
9,659,802	9,479,696	9,231,065	9,307,830	9,563,103	9,773,469	9,674,476	9,563,690	9,414,261	9,316,064	9,216,022	Water vapor from respiration
23,612,849	23,172,590	22,564,827	22,752,474	23,376,474	23,890,702	23,648,720	23,377,909	23,012,637	22,772,601	22,528,054	CO_2 from respiration
115,676,873	118,858,564	114,423,255	116,656,945	110,879,636	108,845,394	108,623,152	105,197,909	103,484,667	101,877,424	99,861,818	**Domestic Hidden Flows**
35,021,000	37,748,000	32,858,000	34,182,000	27,495,000	27,391,000	28,766,000	27,184,000	27,458,000	27,500,000	27,500,000	Excavated soil
79,227,273	79,636,364	80,045,455	80,909,545	81,773,636	79,994,394	78,215,152	76,435,909	74,656,667	72,877,424	70,861,818	Dredging wastes
1,428,600	1,474,200	1,519,800	1,565,400	1,611,000	1,460,000	1,642,000	1,578,000	1,370,000	1,500,000	1,500,000	Soil erosion

Data Sources and Methodology: Technical Notes

The majority of the Dutch data was obtained from Statistics Netherlands (CBS) and its online database Statline. Only in cases in which CBS data were not available were other sources used. A description is provided below of the other data sources used in this study.

Corrections in DMI

DMI data given in Adriaanse et al., 1997 have been corrected in this report. In Adriaanse et al., *Total Domestic* included the category "excavation" that according to the definition consists of hidden flows; thus, *Total Domestic* was not equal to DMI. Furthermore, import data for fossil fuels that were used in Adriaanse et al. were much higher than those recorded in CBS import/export statistics. The figures that were used in Adriaanse et al. were based on the Statistical Yearbook of CBS, in which figures from the energy balance are given. The method of calculating the data in the energy balance changed in 1989. Before that year, the so-called Special Trade System was used, whereas from 1989 onward the General Trade System was used. This means that before 1989, fuels that were not declared at customs were not included in the import and export totals in the energy balance, but they were included after 1989. This causes the imports and exports of fuels in the energy balance and the Statistical Yearbook to increase by 50 percent. In the Statistics for International trade, "not declared" fuels are not included for the whole time series. A part of the "not declared" fuels were used for international transport. In this study, it was decided that emissions from bunker fuels would be accounted for in the material output of the economy. For mass balance purposes, the bunker fuels should thus be added as an inflow. Not declared bunker fuels were therefore added to the DMI. Furthermore, the Wuppertal Institute corrected the DMI data for some minor issues like a dry weight/wet weight problem in the category of renewables. The new, corrected figures for DMI can be found in the dataset.

Exports

Export figures were taken from the trade statistics (CBS). They were available from 1975 to 1988 and from 1992 to 1996. Data for the missing years were interpolated. For 1975 to 1977, a correction was made for the export of natural gas, which was not correctly included at that time in the export statistics. For those years, figures were used from the energy statistics (CBS).

DPO to Air

Carbon Dioxide, Sulfur Dioxide, and Oxides of Nitrogen

Emissions of CO_2, SO_2, and NO_x to air were taken from NAMEA (CBS) for 1987 to 1997. Data for 1975, and 1979 to 1987 were taken from Statline (CBS). In Statline, emissions for industrial (noncombustion) sources were not available for 1975 to 1989. Missing data were extrapolated on the basis of the known data from the sources above. Emissions of CO_2 from the incineration of fuels used for international transport (oil for shipping and kerosene for aviation) are included in the CO_2 emission account. These emissions are not included in the NAMEA or Statline emission figures. They were calculated on the basis of CBS data on the use of fossil fuels combined with their carbon content.

Human respiration was calculated on the basis of an average daily CO_2 production of 0.9 kg per capita (Harte, 1988). Livestock respiration was calculated on the basis of the number of cattle, pigs, poultry, and other farm animals (CBS) and exhalation factors based on the average weight of the animals (Handboek Rundveehouderij), the amount of dry weight manure produced by the animals (Wuppertal Institute), and human respiration. The resulting factors in kg CO_2/day were: cattle, 8.0; pigs for meat, 0.67; pigs for breeding, 0.98; poultry for eggs, 0.04; poultry for meat, 0.03; sheep and goats, 0.65; and horses, 6.0.

Water

Carbon-based fuels are converted into CO_2 and H_2O in combustion processes. Emission of water generated during combustion of carbon-based fuels was calculated on the basis of the use of fossil fuels (Statline) and emission factors for the different fuels. Factors were based on hydrogen content and the water content of the fuel (CBS). Resulting factors in kg H_2O per kg CO_2 were: coal and coal products, 0.55; oil and oil products, 0.98; and natural gas, 1.69.

Non-Methane Volatile Organic Compounds, Carbon Monoxide, and Fine Particles

Emissions of NMVOC, CO, and fine particles are available from Statline (CBS) for the whole period except 1976 to 1979 and excluding industrial (non-combustion) sources from 1975 to 1989. For NMVOC, emissions from industrial sources were filled in with data from RIVM (Nationale Milieuverkenningen) and the Ministry of Housing, Spatial Planning, and the Environment (KWS 2000). CO_2 emissions from industrial sources were extrapolated with the help of data from the Emission Registration. For fine particles, emissions from industrial sources were extrapolated from the Statline data. Missing data were extrapolated on the basis of known data from the sources above.

DPO to Land

Final Waste Disposal (Landfill Only)

The amount of waste disposed of in landfill sites is available from the AOO for 1991 to 1997. The total amount of household waste was available from Statline (CBS) for the entire 1975–96 period. Data on waste from private companies and public institutions was available from Waste Statistics (CBS) for 1984 to 1996 in one-year intervals. The fraction of these two types of waste that was landfilled is known for 1981 to 1996 in one-year intervals (CBS Waste Statistics). All other data were extrapolated from the above.

Landfilled Sewage Sludge

Amounts of dry weight sewage sludge and the types of use, treatment, and disposal were taken from CBS for 1981 to 1996. In wet weight, additional data were available for 1977 to 1979 (CBS). For those years, dry weight data were calculated from the wet weight data. Data for 1975, 1976, and 1980 were extrapolated from the available data.

DPO to Water

Data for emissions of nitrogen, phosphorus, and chlorine to water were available for the years 1985, 1990, 1992, and 1995 (Statline, CBS). All other data were extrapolated. Emissions of other substances were found to be negligible on a mass basis. There is a double count in this data with the dissipative use of fertilizer and manure.

Dissipative Use

Manure (Dry Weight)

Data for the amount of manure produced in the Netherlands were calculated on the basis of time series data for the number of animals (CBS) multiplied by factors for the production of manure per animal (Wuppertal Institute). Some additional data for broilers, horses, goats, and sheep were calculated on the basis of the amounts of P_2O_5 produced by these animals. The factors used in kg dry weight manure per day were: dairy cows, 5.95; calves, 0.85; fattening pigs, 0.50; breeding sows, 0.73; laying hens, 0.03; broilers, 0.023; sheep and goats, 0.48; and horses, 4.5.

Fertilizer

Time series of used amounts of P_2O_5, N, and K_2O were taken from Statline. These data were combined with fractions of P_2O_5, N, and K_2O in typical artificial fertilizers: P_2O_5, 0.35; N, 0.24; and K_2O, 0.45.

Sewage Sludge

See DPO to land.

Pesticides

Data for the use of different categories of pesticides were known from Nefyto, the Dutch organization for pesticide merchants (published in: de Snoo and de Jong, 2000) for 1986 to 1996. Governmental policy plans (IMP-M, 1986, and MJP-G, 1991) provided additional data for 1976, 1984, and 1985. All other data were extrapolated.

Hidden Flows

Surplus Soil

The data for surplus soil were taken from Adriaanse et al., 1997. These data were available in five-year intervals only from 1975 to 1990. Missing years were extrapolated except for 1986 to 1989, which were taken from the original dataset (van Heijningen et al., 1997).

Erosion

The data for erosion were taken from Adriaanse et al., 1997. These data were available for five-year intervals only from 1975 to 1990. Missing years were extrapolated.

Dredged Sediments (Fresh Weight)

Incidental data only are available for the amount of dredging material in the Netherlands. Data were available for 1988 to 1990 (Ministry of Transport Public Works and Water Management, 1989 and 1990) and 1996 (Absil and Bakker, 1999). Anecdotal evidence suggests that dredging before 1988 was relatively stable and that landfilling occurred only from 1984 onward. All other data were extrapolated from the above.

