

Materials Flow Analysis of the Italian Economy

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Summary

This article analyzes the mass of the materials that flowed through the Italian economy during 1994 and compares the results with a similar analysis of Germany, Japan, the Netherlands, and the United States published by a collaboration headed by the World Resources Institute. In order to perform this comparison, we have evaluated the mass of the materials produced within the country and the mass of the imported materials and commodities. For the domestic production, imports and exports, we have also evaluated the mass of the materials that accompany each physical flow as hidden flows.

Our analysis indicates that, in 1994, Italy experienced total material requirements (TMR) of 1,609 million metric tons (Mt), of which 727 Mt was used as direct material input (DMI). A comparison with other developed countries shows that the TMR and DMI flows, measured in mass per person and in mass per GDP unit, are, in Italy, lower than the corresponding figures evaluated for the United States, Germany, and the Netherlands. An interpretation of these results is presented. The analysis may give information useful for environmental considerations, although the limits of such an approach are made clear.

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Introduction

In many industrial countries, there is increasing attention to the mass of materials that flow through the national economies. Such an analysis allows us to know the quantity of minerals, forest, and agricultural resources that are extracted and to know the mass of wastes generated in each exchange (Ayres and Ayres 1998). The materials flow analysis¹ (MFA) methodology adopted here can be usefully applied, in general, to other materials flows, and, in particular, to the analysis of the industrial metabolism of, say, a firm, and to the manufacturing and consumption processes.

In previous articles, the mass flow of raw materials and commodities in the Italian economy in the 1970s has been measured and compared with the figures available for the U.S. economy (De Marco 1975, 1980).² In order to have results comparable to a similar, widely discussed analysis of Germany, Japan, the Netherlands, and the United States that was published by a collaboration headed by the World Resources Institute (Adriaanse et al. 1997), the present analysis is based on a methodology developed mainly by researchers of the Wuppertal Institute in Germany (Bringezu et al. 1997, 1998a, and 1998b).

Methodology

The materials flows are classified as follows: The total material requirement (TMR) is defined as the mass of the materials required for a national economy, including domestic production and imported natural resources and commodities. The TMR is the sum of two components: (a) the direct material input (DMI), defined as the flow of natural resources and commodities that enter an industrial economy for further processing, that is, domestic production (DP) + import (I); and (b) the hidden material flow (HF), consisting of the mass of materials that are extracted from the natural bodies during production and transformation of the “economic” materials, and that are discarded and have, typically or in principle, no monetary value, and so do not enter the economy. The hidden materials flow includes also the mass of soil lost because of erosion.

The imports also have a “hidden material content,” that is, the mass of materials extracted

from natural bodies, within the exporting countries, during the preparation of the materials to be exported. According to the Wuppertal methodology, the imports that enter a country are accounted for as the mass of the imports of economic value, plus the mass of the hidden materials associated with each imported resource or commodity, although the hidden flow of the imports does not enter the importing country, remaining physically within the exporting country instead.

Equation (1) shows the relationship among TMR, DMI, and HF:

$$\begin{aligned} \text{TMR} &= \text{DMI} + \text{HF} \\ &\text{of domestic production} \\ &+ \text{HF of imports} \end{aligned} \quad (1)$$

If we consider that

$$\text{DMI} = \text{DP} + \text{I} \quad (2)$$

then TMR can also be expressed as equation (3):

$$\begin{aligned} \text{TMR} &= \text{DP} + \text{I} \\ &+ \text{HF of domestic production} \\ &+ \text{HF of imports.} \end{aligned} \quad (3)$$

The materials that a country exports also have a “hidden material content” that is counted as “material output” of the domestic economy because it physically remains within the country.

This approach has intrinsic weaknesses that we discuss below, but we have followed it in order to obtain, for the Italian economy, a figure for the total material requirement (TMR) that is comparable with the values calculated by other authors for other countries (Adriaanse et al. 1997).³ At the same time, the comparison of the total material requirement (TMR) with the direct material input (DMI) allows a rudimentary consideration of the environmental impact of the material economy.

This article considers the flows of the major resources and commodities in the Italian economy:

Nonrenewable materials

nonmetal minerals, mainly sand, stones, and clays;
metals, mainly iron and steel, aluminum, and copper;

fossil fuels: mainly oil and oil derivatives, natural gas, and coal.

Renewable materials

food materials;

nonfood materials including wood, cellulose, and fibers.