Sectoral Data for the 1996 Balance

The data for DPO to air allocated among economic sectors were taken mainly from NAMEA (CBS). Human and livestock respiration and water emissions were calculated as described above. There is a discrepancy between the 1996 balance and the time series because the allocation among economic sectors could not be determined for a number of substances: NMVOC, CO, and fine particles. Waste disposal was calculated on the basis of NAMEA (CBS) data. In the sector, "Others," environmental services were excluded. The data on landfilled waste used in the 1996 balance are not exactly the same as in the time series. Because the data for the 1996 balance had to be allocated among economic sectors, a different data source (NAMEA) than in the time series was used (see above). For DPO to water, N and P emissions were distributed among the different sectors on the basis of the N and P balances of CBS (Fong, 1997a; Fong, 1997b). However, there is a discrepancy here with the time series data. On the basis of the N and P balance for 1995, it is clear which part of the N and P emissions to water is leaching from agricultural soils. To include this emission would cause a double count with the dissipative use of fertilizers and manure. Therefore, this N and P emission should be excluded, which is done in the 1996 balance. However, data on leaching are not known for the years before 1995; therefore, the double count is still present in the time series data. Chlorine was attributed entirely to manufacturing/industry. Manure, fertilizer, and pesticides were attributed to agriculture, and sewage sludge was equally divided between households and manufacturing/industry. Regarding dissipative flows, dredging and surplus soil were attributed to construction/infrastructure, and erosion was equally divided between construction/infrastructure and agriculture.

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MATERIAL FLOWS: UNITED STATES

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Overview

The United States is a huge country geographically, and the largest economy in the world. It is so rich in productive land and mineral resources that it can extract or harvest within its national borders over 90 percent (by weight) of the raw materials it requires each year. Only a small fraction of these materials is exported. The balance remains in the economy in the form of buildings, other infrastructure, and durable goods (2 billion metric tons) or is deposited into the environment (over 23 billion metric tons).[1] The immense input and output flows generated by the U.S. economy are dominated by energy-related materials: hidden flows associated with coal mining, and emissions of CO_2 from fossil fuel combustion, account for over 50 percent of total domestic output (TDO). Hidden flows in the form of overburden from mining of other minerals, soil erosion caused by agriculture, and earth-moving for construction make up another 24 percent of TDO.

Quantities of hidden flows fell only slightly in two decades, from 17.2 billion to 16.3 billion metric tons. This small change occurred despite the dramatic shift, in value terms, in the U.S. economy toward high technology and service industries, which are relatively nonintensive energy and material users. Wastes from coal and metal mining actually increased from 1975 to 1996, as operations expanded and ore qualities declined. Soil erosion has declined with the removal of marginal land from cultivation, but it still accounts for nearly 3.5 billion metric tons per year.

In contrast, domestic processed output (DPO)—flows from the economy comprising conventional wastes, emissions, discharges, and system losses—rose substantially, from 5.3 billion metric tons in 1975 to 6.8 billion metric tons in 1996. These flows are dominated by CO_2 emissions, which account for 82 percent of total DPO. Fossil fuel combustion rose by about one third from 1975 to 1996, encouraged by low oil prices and driven in part by resurgent demand for electricity with the growth of information technologies, and electrical and electronic products in the home. Oil consumption for transportation grew substantially over the 21-year period: efforts to improve vehicle fuel efficiency stalled as energy prices fell, and consumer preferences began to shift toward large, heavy sport utility vehicles that consume approximately twice as much fuel per mile as the average car.

The other major flows in domestic processed output comprise nutrients and biosolids from the agriculture sector, which pass through the food processing sector to final disposal as manure (from livestock) and sewage (from humans). From 1975 to 1996, nutrient and other flows from the agriculture sector remained roughly constant. Manure quantities fell slightly as the livestock base shifted from cows to poultry, though outputs became more concentrated with intensification of the livestock sector. Quantities of sewage increased in line with population growth. The data indicate that fertilizer use has saturated at the national level. Regional differences in fertilizer application rates are high, and a regional flow analysis would be required in order to determine nutrient flow rates. A high but uncertain proportion of fertilizer nutrient is not absorbed by growing plants and passes directly into the environment.

The main constituents of hidden flows and domestic processed output are shown in Figure A1. Hidden flows comprise overburden, earth moving, soil erosion, and dredged materials; domestic processed output comprises CO_2, SO_x, NO_x, agriculture, forestry, human waste, and other outputs.

On a per capita basis, as well as an absolute basis, material flows in the United States are the highest of the five study countries. Figure A2 shows the principal material flows generated per capita, and the quantity of material added to physical stock in the form of infrastructure and durable goods.

During the study period, the net effect of marginally decreased domestic hidden flows and sharply increased domestic processed output has been a small increase in total domestic output flows of less than 1 billion tons (3 percent). During this same period, the U.S. economy grew by 74 percent, and the population by 23 percent. These trends

FIGURE A1 COMPOSITION OF TOTAL DOMESTIC OUTPUT, UNITED STATES 1975–1996

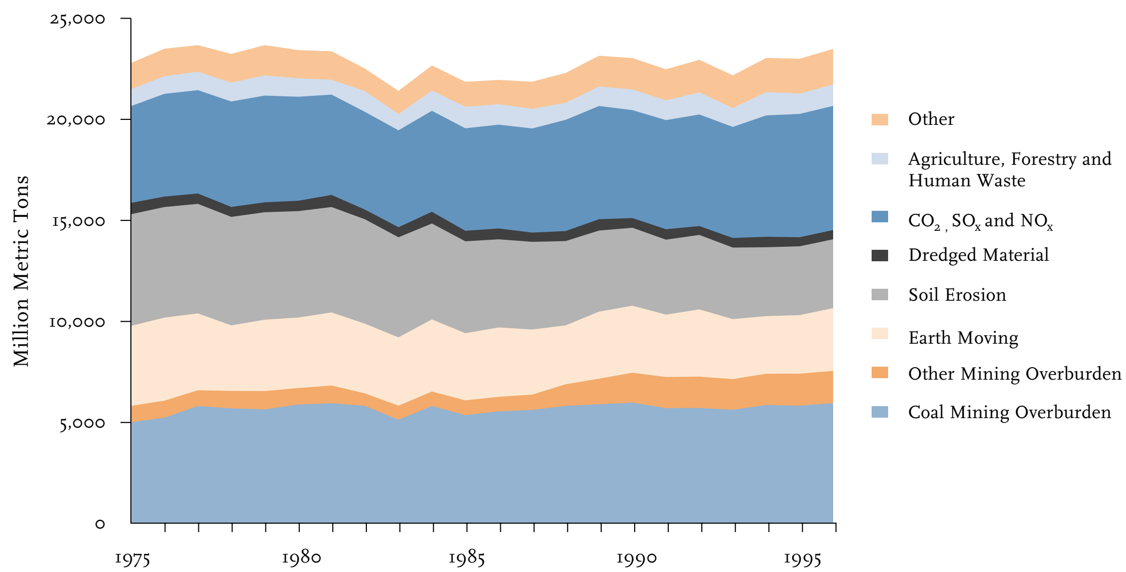
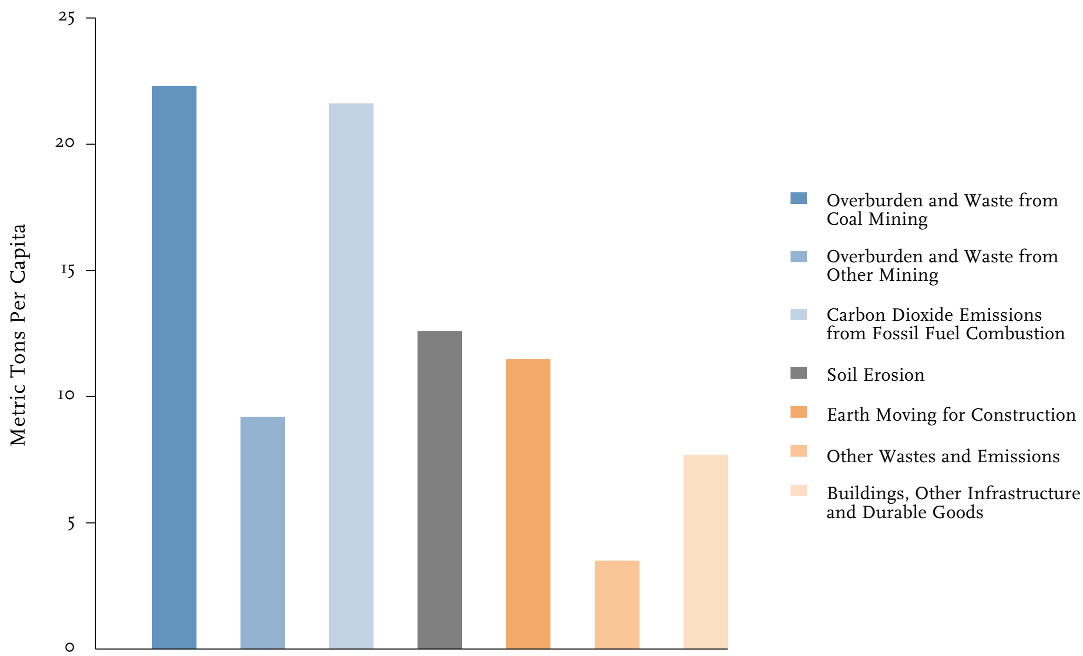


FIGURE A2 PRINCIPAL MATERIAL FLOWS GENERATED PER CAPITA, UNITED STATES 1996



represent a substantial decoupling of output flows from economic and population growth (*Figure A3*). However, decoupling is much less pronounced when hidden flows are excluded. Conventional wastes, emissions, and discharges rose by 28 percent since 1975 (5 percent on a per capita basis), the largest increase of all the study countries. (*See Figure A4.*)

Surprisingly, the amount of material going to stock (infrastructure and durable goods) each year has increased since 1975, though the trend has fluctuated with economic growth and recession. The great national infrastructure projects—the railroad network, interstate highway system, and industrial and housing base—were mostly completed by the 1970s, and it might be expected that quantities of material going to stock annually would have decreased since then. Domestic hidden flows associated with stock flows—principally earth moving—have indeed declined as a result of reduced highway construction (*see data table*). However, most of this decline has been offset by construction of new and

FIGURE A3 **DECOUPLING BETWEEN TDO, POPULATION, AND GDP, UNITED STATES 1975–1996**

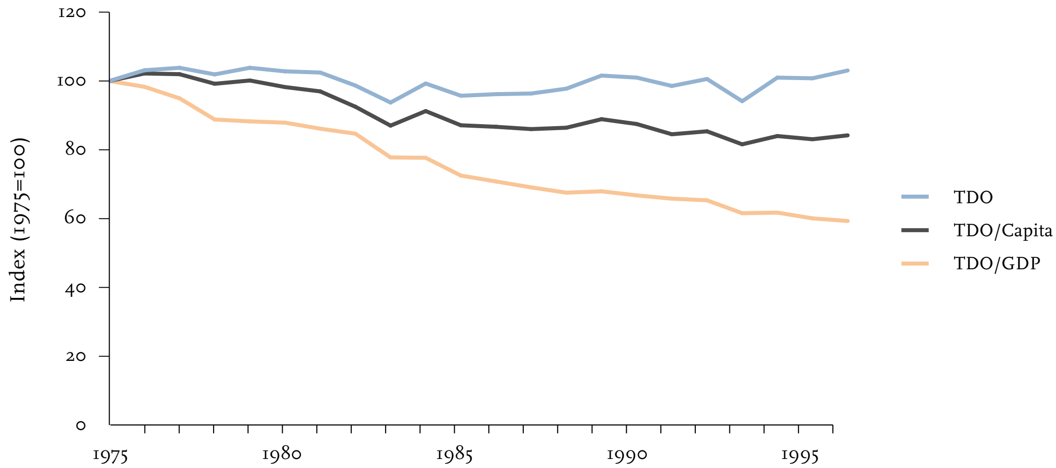
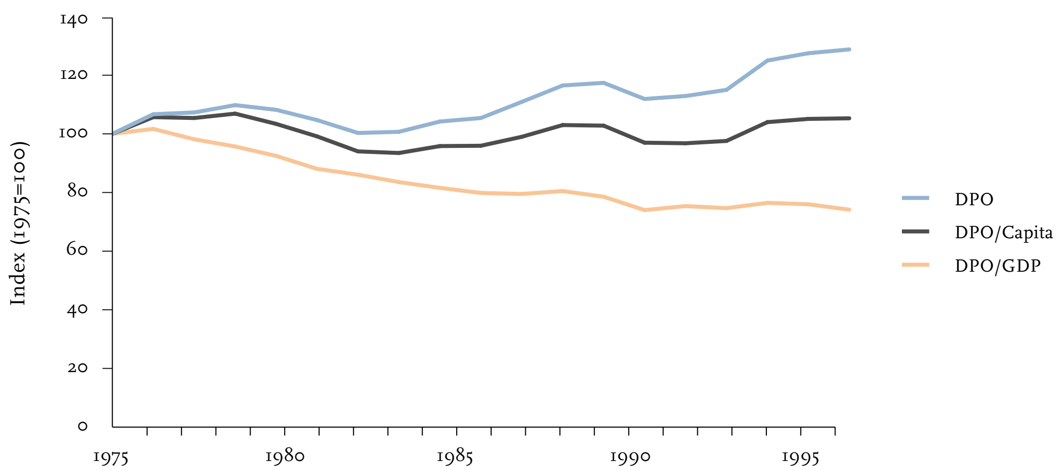
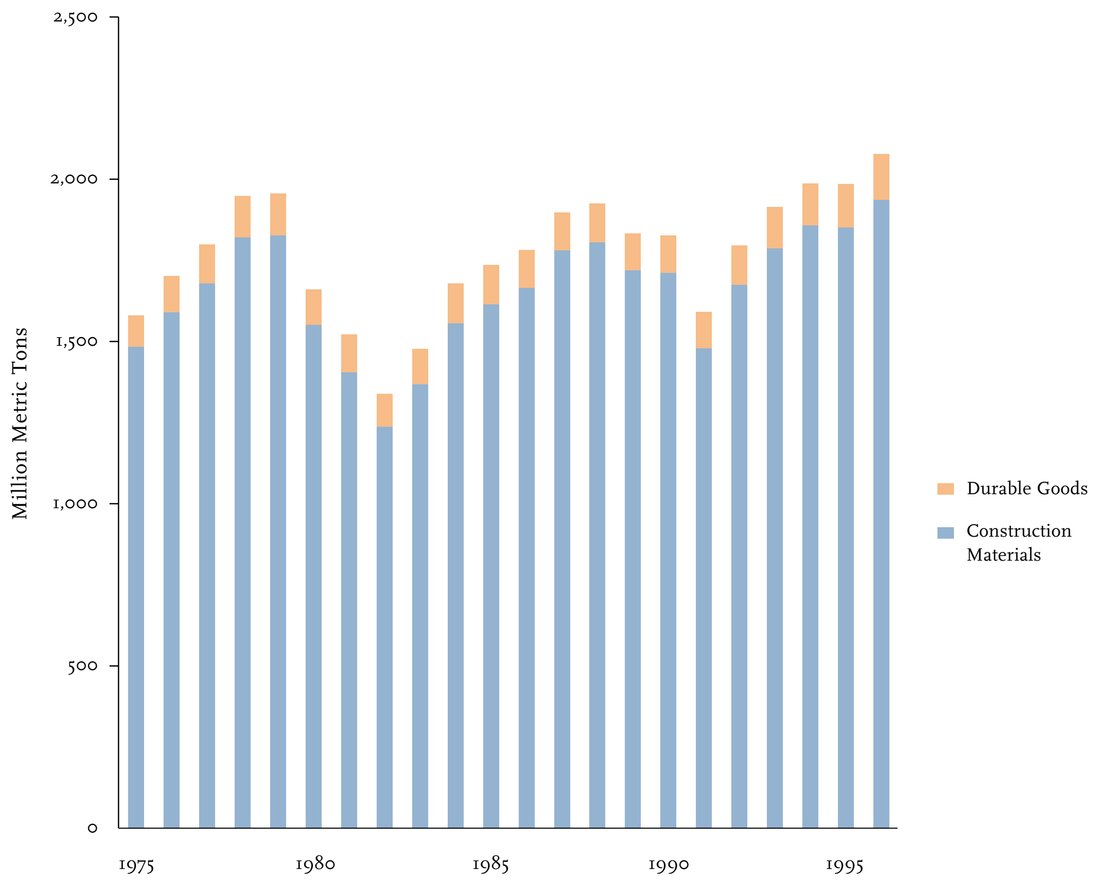


FIGURE A4 **DECOUPLING BETWEEN DPO, POPULATION, AND GDP, UNITED STATES 1975–1996**



bigger housing, as well as ongoing infrastructure maintenance. Extensive urban sprawl uses more space than high-density housing; further study would be required to determine whether it also uses more material. Figure A5 shows that the material weight of durable goods added to the economy each year increased by more than 40 percent from 1975 to 1996, though durable goods still accounted for only about 7 percent of total materials added to stock each year.