Unfortunately, in Italy, many statistical data are relatively unreliable or are not available at all. For instance, the collection of statistical data on quarry stones or deposits lies within the jurisdiction of the Regional Authorities in Italy and is often incomplete because collection procedures depend on the different efficiencies of each regional institution. Some regions, such as Trentino Alto Adige, Tuscany, and Valle D'Aosta are particularly active in this field, whereas others are unable to provide any information. In general, the statistical data in Italy are of high quality with regard to the fossil fuels category, but they get worse and worse as we consider the metals, the renewable materials, and, finally, the nonmetals categories. The results presented here are the best estimates done on the basis of official information that was sometimes integrated, corrected, and improved by the authors (see notes 1, 3, and 5 following the complete table 6 at the JIE web site at <http://mitpress.mit.edu/JIE>) in conformity with the knowledge of the production chain.

The coefficients used to evaluate the hidden flows, expressed as mass per unit mass of each "economic" resource, have been obtained from the research literature and through direct inquiries (see the appendix) and have been corrected on the basis of reasonable estimates. Such coefficients unfortunately have a high level of uncertainty.

The flow of materials through the Italian economy is responsible also for a loss, or flow, of erosion materials from the soil to the rivers and sea. The mass of the erosion losses is difficult to measure; for the Italian economy in 1994, an estimate of a loss of 200 Mt/year (Mt = megaton = 1 million metric tons)⁴ seems reasonable and this figure is treated as part of the hidden flows of the domestic production.

Results and Discussion

Table 1 contains the summary results of the present investigation: All the results are in megatons per year (Mt/year). Detailed data are

presented in table 6 of the appendix.⁵ Table 1 reports the figures for domestic production, imported materials, and their hidden flows (HF), direct material inputs (DMI), and total material requirements (TMR). The table also contains the data on the exported materials and their respective hidden flows. These data are displayed in figure 1 showing the total flow of materials in the Italian economy in 1994.

Analyzing table 1 and figure 1, we find that in 1994, the DMI of the Italian economy was about 727 million metric tons (727 Mt), of which 70% was produced in Italy (over 500 Mt) and over 30% was imported (about 225 Mt). More than 40 Mt was exported.

National production mainly included nonmetals, with about 290 Mt, and food and nonfood organic materials, which amounted to about 180 Mt. Fuels predominate among the imports, with about 150 Mt. As for exports, fossil fuels (i.e., refinery products) are predominant among the nonrenewable materials, whereas food organic materials rank first among the renewables. The hidden flow of imports, consisting of over 430 Mt, is linked to more than 200 Mt of nonrenewable materials, plus 25 Mt of renewable, direct materials. It has been situated, in figure 1, to the left of the national borderline (in the abroad column).

The central part of the diagram represents the technosphere, that is, the economic activities in a given period (in this case one year), expressed in physical units. The materials of domestic production (over 300 Mt of nonrenewables and about 180 Mt of renewables) together with their hidden flows (about 450 Mt, 200 Mt of which consists of erosion), are depicted in figure 1 as departing from the borderline and entering the technosphere. The technosphere also receives about 22 Mt of recycled waste, imported materials, and oxygen—reckoned to be about 314 Mt on the basis of emissions (Ministero dell'Ambiente 1997b). A part of the materials entering the technosphere (over 480 Mt) becomes fixed as durable equipment and structures (roads, buildings, books, various machines or vehicles, etc.), and another part is exported (33 Mt of nonrenewable materials and 8 Mt of renewable materials). The hidden flows of exports (44 Mt) leave the technosphere and remain in the environment of the country (output) together

Table 1 Summary of major flows of the Italian economy in 1994 (in Mt)

	Domestic production (a)	HF domestic production (b)	Import (c)	HF import (d)	DMI (e = a + c)	TMR (f = a + b + c + d)	Export (g)	HF export (h)
Nonrenewable materials								
Nonmetals	290	170	11	14	301	485	3	2
%	58	38	5	3	41	30	7	4
t/inhabitant	5	3	<1	<1	5	9	<1	<1
Fossil fuels	22	5	150	112	172	289	21	2
%	4	1	67	26	24	18	51	5
t/inhabitant	<1	<1	<3	2	3	5	<1	<1
Metals	12	1	39	275	51	327	9	27
%	2	<1	17	63	7	20	22	62
t/inhabitant	<1	<1	<1	5	1	6	<1	<1
Renewable materials								
Food materials	170	66	12	34	182	282	6	13
%	34	15	5	8	25	18	15	30
t/inhabitant	3	1	<1	1	3	5	<1	<1
Nonfood materials	8	3	13	2	21	26	2	2
%	2	1	6	<1	3	2	5	5
t/inhabitant	<1	<1	<1	<1	<1	<1	<1	<1
Erosion		200				200		
%		45				12		
t/inhabitant		3				3		
ITALY	502	445	225	437	727	1,609	41	44
t/inhabitant	9	8	5	8	13	28	1	1

Table 2 Municipal and industrial wastes generated in Italy in 1994 net of recycled waste (in Mt)

incineration	landfills	other	Total amount disposed
2	48	5	55

Source: Ministero dell'Ambiente (1997a).

with the hidden flows of domestic production (201 Mt, i.e., 245 Mt less 44 Mt) and total disposable waste (over 55 Mt of municipal solid waste (MSW), industrial wastes, and hazardous and nonhazardous wastes. See table 2).