FIGURE A5 **ANNUAL NET ADDITIONS OF MATERIAL TO STOCK, UNITED STATES 1975–1996**



Material Output Flows United States 1975-96

All units in 1,000 metric tons unless otherwise stated

	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
Summary Data											
Population *(1,000 capita)*	220,165	222,168	224,177	226,208	228,279	230,406	232,597	234,847	237,149	239,488	241,855
GDP *(constant 1996 billion US dollars)*	4,253,953	4,461,396	4,651,453	4,882,043	5,004,618	4,975,822	5,059,821	4,957,240	5,126,216	5,436,240	5,614,670
Summary Indicators *(as presented in main report)*											
DPO *(including oxygen)*	5,258,712	5,609,653	5,643,144	5,774,738	5,838,169	5,688,300	5,508,117	5,274,228	5,294,423	5,481,629	5,542,187
DPO *(excluding oxygen)*	2,122,952	2,262,727	2,276,800	2,333,765	2,364,561	2,296,529	2,217,611	2,120,391	2,133,378	2,205,072	2,219,514
Hidden flows *(including oxygen)*	17,314,505	17,665,117	17,794,123	17,229,690	17,599,961	17,516,765	17,618,168	17,001,275	15,865,246	16,925,255	16,061,794
Hidden flows *(excluding oxygen)*	17,192,354	17,539,492	17,662,095	17,093,056	17,450,954	17,385,206	17,520,339	16,857,076	15,759,806	16,786,692	15,910,969
TDO *(including oxygen)*	22,573,217	23,274,771	23,437,268	23,004,428	23,438,130	23,205,065	23,126,284	22,275,503	21,159,669	22,406,884	21,603,982
TDO *(excluding oxygen)*	19,315,306	19,802,219	19,938,895	19,426,822	19,815,514	19,681,735	19,737,950	18,977,467	17,893,184	18,991,763	18,130,483
Net additions to stock	1,580,939	1,701,124	1,799,442	1,948,796	1,955,529	1,660,354	1,521,919	1,338,629	1,476,558	1,678,846	1,736,143
Summary Indicators *(metric tons per capita)*											
DPO *(including oxygen)*	23.89	25.25	25.17	25.53	25.57	24.69	23.68	22.46	22.33	22.89	22.92
DPO *(excluding oxygen)*	9.64	10.18	10.16	10.32	10.36	9.97	9.53	9.03	9.00	9.21	9.18
Hidden flows *(including oxygen)*	78.64	79.51	79.38	76.17	77.10	76.03	75.75	72.39	66.90	70.67	66.41
Hidden flows *(excluding oxygen)*	78.09	78.95	78.79	75.56	76.45	75.45	75.32	71.78	66.46	70.09	65.79
TDO *(including oxygen)*	102.53	104.76	104.55	101.70	102.67	100.71	99.43	94.85	89.23	93.56	89.33
TDO *(excluding oxygen)*	87.73	89.13	88.94	85.88	86.80	85.42	84.86	80.81	75.45	79.30	74.96
Net additions to stock	7.18	7.66	8.03	8.62	8.57	7.21	6.54	5.70	6.23	7.01	7.18
Gateway Indicators											
DPO to Air *(including oxygen)*	4,543,749	4,846,064	4,868,554	4,974,693	5,021,260	4,899,828	4,751,225	4,551,493	4,558,364	4,724,943	4,788,462
CO_2 from fossil fuels, incl. bunkers	4,228,729	4,519,024	4,532,068	4,608,279	4,623,719	4,474,631	4,328,829	4,126,521	4,139,250	4,282,864	4,349,754
CO_2 from cement & lime making	51,799	53,975	53,540	55,716	56,152	50,928	50,058	40,917	45,269	42,223	44,834
SO_2	25,914	25,426	25,593	25,798	25,568	24,858	23,727	22,790	21,874	22,884	22,617
NO_x	20,330	20,715	20,715	20,715	21,100	21,120	20,929	20,929	20,929	20,929	20,738
Other	216,978	226,925	236,639	264,185	294,721	328,291	327,682	340,336	331,042	356,043	350,519
Additional outputs to air not included in DPO											
Water vapor from fossil fuel combustion	1,923,339	2,024,892	1,981,065	2,014,316	2,022,672	1,946,437	1,868,163	1,766,686	1,743,080	1,796,773	1,799,218
DPO to Land	507,156	535,290	554,033	574,103	589,377	554,853	542,583	512,121	522,384	551,338	544,107
DPO to Land *excluding dissipative flows (landfill, other)*	341,415	359,574	384,451	402,528	415,018	383,088	371,489	349,143	359,913	383,617	377,131
Dissipative flows	165,741	175,715	169,582	171,575	174,358	171,765	171,094	162,978	162,471	167,721	166,976
Fertilizers *(P, K, N, gypsum, lime)*	47,357	56,658	51,791	54,421	56,331	56,457	51,907	39,592	41,620	43,366	42,867
Sand, salt, slag, & ash on roads	14,430	15,747	15,996	16,332	17,535	13,304	14,224	16,433	12,707	15,462	15,751
Manure spread on fields	95,451	94,578	91,877	89,712	88,213	88,577	90,337	91,143	91,123	90,703	88,961
Sewage sludge	6,801	6,863	6,925	6,988	7,052	7,113	7,180	7,250	7,321	7,393	7,466
Forestry residues *(slash etc)*	1,452	1,603	2,719	3,836	4,952	6,068	7,184	8,301	9,417	10,533	11,649
Other	250	265	274	287	276	245	262	259	283	264	283
Dissipative losses from vehicle tires *(not included in DPO)*	778	900	979	960	976	799	813	808	816	844	711
DPO to Water	6,394	6,863	7,087	7,043	7,775	7,247	6,731	5,880	6,212	6,322	6,457

Material Output Flows United States 1975-96

All units in 1,000 metric tons unless otherwise stated

1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	
											Summary Data
244,238	246,640	249,074	251,559	254,106	256,722	259,389	262,054	264,646	267,115	269,444	Population *(1,000 capita)*
5,778,213	5,933,713	6,157,349	6,359,902	6,435,208	6,370,769	6,550,068	6,708,938	6,957,023	7,135,887	7,390,600	GDP *(constant 1996 billion US dollars)*
											Summary Indicators *(as presented in main report)*
5,638,541	5,831,595	6,126,652	6,175,301	5,886,766	5,935,201	6,045,559	6,065,654	6,576,001	6,702,463	6,773,843	DPO *(including oxygen)*
2,257,757	2,346,203	2,455,809	2,452,487	2,360,914	2,362,167	2,409,876	2,425,912	2,603,534	2,640,127	2,667,736	DPO *(excluding oxygen)*
16,068,460	15,919,244	15,941,118	16,752,519	16,908,597	16,310,117	16,658,544	15,856,420	16,216,666	16,046,243	16,487,220	Hidden flows *(including oxygen)*
15,928,483	15,780,427	15,824,197	16,616,678	16,765,680	16,176,599	16,504,327	15,727,375	16,050,117	15,904,228	16,332,950	Hidden flows *(excluding oxygen)*
21,707,002	21,750,839	22,067,769	22,927,819	22,795,363	22,245,317	22,704,103	21,922,073	22,792,667	22,748,706	23,261,063	TDO *(including oxygen)*
18,186,240	18,126,630	18,280,007	19,069,165	19,126,594	18,538,766	18,914,203	18,153,288	18,653,651	18,544,354	19,000,686	TDO *(excluding oxygen)*
1,781,446	1,897,374	1,924,920	1,833,606	1,827,581	1,591,148	1,795,224	1,913,624	1,986,226	1,985,740	2,077,523	Net additions to stock
											Summary Indicators *(metric tons per capita)*
23.09	23.64	24.60	24.55	23.17	23.12	23.31	23.15	24.85	25.09	25.14	DPO *(including oxygen)*
9.24	9.51	9.86	9.75	9.29	9.20	9.29	9.26	9.84	9.88	9.90	DPO *(excluding oxygen)*
65.79	64.54	64.00	66.59	66.54	63.53	64.22	60.51	61.28	60.07	61.19	Hidden flows *(including oxygen)*
65.22	63.98	63.53	66.05	65.98	63.01	63.63	60.02	60.65	59.54	60.62	Hidden flows *(excluding oxygen)*
88.88	88.19	88.60	91.14	89.71	86.65	87.53	83.65	86.13	85.16	86.33	TDO *(including oxygen)*
74.46	73.49	73.39	75.80	75.27	72.21	72.92	69.27	70.49	69.42	70.52	TDO *(excluding oxygen)*
7.29	7.69	7.73	7.29	7.19	6.20	6.92	7.30	7.51	7.43	7.71	Net additions to stock
											Gateway Indicators
											DPO to Air
4,873,396	5,025,876	5,292,737	5,368,882	5,086,690	5,155,448	5,246,533	5,253,285	5,726,778	5,856,019	5,918,616	including oxygen
4,429,564	4,588,530	4,852,638	4,927,036	4,679,969	4,743,587	4,826,987	4,831,731	5,300,493	5,418,030	5,482,781	CO_2 fossil fuels, incl. bunkers
44,434	52,143	54,201	47,925	43,446	39,176	41,252	45,704.7	48,342.6	49,557	51,085	CO_2 from cement & lime making
21,769	21,504	21,950	22,149	21,673	21,418	21,247	20,893	20,535	18,044	17,994	SO_2
20,274	20,324	21,426	21,067	20,900	20,568	20,727	21,116	21,465	19,758	19,758	NO_x
357,356	343,375	342,522	350,706	320,703	330,700	336,321	333,839	335,943	350,630	346,998	Other
											Additional outputs to air not included in DPO
1,849,904	1,924,449	2,022,526	2,065,579	1,963,261	2,005,819	2,055,375	2,067,036	2,191,382	2,255,054	2,268,308	Water vapor from fossil fuel combustion
553,091	590,722	596,554	579,695	560,932	534,670	543,933	557,398	578,571	574,879	579,396	**DPO to Land**
382,710	415,138	424,267	411,661	402,811	383,141	389,718	406,749	423,357	418,672	431,596	DPO to Land *excluding dissipative flows (landfill, other)*
170,381	175,584	172,287	168,034	158,121	151,529	154,215	150,649	155,213	156,206	147,800	Dissipative flows
47,013	52,600	55,173	54,289	44,162	41,209	43,384	38,164	40,850	40,109	41,573	Fertilizers *(P, K, N, gypsum, lime)*
14,941	14,503	16,020	15,987	18,188	16,303	15,851	16,345	16,682	17,314	16,910	Sand, salt, slag, & ash on roads
87,874	90,333	85,327	84,399	84,775	85,425	86,307	87,395	88,805	89,793	80,231	Manure spread on fields
7,524	7,581	7,656	7,732	7,811	7,889	7,971	8,053	8,131	8,206	8,278	Sewage sludge
12,766	10,306	7,846	5,386	2,926	466	480	463	475	467	458	Forestry residues *(slash etc)*
262	261	265	241	259	237	221	229	269	318	350	Other
731	823	861	825	861	829	994	1,015	975	984	981	Dissipative losses from vehicle tires *(not included in DPO)*
5,920	6,160	6,815	6,959	6,806	7,101	6,572	6,899	6,685	7,517	7,870	**DPO to Water**

Material Output Flows United States 1975-96

All units in 1000 metric tons unless otherwise stated

	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
DPO to Uncertain Gateways											
	201,414	221,437	213,469	218,899	219,758	226,372	207,578	204,735	207,462	199,027	203,161
Hidden Flows											
(excluding oxygen)	17,192,354	17,539,492	17,662,095	17,093,056	17,450,954	17,385,206	17,520,339	16,857,076	15,759,806	16,786,692	15,910,969
Minerals, mining overburden & waste	1,394,271	1,442,879	1,310,446	1,475,475	1,567,057	1,416,361	1,521,250	1,027,724	1,121,400	1,195,798	1,216,504
Coal, mining overburden & waste	5,043,965	5,268,554	5,847,632	5,729,793	5,683,300	5,926,558	5,989,966	5,856,084	5,171,570	5,853,806	5,402,715
Earth moving for infrastructure creation	3,960,248	4,110,773	3,805,110	3,241,419	3,533,743	3,488,840	3,616,521	3,448,536	3,385,289	3,569,824	3,322,865
Dredging	559,625	517,000	511,500	489,500	490,875	511,500	596,750	477,125	497,750	578,875	519,750
Soil erosion	5,525,300	5,472,562	5,420,327	5,368,591	5,317,348	5,266,595	5,216,326	5,166,536	4,952,406	4,747,151	4,550,402
Other	708,944	727,725	767,080	788,278	858,631	775,353	579,526	881,071	631,391	841,239	898,734
Selected Material Flows of Environmental Concern											
Arsenic DPO	15.0	9.6	10.5	10.4	11.6	8.0	10.0	8.4	6.1	7.8	6.1
Arsenic NAS	1.7	3.2	5.3	5.3	6.1	6.8	12.1	10.1	10.1	12.9	13.5
Cadmium DPO	1.5	2.3	1.6	1.9	2.4	1.7	2.1	2.1	1.8	1.9	2.1
Cadmium NAS	2.0	3.7	2.7	3.2	3.2	2.3	2.8	2.0	1.8	1.8	2.0
Lead DPO	414	368	310	276	336	295	234	201	158	146	135
Lead NAS	235.6	265.1	289.2	318.6	234.1	138.6	250.9	315.4	332.8	240.6	329.2
Mercury DPO	0.9	1.1	1.0	1.2	1.3	1.2	1.3	1.0	0.9	1.4	1.1
Mercury NAS, later yrs. represent stock withdrawals	0.6	1.1	1.0	0.8	0.8	0.6	0.7	0.5	0.4	0.3	0.4
Synthetic chemicals, medical DPO	0.95	1.07	1.09	1.22	1.42	1.11	1.11	1.03	1.06	1.27	1.02
Synthetic chemicals, plastic in DPO	7,755	8,949	9,915	10,987	10,994	11,000	11,609	11,238	12,348	13,092	13,682
Synthetic chemicals NAS	22,722	25,626	29,156	31,295	32,763	32,043	32,569	31,694	33,432	34,529	34,207

Note: Substances DPO are direct outputs to the environment in the year indicated.
Substances NAS are additions to stock in the year indicated, which will become outputs to the environment in future years.

Material Output Flows United States 1975-96

All units in 1,000 metric tons unless otherwise stated

1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	
											DPO to Uncertain Gateways
206,134	208,838	230,545	219,765	232,338	237,981	248,520	248,072	263,967	264,049	267,961	
											Hidden Flows
15,928,483	15,780,427	15,824,197	16,616,678	16,765,680	16,176,599	16,504,327	15,727,375	16,050,117	15,904,228	16,332,950	*(excluding oxygen)*
1,173,242	1,304,011	1,721,256	1,988,734	2,235,625	2,299,747	2,365,599	2,316,250	2,393,716	2,463,852	2,478,403	Minerals, mining overburden & waste
5,592,395	5,664,322	5,863,572	5,947,665	6,029,096	5,756,733	5,763,316	5,673,111	5,910,457	5,878,950	6,006,355	Coal, mining overburden & waste
3,432,597	3,220,877	2,913,839	3,317,126	3,318,473	3,087,425	3,329,361	2,966,729	2,853,623	2,894,809	3,105,838	Earth moving for infrastructure creation
536,250	458,150	496,238	562,238	478,500	515,625	438,763	473,000	517,963	448,388	458,700	Dredging
4,361,808	4,338,900	4,172,384	4,012,258	3,858,278	3,710,207	3,684,173	3,542,784	3,406,820	3,406,820	3,448,536	Soil erosion
832,192	794,168	656,909	788,657	845,708	806,862	923,115	755,502	967,538	811,409	876,834	Other
											Selected Material Flows of Environmental Concern
5.9	6.1	6.6	6.1	5.7	5.9	4.0	3.7	3.9	2.4	2.5	Arsenic DPO
15.7	16.4	17.9	17.0	15.7	16.5	19.5	17.4	17.5	20.8	20.5	Arsenic NAS
2.5	2.5	2.2	2.7	2.4	2.8	3.1	2.8	1.1	0.8	1.8	Cadmium DPO
2.4	2.2	2.0	1.9	1.7	1.2	0.8	0.7	0.2	0.2	0.5	Cadmium NAS
106	90	112	107	133	167	174	188	149	238	128	Lead DPO
248.8	254.2	286.2	294.0	296.7	235.7	241.1	319.6	470.3	382.3	469.1	Lead NAS
0.9	0.8	0.8	0.6	0.4	0.2	0.3	0.2	0.2	0.2	0.1	Mercury DPO
0.5	0.4	0.6	0.5	0.2	0.2	0.2	0.0	-0.1	-0.2	-0.2	Mercury NAS, later yrs. represent stock withdrawals
1.20	1.18	1.17	1.30	1.44	1.84	1.49	1.49	1.68	1.68	1.68	Synthetic chemicals, medical DPO
15,311	15,481	17,338	15,212	16,569	16,801	16,532	16,870	16,720	16,713	16,706	Synthetic chemicals, plastic in DPO
36,690	38,123	42,363	42,929	44,525	42,720	48,064	51,087	48,415	48,408	48,401	Synthetic chemicals NAS

Note: Substances DPO are direct outputs to the environment in the year indicated.
Substances NAS are additions to stock in the year indicated, which will become outputs to the environment in future years.