The figures of table 1 may be considered reliable to within a statistical error that we estimate to be about 5%. This means that, for the Italian economy of 1994, the figure of 1,609 Mt/year of total material requirement (TMR) may realistically be any value between 1,550 and 1,650 Mt/year.

In conclusion, in 1994, Italy had, besides a DMI of about 727 Mt, a hidden flow estimated at

about 900 Mt and, therefore, a TMR of more than 1,600 Mt. We infer that in 1994, each Italian determined a materials flow of 28 t (TMR), of which he directly used only 13 t (DMI). If we relate the materials flows to GDP (1994 dollars), we deduce that in order to produce 1 million dollars of wealth, about 1,500 t of materials (TMR) have been handled and only a little over 660 t (DMI) used. The above analysis has some drawbacks and limits. An indicator such as the direct materials input (DMI) does not give information on how and where the input materials are used. The materials that are called "inputs" and "imports" are partly natural resource commodities, partly raw materials. The wastes and their environmental impact take place in each of the transactions. Each "input" material enters into a complex series of flows and exchanges: Raw materials are subjected to various transformation processes before becoming a final commodity used in the household and service sectors of the economy. Each exchange is associated with different impacts on the environment that are only

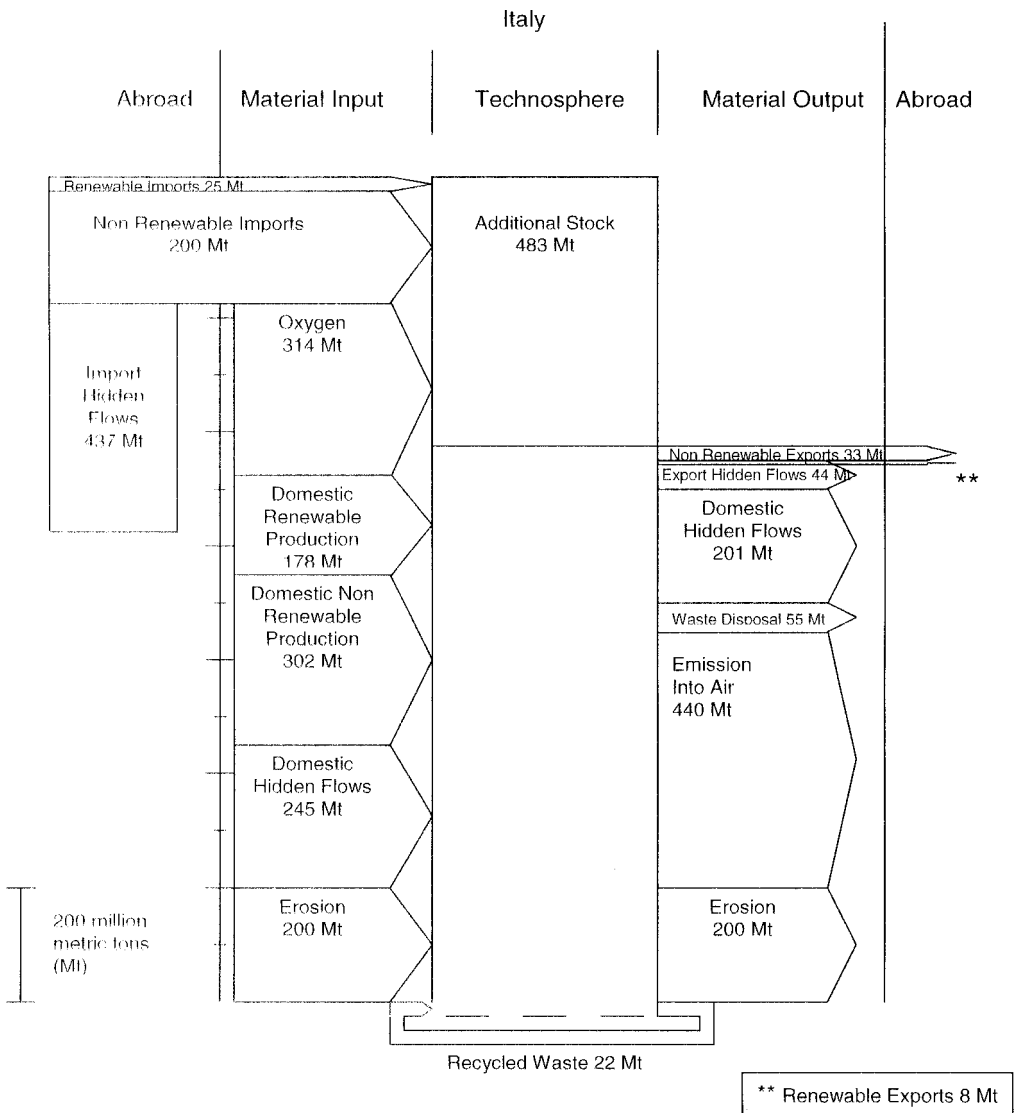


Figure 1 Materials flow account of the Italian economy in 1994.