The U.S. material flows documented for this study account for about 95 percent of total material outputs to the environment in the United States. Imports of finished goods and semimanufactured products were two specific flows considered in our 1997 report which are not listed in the U.S. data sheet. In this study, imported semi-manufactured products are included as imports in the individual commodity flows. We considered finished goods on a partial basis only for several reasons: (1) their overall contribution to the total weight of all flows in the United States is small, (2) exports, which offset the imports of finished goods, also are not considered, and (3) the development of an accurate picture is extremely complex. Only outputs that occur within the continental boundary of the United States have been counted.

The methodology used to compile the U.S. dataset differs somewhat from that used in the other study countries. Unlike many European countries, U.S. official data in many cases do not provide reliable data in aggregated form for such factors as, for example, total quantities of industrial waste going to landfills. Outputs within the United States have therefore been estimated by considering the domestic production of a particular commodity, adding the imports and recycled quantities, and subtracting the exports. This is termed the apparent use of the commodity. However, where a portion of a commodity is extracted or produced in the United States, and then exported, the ancillary (hidden) flows associated with the extraction/production function are included, since they occur in this country.

The overall output flows from the industrial economy of the United States were, for the most part, derived from data on the inputs and apparent use for each discrete material flow stream. The datasheet presented here is a highly aggregated version of the current U.S. material flow database, which may be accessed on the Internet at http://www.wri.org/wri/materials/. The complete database lists some 460 individual flows, documenting their output quantities at the extraction, processing, manufacturing, apparent use, and post-use stages of the material cycle. Where it was deemed useful, some primary material flow categories have been subdivided. This is the case for salt, for example, where the use of salt per se is documented, but the flows of chlorine and caustic soda derived from salt have been broken out as separate flows. In order to track flows in a coherent manner, linkages between flows are noted, and individual quantities can be combined to provide a complete picture. As an example, the carbon or CO_2 emitted during the production of cement or lime can be combined with the carbon from the combustion of fossil fuel.

Characterizing Material Flows: A Pilot Scheme

Every flow in the U.S. material flow database is characterized in three ways, based on its mode of first release to the environment (M), its quality, as determined by physical and chemical characteristics (Q), and its velocity through the economy (V). The MQV scheme is detailed in Box A1. These characteristics are fully searchable in the U.S. materials flow database; as an example, researchers can sort for and track total quantities of unprocessed but chemically active flows (Q3), which are resident in the economy less than two years (V1) and which are dispersed directly on land in solid, partially solid, or liquid form (M3).

BOX A1 CHARACTERIZING MATERIAL FLOWS

In the U.S. dataset, the fate of a flow in the environment is estimated based on the use to which a flow is put in the industrial economy. For the most part, the disaggregated use data for discrete material flows allowed a reasonable judgment of fate to be made. The fate of each flow quantity is described by employing three characteristics: mode of first release (M), quality (Q), and velocity (V) from input to output (that is, the useful lifetime of a material in the human economy). It should be noted that all outputs to the environment are shown in the same year as the input occurred. This is not too unrealistic for fast throughput goods such as packaging, but becomes less accurate the longer a material remains useful in the economy. Where the overall quantity and use of a material flow is fairly stable from year to year, this should not be a serious deficiency. Where flows are undergoing rapid changes over time, however, this could be a problem. Overcoming this deficiency would have required the extension of the data time series both backward and forward over time, and this did not appear to be warranted for this study.

Mode of first release categories:

M0: Flows that become a "permanent" part of the built infrastructure and do not exit the economy during the period under consideration, that is, they remain for more than 30 years.

M1: Flows contained or controlled on land as solids (landfills, overburden).

M2: Flows contained on land as liquids or partial solids (tailings ponds, impoundments).

Since both M1 and M2 are controlled in essentially the same manner, it may be possible to combine them.

M3: Flows dispersed directly onto land in a solid, partial solid, or liquid form (fertilizers, pesticides).

M4: Flows discharged into water systems in a solid, partial solid, or liquid form (dredge spoil, soil erosion, sewage effluent, deep well injection). Although it could be argued that deep well injection is a controlled release more appropriate to category M1, the degree of containment in the geologic structure can be uncertain.

M5: Flows discharged into air from point sources in a gaseous or particulate form (power plant and industrial source stack emissions).

M6: Flows discharged into air from diffuse sources in a gaseous or particulate form (auto emissions, household heating plants, spray paints).

M7: Flows that take many paths or no clearly defined path, or which are not classifiable. Although it is useful to differentiate between point and diffuse sources, it is acknowledged that the spatial domain affected by multiple point sources may be the same as that for diffuse sources.

Many quality measures, useful for addressing specific questions, could be suggested, but the following categories were used in the study:

Quality categories:

Q1: Flows that are biodegradable (agriculture, forestry, and fishery products).

Q2: Flows that replicate rapid continuous geologic processes (particle size reduction and movement only).

Q3: Flows that have not been chemically processed but are chemically active (salt), or biologically hazardous (asbestos).

Q4: Flows that have undergone chemical processing. These may or may not be chemically active (fuel emissions, fertilizers, industrial chemicals, certain mineral processing wastes).

BOX A1 | **(CONTINUED)**

Q5: Flows that are heavy metals, synthetic and persistent chemical compounds, or radioactive.

Velocity categories:

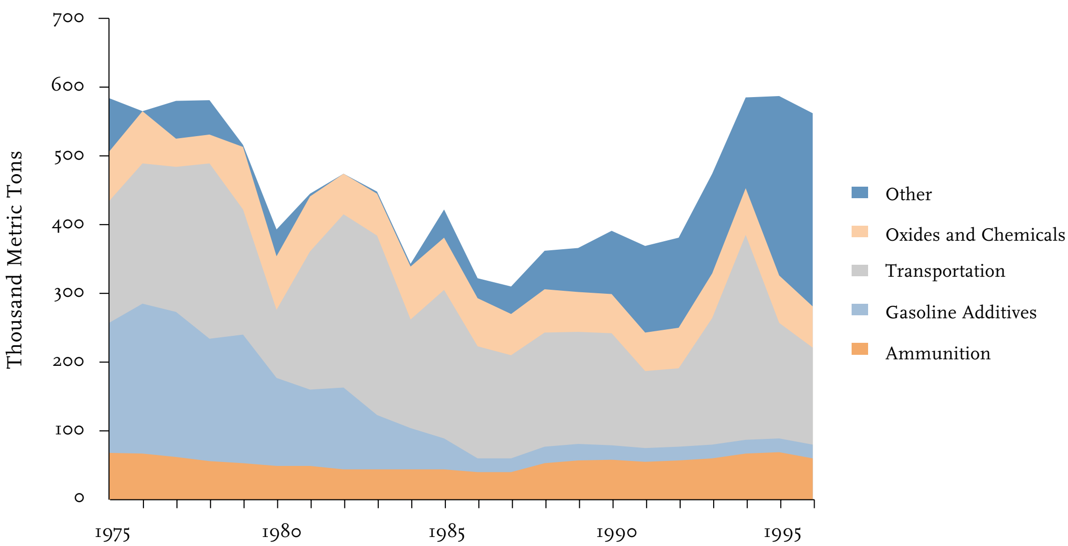
V1: Flows that exit the economy within two years of entry (food, fertilizer, packaging, petroleum used as fuel).

V2: Flows that exit the economy in 3 to 30 years (durable consumer goods, automobiles). It would be useful if V2 could be further divided into 3–10 and 10–30 year categories, but it is not clear that the available data permit this distinction to be made.

V3: Flows that stay in the economy for more than 30 years and are additions to the stock of built infrastructure (highways, buildings).