in part described by the aggregate mass of the wastes. Some materials that are included in the so-called hidden flows are used as raw materials for other production processes, and in this field, the technology is continuously changing. For example, the bark that accompanies commercial wood production may be burned and used as a “renewable” source of energy. Some residuals of marble extraction and cutting are increasingly used as fillers for industry and for road paving.

Another limit of the analysis is the paucity of information on the water flow that accompanies

the TMR. Water, in part, is contained within the various natural resource commodities and in the hidden flow materials, and, in part, enters as process or “metabolic” water during the use of the materials and commodities.

Environmental Considerations

The present analysis, in spite of the lack of information on the materials’ fate, offers the possibility of saying a limited number of things about the environmental considerations. The

environmental effects of such flows may be divided into two classes: (a) the depletion of the reserves of domestic natural resources, due to the extraction of materials and commodities produced within the country and to the hidden materials flow associated with such domestic production; and (b) the degradation of natural environmental bodies (air, water, and soil), due to the discharge of the gaseous, liquid, and solid wastes generated during the transformation of the whole direct materials input (DMI), and during the “use” or “consumption” of the manufactured goods.

Part of the manufactured goods become fixed within the technosphere as durable commodities—cars, buildings, machinery, plastics, and so on—for a time period longer than the year to which the analysis refers: Cars may have a useful life of a few years; other machinery and furniture may have a life longer than a decade; and buildings may remain for many decades, sometimes for centuries. This means that the Italian technosphere is subject to a continuous growth. According to reasonable estimates, its physical stocks increase at a rate of about 450–550 Mt/year.

The gaseous wastes include gases formed by the oxidation—with the addition of about 300 Mt/year of oxygen from the air and smaller amounts of nitrogen—of the carbon and sulfur content of fossil fuels and foods, by the decomposition of calcareous stones, and by the formation of other gases. The gaseous wastes formed following the consumption of the materials and goods obtained from the direct material input (DMI) are on the order of just over 440 Mt/year (see table 3).

Data indicating the amount of solid and liquid wastes that are discharged in the surface and underground water-receiving bodies, following

Table 3 Gas emissions in Italy in 1994 (in Mt)⁶

Carbon dioxide	424
Carbon monoxide	8
Methane	3
Volatile organic compounds	3
Nitrogen oxides	2
Sulfur oxides	2
Total	442

Source: Ministero dell'Ambiente (1997b).

Table 4 Recycled waste in 1994 in Italy (in Mt)

Iron scraps	12
Inerts	4
Paper	2.5
Wood packaging	2
Glass	1
Other	0.5
Total	22

Sources: ISTAT (1996); Ministero dell'Ambiente (1997a).

the production and consumption of the materials, are not available. According to a recent estimate (Nebbia 1999b), the solid wastes generated in 1994 during the production and consumption processes, apart from what has been called hidden materials flow, may be evaluated as: (a) industrial and demolition wastes, metal scraps, and so on: 80 Mt/year; (b) domestic wastes: 25 Mt/year. A small fraction of such solid wastes are recycled. Italy also imports metal and glass scraps and paper wastes. An estimate of the domestic and imported materials subjected to recycling in Italy in 1994 is 22 Mt/year (see table 4).

International Comparisons

Table 5 contains a comparison of the main material indicators of the Italian economy, that is, the direct material input (DMI), the total material requirement (TMR), and the hidden flows (HF), with data for the other countries for which a similar investigation has been carried out. The indicators are reported as the number of inhabitants, as the gross domestic product (GDP) in 1994 U.S. dollars, and as the per capita energy consumption.

The comparison of the various countries' data for 1994 shows that the impact of domestic HF as compared to the DMI is particularly conspicuous in the United States, where the ratio is 2.8 to 1 (15,757 Mt over 5,646 Mt), and in Germany, with a ratio of about 1.2 to 1 (2,312 Mt over 1,930 Mt). By contrast, the HF impact decreases sharply as expected in Japan and Italy, which import most of the materials they require, thus leaving possible environmental degradation elsewhere (for instance, Italy's “responsibility” is for over 430 Mt of hidden flow associated with imported materials,

Table 5 Summary of the main indicators and comparison of some countries (1994)

	<i>Italy</i>	<i>Germany</i>	<i>United States</i>	<i>Japan</i>	<i>Netherlands</i> §
DMI (Mt)	727	1,930	5,646	1,975	449
Domestic HF (Mt)	445	2,312	15,757	1,216	na
TMR (Mt)	1,609	5,754	21,947	5,657	na
Population (millions of inhabitants)	57	81	260	125	15
DMI per capita (t/inhabitant)	13	24	22	16	29
Domestic HF per capita (t/inhabitant)	8	28	60	10	na
TMR per capita (t/inhabitant)	28	71	84	46	na
TMR / DMI	2.2	3.0	3.9	2.9	na
Energy per capita (toe/inhabitant) ⁷	2.9	4.1	8.1	3.8	5.3
GDP (billion dollars)	1,100	2,072	6,723	4,320	337
GDP per capita (dollars/inhabitant)	19,300	25,580	25,860	34,840	22,470
DMI/GDP (t/million dollars)	660	931	840	457	1,332
Domestic HF/GDP (t/million dollars)	405	1,116	2,344	281	na
TMR/GDP (t/million dollars) ⁸	1,463	2,777	3,264	1,309	na

Sources: Adriaanse et al. (1997); Calendario Atlante De Agostini (1997); and ENEL (1999).

§ The data published by Adriaanse et al. (1997) are under revision for this country. The table shows the available corrected figures (Personal communication).

equal to approximately 8 t/inhabitant, whereas the United States is “responsible” for about 600 Mt, slightly over 2 t/inhabitant).

The quantity of hidden flows for the United States at home amounts to 60 t/inhabitant, as opposed to 28 t/inhabitant for Germany, 10 t/inhabitant for Japan, and 8 t/inhabitant for Italy. These numbers, although approximate, raise some questions and merit a few remarks. For example, the mass of useless materials that are handled in the production of useful materials is conspicuous, and this is true for practically all the countries. The TMR to DMI ratio of the United States (equal to 3.9), differing slightly from those of Germany and Japan (equal respectively to 3.0 and 2.9), leads us to suspect that the lower value registered in Italy (equal to 2.2) may depend on the high energy efficiency of the Italian economy,⁹ on some differences in data collection and in the materials considered,¹⁰ and on the large amount of metal scraps used¹¹ (Newman 1997).

The examination of the energy consumption rates of the various countries, expressed as toe/inhabitant, also reveals an extremely high value for the United States (8.1). This value is almost

twice that of Germany and Japan, and about 2.8 times greater than the value for Italy. For the United States, this may be ascribed to the considerable mass of materials mobilized in a year, to more energy-intensive production cycles, and to the high standard of living of this country. In order to assess whether the other countries are “virtuous,” a more detailed analysis would have to be carried out cycle by cycle to determine the energy consumption rates, as well as the amounts and quality of the (useless) materials mobilized or discarded. Needless to say, the quantity of materials mobilized is only a proxy for environmental damage, because more severe environmental degradation may be brought about by smaller and yet more hazardous hidden flows. Finally, the physical units expressing the flows may be correlated with monetary units to reveal how much useful and “useless” material has been used and conveyed into manufacturing processes for producing 1 million dollars of GDP, and, therefore, to provide an indicator of the physical efficiency of a country.

According to the data reported in table 5, Japan seems to have the greatest efficiency: For 1 million dollars of GDP, it required only about

460 t of DMI, 1,300 t of TMR, and about 280 t of domestic hidden flows. The Netherlands seems to rank last, and the levels of the United States and Germany are similar. Italy comes second after Japan, with a DMI over 660 t, a TMR of about 1,500 t, and domestic hidden flows of about 400 t. It is important to reiterate that these assessments require further verification due to the quality of the data on which this analysis is based.

Conclusions

The analysis that we have performed has allowed us to describe the general layout of the materials used in the Italian economy of 1994. A general breakdown of the sources of the 1,609 Mt of mass that flowed through the Italian economy in 1994 is given in table 1. Further discussion of the detailed data that form the basis for this analysis is provided in the appendix. We emphasize, however, that the methodology only allows us to know the amounts of materials that entered the technosphere of our country. It cannot find (a) which sector has used the greatest amount of materials; (b) which sector has been the most responsible for emissions and waste production; or (c) which economic activities have accumulated (as durable commodities) the most materials extracted from the ecosphere every year.

What the survey results can do is give decision makers some necessary information for enhancing the use of low-waste technologies. These results provide a baseline against which future data can be compared to verify if the country's political and economic choices are having the anticipated effect on mass uses such as the utilization of renewable resources. The results also provide summary figures of the quantity, but not the quality, of waste disposal per year.