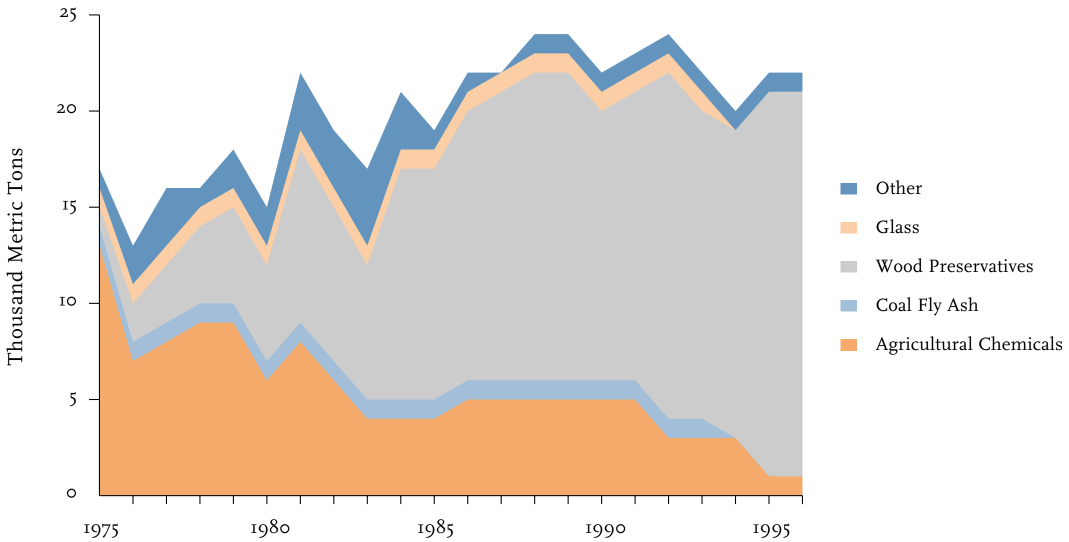
Flows retained in stock (V3) are not considered to be outputs. Also, the quantity of material recycled is subtracted from individual output flows as appropriate.

FIGURE A6 | **LEAD OUTPUTS TO THE U.S. ENVIRONMENT, 1975–1996**



Note: The “other” category is dominated by lead in electrical products, notably computer monitors. The “transportation” category is dominated by lead acid vehicle batteries. The spike in 1994 is an accurate reflection of U.S. Geological Survey data but appears to be a statistical anomaly. “Ammunition” is civilian use.

FIGURE A7 **POTENTIAL ARSENIC OUTPUTS TO THE U.S. ENVIRONMENT, 1975–1996**



Note: Data for arsenic in wood preservatives corresponds to apparent use; we have not accounted for the time lag between use and disposal. This arsenic is currently a net addition to stock (*see U.S. datasheet, Arsenic NAS*). It will become an output to the environment at the end of the wood's useful life, typically 15–30 years.

Use of this characterization scheme allowed the aggregation of all toxic and potentially hazardous flows to the environment (Q3 and Q5) that were presented in Figure 8 of this report *(p. 33)*. At a finer level of detail, flows can be broken down by stage in the material cycle (processing, use, disposal) and by different product applications and different end uses. Numerous examples could be presented here, illustrating how material use, in both quantity and application, has changed over time. Figures A6 and A7 present data for just two substances: lead and arsenic. The data show that, while some applications have declined, others have increased, with different implications for environmental quality and human health. Dispersive use of lead in gasoline, the application most immediately harmful to human health, has declined due to regulatory controls, but lead outputs from other uses such as post-use electrical goods has increased. Arsenic is little used today in agricultural applications, but its use as a wood preservative (currently unregulated) has risen nearly 25-fold. Arsenic in treated wood is believed to pose a threat to soil and water quality when wood products such as fences and flooring are chipped or burned at the end of their useful life.

Commodity Flow: Arsenic

(1,000 metric tons)

INPUTS	M	Q	V	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
Domestic Production				2.18	4.40	4.06	1.28	4.11	3.40	2.74	3.58	2.81	6.80	2.20
Imports				12.50	4.80	7.90	11.60	11.50	9.10	17.30	14.70	11.00	14.20	16.90
Recycling														
estimated @80% of alloy from lead acid batteries				0.32	0.80	1.04	1.12	0.36	0.32	0.48	0.38	0.34	0.42	0.43
Exports				0.00	0.00	0.00	0.00	0.97	1.51	0.52	2.66	0.15	0.08	0.16
Apparent Use				15.00	10.00	13.00	14.00	15.00	12.40	20.00	16.00	14.00	17.30	18.10
OUTPUTS														
Extraction Phase														
Hidden Domestic Overburden				Arsenic extracted as a byproduct with nonferrous ores (copper and lead), overburden counted with those ores										
Processing Phase														
Hidden Domestic Gangue				Gangue counted with nonferrous ores										
assume 40%														
domestic production *(arsenic units)*	2	5	1	0.87	1.76	1.62	0.51	1.64	1.36	1.10	1.43	1.13	2.72	0.88
(Based on information in USBM IC 9382, 1994, The Materials flow of Arsenic in the US)														
Manufacturing Phase														
Process losses														
Assume 0.1% of consumption IC 9382	7	5	1	0.02	0.01	0.01	0.01	0.02	0.01	0.02	0.02	0.01	0.02	0.02
Use Phase														
Direct dissipation														
agricultural chemicals	3	5	1	13.40	7.00	8.00	9.00	9.00	5.70	8.00	6.00	4.00	3.98	4.16
Post Use Phase														
Post use disposal														
wood preservatives	7	5	2	0.80	2.00	3.00	4.00	5.00	5.40	9.00	8.00	7.00	11.76	12.31
glass	1	5	2	0.80	0.80	1.04	1.00	0.75	0.60	1.00	0.80	0.70	0.69	0.72
alloys	1	5	2	0.08	0.20	0.26	0.28	0.09	0.08	0.12	0.10	0.08	0.10	0.11
other	7	5	2	0.00	0.20	0.96	0.00	0.25	0.70	2.00	1.20	2.30	0.35	0.36
Recycling Phase														
Process losses assume 1%				0.004	0.010	0.013	0.014	0.005	0.004	0.006	0.005	0.004	0.005	
Total Outputs				15.97	11.98	14.91	14.82	16.75	13.86	21.24	17.55	15.23	19.63	18.57
Additions to Stock														
Links to Other Flows Arsenic losses in gangue report to copper mining and processing sites														
Uses														
wood preservatives				0.8	2.00	3.00	4.00	5.00	5.4	9.00	8.00	7.00	11.764	12.31
agricultural chemicals				13.4	7.00	8.00	9.00	9.00	5.7	8.00	6.00	4.00	3.979	4.16
glass				0.8	0.8	1.04	1.00	0.75	0.6	1.00	0.80	0.70	0.692	0.72
alloys				0.4	1.00	1.30	1.40	0.45	0.4	0.6	0.48	0.42	0.519	0.54
other				0.00	0.20	0.96	0.00	0.25	0.70	2.00	1.20	2.30	0.346	0.36
Assume only alloy uses recycle in amounts shown above					0.20	0.96	0.00							

Commodity Flow: Arsenic

(1,000 metric tons)

1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**Domestic Production**
26.00	26.80	30.00	29.20	27.07	28.52	31.48	28.27	28.21	29.99	29.27	**Imports**
											Recycling
0.51	0.00	0.38	0.36	0.33	0.35	1.53	1.36	1.38	0.36	0.35	estimated @80% of alloy from lead acid batteries
0.22	0.17	0.40	0.13	0.15	0.23	0.09	0.36	0.08	0.43	0.02	**Exports**
21.10	21.80	23.70	22.30	20.50	21.60	23.90	21.30	21.50	22.30	22.00	**Apparent Use**
											OUTPUTS
											Extraction Phase
											Processing Phase
											assume 40%
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	domestic production *(arsenic units)*
											(Based on information in USBM IC 9382, 1994, The Materials flow of Arsenic in the US)
											Manufacturing Phase
											Process losses
0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	
											Use Phase
											Direct dissipation
4.85	5.01	5.45	4.91	4.51	4.75	2.87	2.56	2.58	1.12	1.10	agricultural chemicals
											Post Use Phase
											Post use disposal
14.35	15.04	16.35	15.61	14.35	15.12	17.69	15.76	15.91	20.07	19.80	wood preservatives
0.84	0.87	0.95	0.89	0.82	0.86	0.96	0.85	0.86	0.45	0.44	glass
0.13	0.00	0.09	0.09	0.08	0.09	0.38	0.34	0.34	0.09	0.09	alloys
0.42	0.44	0.47	0.45	0.41	0.43	0.48	0.43	0.43	0.22	0.22	other
											Recycling Phase
0.005	0.006	0.000	0.005	0.004	0.004	0.004	0.019	0.017	0.017	0.004	Process losses
20.62	21.39	23.35	21.97	20.20	21.28	22.41	19.98	20.16	21.97	21.67	**Total Outputs**
											Additions to Stock
											Links to Other Flows
											Uses
14.348	15.042	16.353	15.61	14.35	15.12	17.686	15.762	15.91	20.07	19.8	wood preservatives
4.853	5.014	5.451	4.906	4.51	4.752	2.868	2.556	2.58	1.115	1.1	agricultural chemicals
0.844	0.872	0.948	0.892	0.82	0.864	0.956	0.852	0.86	0.446	0.44	glass
0.633	0.0034	0.474	0.446	0.41	0.432	1.912	1.704	1.72	0.446	0.44	alloys
0.422	0.436	0.474	0.446	0.41	0.432	0.478	0.426	0.43	0.223	0.22	Assume only alloy uses recycle in amounts shown above

Notes on Data Sources and Quality

The data used in this study were obtained from a variety of sources and are not of uniform quality. Some data come directly from annual published figures, others are based on technical judgments and estimates of relationships. Detailed technical notes on data sources and formulae used in calculating outputs may be found at the WRI Web address noted above.