Furthermore, the method used allows us to broadly compare different countries, even if the figures are not entirely comparable. In fact, each country is a special case in terms of the resources it has, how it transforms them, and how it uses the products derived from them. It follows that the data need to be interpreted on the basis of the parameters used. To this end, the efforts of the researchers in the MFA community to har-

monize and make the data clearer are valuable, even if there are still some gaps in them.

The results of this paper lead us to suggest that it would be useful to do the following:

- Harmonize the inventory structure for the collection of the different kinds of materials in the categories. For instance, in our analysis, unlike other researchers (Adriaanse et al. 1997), we included the iron, copper, and other metal scrap among material inputs.
- Concentrate the efforts on the development of the MFA methodology in order to have more information that is also useful to decision makers.
- Refine the parameters for the estimate of hidden flow.
- Improve the quality of available data; for instance, by stimulating the writing and circulation (systematic and not occasional) of statistical data as an analysis of input-output flows (or materials balance). In this way, it could be easier to know how the materials flow in the technosphere, how they go through the technosphere and ecosphere, and how they are transformed into waste.¹²

For a better understanding of mass flows, it would be necessary for these studies to be better coordinated with input-output analysis, that is, the study of the circulation (or metabolism) of materials entering the technosphere sector by sector (for instance, the metabolism of materials in the sector of energy production, or in the iron and steel industry, etc.) (Pizzoli et al. 2000). In fact, a better understanding of the mass flows of materials through an economy could be obtained with the preparation of input-output tables in physical units, suitable for comparison with the input-output tables in monetary units of traditional national accounting. This could allow us to better estimate the source and quality of waste and emissions, to find, in a more detailed way, the economic sectors that contribute to greater resource consumption, and to better understand the environmental impact of useless materials (hidden flow) entering the technosphere. This type of work is in its beginning stages, and the few published tables refer to Germany (Stahmer et al. 1998), Denmark (Gravgård Pedersen

1999), and Italy (Nebbia 1999a, 1999c); in the case of Italy, an attempt to evaluate a physical gross materials product has been made.

Acknowledgments

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Notes

1. MFA can be used to refer to both the accounting of the flows of specific substances, often called "substance flow analysis" (SFA) and "bulk-MFA," the accounting of flows in aggregate across economies and regions. In this article we use MFA to refer to the latter.
2. The researchers from the Department of Geographical and Commodity Sciences of the University of Bari, Italy became aware of these problems in the early 1970s and carried out studies on the material and energy balances in the production cycles of some goods (Nebbia 1971, 1975a, 1975b, 1996; Pizzoli 1975; De Marco 1979; Nebbia and Notarnicola 1979a, 1979b; Notarnicola 1983; Notarnicola and Proto 1983). Their interest in this field of research has continued to the present day (Pizzoli 1989, 1994; Costantino and Nebbia 1994; De Marco and Lagioia 1997; Pizzoli and Camaggio 1997; Spada and Tricase 1998; De Marco and Lagioia 1998a, 1998b; Notarnicola and Lagioia 1998; Lagioia and De Marco 1999; Spada and Tricase 1999).
3. It is necessary to note that considering imports (I) and HF of imports in the TMR calculation can be misleading. For instance, if we want to calculate the TMR in the European Union, we will have a double-counting because the exported share of domestic production of a country becomes the import of the other country. In this case, it would be more appropriate not to con-

sider the total material requirement (TMR), but rather the total (material) consumption (TMC) according to the following equations:

$$\begin{aligned} \text{TMC} &= \text{TMR} - \text{E (exports)} \\ &- \text{HFE (hidden flows of exports)} \end{aligned} \quad (4)$$

or

$$\begin{aligned} \text{TMC} &= \text{DP} + \text{I} - \text{E} \\ &+ \text{HF DP} + \text{HF I} - \text{HFE} \end{aligned} \quad (5)$$

In the same way, we can find DMC (direct material consumption):

$$\text{DMC} = \text{DMI} - \text{E} \quad (6)$$

In our opinion, it is interesting to know both TMR and TMC. Because of these considerations, we reported the figures of Italian exports in tables 1 and 6.

4. All references to ton in this article refer to metric tons. 1 metric ton = 1 Mg (SI unit) = 1.1 short ton = 2205 lbs.
5. Available on the Journal of Industrial Ecology web site at <http://mitpress.mit.edu/JIE>.
6. The figures for atmospheric emissions were estimated by ENEA (Government Agencies for the New Technology, Energy, and Environment) for the Ministry of Environment with the "bottom-up" emission inventory methodology, used in the CORINE Programme (EMEP/CORINAIR 1996), and with the "top-down" methodology developed by IPCC (IPCC 1995). The calculation of TMR and DMI does not include these numbers, and they are only displayed in figure 1 as materials output.
7. The unit "toe" is the "metric ton of oil equivalent" and it is equal to 41.87 GJ.
8. It is important to note that, because imports are not included in GDP but they are in TMR, this ratio can give the same efficiency at converting resource mass into economic value, even if the countries have different import profiles.
9. The TMR comparison of each materials category of the different countries shows that Italy has much lower figures in the fossil fuel category. In fact, the Italian economy consumed 5 t of fossil fuels per inhabitant, whereas the values for other countries are as follows: United States, 32 t/inhabitant; Germany, 28 t/inhabitant; the Netherlands, 21 t/inhabitant; Japan, 13 t/inhabitant (Adriaanse et al. 1997).

We should emphasize that besides a lower direct consumption of fossil fuels, the lower TMR figure of Italy is also due to its lower coal consumption. It is well known that coal use is associated with a large quantity of hidden flows.

- Finally, the energy efficiency of fossil fuel utilization is high in Italy. In fact, in order to produce 1 million dollars of wealth in Italy in 1994, about 170 toe was used. In Japan, the corresponding amount was about 200 toe/million \$ of GDP, and in Germany, the Netherlands, and the United States, the values were 245, 300, and 350 toe/million \$ of GDP, respectively (Enel 1999).
10. For instance, due to the lack of data, we did not estimate the amount of excavation for infrastructure (roadway or building construction, dredging in harbors, etc.). In the United States, the amount of excavation for infrastructure and dredging was about 3,450 Mt (equal to 13 t/inhabitant and to 16% of TMR), and in Japan the amount was equal to 1,117 Mt (about 9 t/inhabitant and 20% of TMR) (Adriaanse et al. 1997).
 11. In Italy, about 60% of steel was produced by electric furnace, whereas in the other countries only 40% was produced in this way. Consequently, the steel industry TMR/DMI ratio is equal to 1.7. If we suppose that iron ore was used instead of iron scrap (assuming that 1 t of scrap = 1.6 t of iron ore and 1 t of iron ore is associated with 1.5 t of HF), the TMR/DMI ratio would increase to 2.5 (about 50% higher).
 12. In Italy, a similar statistical report is published for the energy sector only (MICA 1997, 2000).
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Appendix

This appendix shows the detailed figures used in the materials flow analysis (MFA) of the Italian economy in 1994. It consists of a large multipart table (table 6) and a series of technical notes about the main parameters used to calculate the hidden flows. A summary table, the technical notes, and a source list are given here, and the complete table including endnotes is available on the JIE web site at <http://mitpress.mit.edu/JIE>.

The data on the mass of the materials mobilized by domestic production and imports allowed us to calculate the DMI (direct material input) to be 727 Mt and the TMR (total material requirement) to be 1,609 Mt for the Italian economy in 1994. These data are briefly reported in table 1 and shown in figure 1. In table 6, we also included the data referring to exported materials (both nonrenewable and renewable), together with their hidden flows, to give the readers a better comprehension (for example, to calculate the estimate of the apparent consumption) of the Italian situation in 1994. As mentioned in the main text of the article, we emphasize that the exported materials are not considered in the DMI's and TMR's estimate.

Technical Notes on Parameters for Calculating Hidden Flows

Nonmetals (or Construction Materials)

Sand and gravel. The domestic production was about 117 Mt (40% of total production of nonmetals). The overburden was 2% of production according to statistical data provided by the local authorities of Trento (Servizio Minerario 1998) and according to the literature (Schmidt-Bleek 1994).

Clay. The domestic production of clay was 40–50 Mt (15% of total production of nonmetals). The domestic hidden flow factor (3 metric tons/metric ton of clay production) was derived from personal communications with ANDIL (Italian association of brick manufacturers) and ASSOPIASTRELLE (Italian association of tile manufacturers).

Marble. In 1994 the domestic production of marble and granite was 8 Mt (3% of total nonmetals). The overburden has been estimated to be 1.5 tons per ton of products (Baldassare 1979; Spada 1990; Atti 1985; Consorzio Gestione e Servizi delle Aziende di Lavorazione di Marmi e Pietre 1998).

Lava. The domestic production of lava (volcanic origin) was about 3 Mt. The overburden has been calculated as 0.5 tons/ton of products (Servizio Minerario 1998).