Population and GDP

Population data are from the United Nations Population Division, *Annual Populations 1950–2050, (The 1998 Revision)*. GDP is from the World Bank, *World Development Indicators 1999*.

Fossil Fuels

Coal combustion products: Waste from coal combustion, including fly ash, bottom ash, slag, and flue gas desulfuration materials have gradually gained value as raw material for other products. Originally compiled by an industry association (American Coal Ash Association), coal combustion products are now also tracked by the U.S. Geological Survey (USGS) as a mineral commodity. Data were obtained from the Association and the USGS. Missing data were interpolated. The production of fly ash, bottom ash, slag, and flue gas desulfuration materials was estimated from coal consumption data.

Carbon dioxide emissions were derived from data supplied by the Carbon Dioxide Information and Analysis Center at the U.S. Department of Energy's Oak Ridge National Laboratory.

Liquid and gas fossil fuel data were derived from the U.S. Energy Information Administration's report *Annual Review of Energy 1996*. Petroleum was converted to mass units on the basis of .135 metric tons per barrel.

Processing waste from the production and processing of petroleum was estimated at 11.7 percent of domestic production. Toxic wastes from petroleum production were extracted from the U.S. Environmental Protection Agency (EPA) Toxic Release Inventory. The production of nonfuel petrochemicals was either counted as feed stocks for other products or as end uses in themselves that would be disposed of as waste or dissipated in use.

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). Hidden flows from gas production were estimated at 10 percent of production. Missing data on losses from gas use for years prior to 1985 were estimated on the basis of the 1985 ratio of losses to production.

Basic coal production data were derived from the publications of the Energy Information Administration. Overburden, as a hidden flow, was estimated separately for surface and underground mines. For underground mining, hidden flows were estimated at 10 percent of coal mined (based on the German experience). For surface mining, estimation of hidden flows was more complicated. Based on the one extant publication that compares four western mines (average overburden ration 4.8:1) to one eastern surface mine (overburden ratio 26.9:1), the country was divided into two zones, west (including midwestern) and east, and these ratios were applied to production in each zone for each year using data found in the *Annual Energy Review 1996*. Gangue was set at 5 percent of production as representing a reasonable average figure for all forms of coal. Methane emissions from coal were reported based on the 1985 ratio of methane to production.

Coal wastes and the chemical makeup of those wastes were derived from estimates of ash content (from Environmental Impact Assessment [EIA] publications) as well as from general coal chemistry data (including trace elements) found in the *Handbook of Coal Chemistry, 1985.*

Minerals and Metals

General References: MCS: Mineral Commodity Summaries, an annual report published by the U.S. Bureau of Mines (USBM), now part of the USGS. MIS: Mineral Industry Surveys are commodity specific reports published annually or periodically by the USGS. Statistical Compendium: A USBM Special Publication published December 1993. Personal communication: Verbal information or estimates were obtained from USGS commodity specialists. The help of these specialists facilitated the data gathering, and is greatly appreciated.

Domestic production, import, export, recycling, and apparent use: These data are from USBM annual reports and the Statistical Compendium of the USBM. Apparent use was calculated from these data by considering old (post-consumer) scrap only.

Overburden and gangue: For the most part, these are estimates based on the technical judgment of commodity specialists at the USGS. The estimates of ore grade and overburden were assumed to be constant for the entire time period. Exceptions to this were iron ore, copper, and gold, where some time series data were available for average grade and overburden, and for commodities where major changes in mining practice or location occurred.

Process losses: These are entirely based on technical judgments, mainly by USGS commodity experts.

Commodity uses data: These were obtained mainly from the USGS annual mineral commodity summaries, supplemented with information from the USBM Statistical Compendium. A good deal of the commodity use data is quite fine-grained and continuous, but much is spotty, discontinuous, and not very detailed. Since these data are used as a proxy for the fate of the material flow, their improvement would enhance the quality of the entire database.

Recycling: Recycled flows were deducted from commodity use data based on selected uses that are known to be recycled, or on a pro rata basis. Where possible, these flows were compared with EPA recycling data as a check on accuracy.

Infrastructure

Highway earth moving: These data are derived from detailed annual highway expenditure data by use of cost-estimating relationships. They represent reasonable order-of-magnitude estimates of the amounts of material handled. A major deficiency is that there is no way to distinguish first movement from subsequent rehandling.

Private and public construction earth moving: These are derived from expenditure data in the annual *Economic Report to the President*. Construction cost-estimating relationships were used to convert these expenditures to earth moving quantities. The quality of these data is similar to that for highways.

Dredging: These are annual cubic yardage quantities reported by the U.S. Army Corps of Engineers. An average density was used to convert to metric tons. Although the quantity data are good, the ultimate disposition on land or water is speculative.

Agriculture

Most agricultural data were obtained from *Agricultural Statistics*, published annually by the U.S. Department of Agriculture. Some information was also obtained from the Food and Agriculture Organization of the United Nations (FAO). A mass-balance approach, in which the products of a process are subtracted from the inputs to the process, was used to arrive at outputs from processes for which there are no measured waste statistics. Other outputs not measured were arrived at using multiplication factors, such as amount of manure per cow.

Soil erosion: Erosion rates were derived from the U.S. Natural Resource Inventory, which is the five-year physical survey of the non-federal land resources in the United States. Erosion estimates of federal lands, which amount to 21 percent of the total land area, 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.

Forestry

Data on production and products were obtained from FAO and the U.S. Department of Agriculture Forest Service (USFS). Logging and mill residue data and their uses are from the Forest Inventory and Analysis group of the USFS. The breakdown of forest products into uses is based on FAO data.

Synthetic Organic Chemicals and Medical Chemicals

Data were taken from the production data produced by the U.S. International Trade Commission and published in its annual *Synthetic Organic Chemicals*. The last year the International Trade Commission collected data was 1996, but it ceased to aggregate data in the manner reported here in 1994. Data for 1995 and 1996 are estimated here as identical to that of 1994. Data collection ceased due to congressional mandate. Except for medical chemicals and plastics, waste from end-use synthetic organic chemicals was estimated at production. Recycling data were used to estimate wastes from the production of plastics.

Waste from medical chemicals production, often in sludges and liquid waste carrying biologically active ingredients, was estimated to make up 1 percent of production. Waste from the use of medical chemicals—either through the excretion of biologically active ingredients or their biologically active metabolites, or through their disposal at end of use—was estimated at 50 percent of production, the intermediate value in an estimated range of 30 to 90 percent.

NOTE

1. Please note that the total domestic output (TDO) recorded from the U.S. economy (23 billion tons), plus net additions to stock (2 billion tons) do not tally with the 22 billion tons of total material requirement (TMR) documented in the 1997 report: Resource Flows: the Material Basis of Industrial Economies. The input and output data cannot be directly compared in this way. This is due to a number of differences in the accounting methodology used for each study. An important factor is the earlier report's inclusion of foreign hidden flows associated with imports in TMR, whereas this report is concerned only with domestic hidden flows. Another key factor is that the earlier report excludes atmospheric oxygen from direct material inputs to the economy, whereas the present study includes oxygen (in carbon dioxide, oxides of nitrogen, etc.) as part of waste outputs from the economy.

FOR FURTHER INFORMATION

Centre of Environmental Science (CML), Leiden University
Van Steenisgebouw, Einsteinweg 2, 2300 RA, Leiden, The Netherlands
http://www.leidenuniv.nl/interfac/cml/ssp/

Institute for Interdisciplinary Studies of Austrian Universities (IFF)
Department of Social Ecology, Schottenfeldgasse 29, A-1070 Vienna, Austria
http://www.univie.ac.at/iffsocec

National Institute for Environmental Studies (NIES)
16–2 Onogawa Tsukuba, Ibaraki 305–0053, Japan
http://www.nies.go.jp/index.html

World Resources Institute (WRI)
10 G Street N.E. Suite 800, Washington D.C. 20002, U.S.A.
http://www.wri.org/wri/materials/

Wuppertal Institute (WI)
Postfach 100480, Doppersberg 19, D-42103, Wuppertal, Germany
http://www.wupperinst.org

World Resources Institute

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