Tuff. The domestic production of tuff was nearly 11 Mt (about 3.5% of total domestic non-

Table 6 Direct materials inputs (DMI), hidden flows (HF), and total material requirement (TMR) in the Italian economy in 1994 (these data are only good to within +/- 5%)

Table Section	Category	Summary		
		Product mass (kt)	Hidden flow mass (kt)	Product + Hidden flow mass (kt)
A	Nonrenewable domestic production	318,585 to 328,585	156,171 to 187,549	474,756 to 516,134
B	Nonrenewable imports	199,116	400,752 to 401,952	599,868 to 601,068
Nonrenewable totals	Nonrenewable DMI	517,701 to 527,701		
	Nonrenewable HF		556,923 to 589,501	
	Nonrenewable TMR			1,074,624 to 1,117,202
C	Nonrenewable exports	-32,286	-30,224 to -30,534	-62,510 to -62,820
D	Renewable domestic production	180,779	268,695	449,474
E	Renewable imports	25,024	34,926 to 36,701	59,950 to 61,725
Renewable totals	Renewable DMI	205,803		
	Renewable HF		303,621 to 305,396	
	Renewable TMR			509,424 to 511,199
F	Renewable exports	-8,619	-11,008 to -11,566	-19,627 to -20,185
Italian totals	Total DMI of Italy	723,504 to 733,504		
	Total HF of Italy		860,544 to 894,897	
	Total TMR of Italy			1,584,048 to 1,628,401

metals production). The hidden flows have been estimated to be 20–30% of the produced mass (Baldassare 1979).

Other nonmetals. The overburden of other nonmetals has been calculated considering factors from the literature (Schmidt-Bleek 1994; Adriaanse et al. 1997).

Fossil Fuels

Crude oil. The hidden flows (8% of oil weight) of imported and domestic crude oil and its derivative materials were calculated following the database of the Wuppertal Institute (Adriaanse et al. 1997) and confidential information from Italian manufacturers (Saipem-Agip-Eni 1998).

Coal. The overburden of imported and exported coal was estimated to be 6 tons per ton of coal production, and the overburden of domestic production was calculated to be 8 tons per ton of coal production considering data from the literature (Schmidt-Bleek 1994; Adriaanse et al. 1997; Bringezu et al. 1997).

Natural gas. The domestic hidden flows of natural gas have been calculated on the basis of 2% of the production (Saipem-Agip-Eni 1998). The hidden flows of imported natural gas were calculated based on the data of Annual Energy Review 1995 (EIA 1995).

Metals

Iron and steel. The hidden flows (1.5 tons per ton of iron ore) have been calculated by ac-

counting for the imported mineral ores (Fe content 60%) and considering the average data from Germany, the United States, Japan, and other research literature sources (Adriaanse et al. 1997; Ayres and Ayres 1998).

Aluminum. The overburden of domestic, imported, and exported aluminum has been calculated by considering a worldwide weighted average of 0.48 tons of overburden per ton of bauxite (Adriaanse et al. 1997; Ayres and Ayres 1998) and assuming that 4 tons of bauxite yields, on average, 1 ton of aluminum.

Others. The overburden of metals has been calculated considering the parameters reported in the literature (Schmidt-Bleek 1994; Adriaanse et al. 1997; Ayres and Ayres 1998).

Renewables

In 1994, the domestic production of renewables amounted to about 180 Mt, thus accounting for 25% of DMI. Imports were 25 Mt and exports were over 8 Mt.

The hidden flows of plant and animal biomass were estimated by applying a parameter specific for each plant and animal biomass. When possible, parameters have been taken from the literature and personal communications.

As for timber and semimanufactured timber products (plywood, wood chips, wood coal, etc.) it has been assumed that, for each traded ton of timber, it is necessary to cut about 1.5 tons of trees (Adriaanse et al. 1997).

Hidden flows of agricultural products (fruit, vegetables, etc.) have been roughly estimated by

Table 7 Estimate of Italian erosion (1994)

	1,000 ha	%	Erosion rate (t/ha · year)	Erosion (Mt)
Agricultural areas	13,500	45	10	135
Forest	7,000	23	10	70
Pastureland	3,500	12	5	17
Uncultivated land	4,000	13	7	28
Others (city, road, river, lake)	2,000	7	0	0
Total ITALY	30,000	100		250
Total muddy runoff estimate				150–180

Sources: Gentile (1995); Palmieri (1983); Graziani (1988); Boardman (1998); Poesen et al. (1996); Pimentel et al. (1987); and Pimentel et al. (1995).

applying a factor that depends on the type of product; generally, the applied factor ranged from 0.2 to 1.5 tons per ton of product (Macchia 1998).

Hidden flows of livestock and meat have been estimated by assuming 4.5 tons of fodder per ton of meat, and considering that one ton of living cattle—on average—provides 0.5 tons of meat. The result is that there is a hidden flow of 2.5 tons of fodder per ton of living cattle (Adriaanse et al. 1997, our calculations). According to the literature, hidden flows of fish are 30 tons per ton of fish (Vitousek et al. 1986).

Erosion

There is no formal national inventory of soil erosion over agriculture areas. Calculating (table 7) Italian erosion using the soil erosion rate gives an estimate of 250 Mt, whereas the Italian estimate of muddy runoff comes in at 150 to 180 Mt for 1994. The approximate average of these estimates, 200 Mt, was chosen as the value for domestic erosion. Erosion associated with imported materials was not estimated.

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