Chapter 9
Constructing Physical Input-Output Tables with Material Flow Analysis (MFA) Data: Bottom-Up Case Studies

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Introduction

In an economic system that aims at sustainable development, material indicators become increasingly more important than monetary indicators, as much of the literature now testifies (Ayres and Ayres 1998). Monetary indicators are often not able to reveal all the implications and interactions between the biosphere and technosphere (Nebbia 2000; De Marco et al. 2001).

The knowledge of these indicators is an essential requisite to evaluate the environmental impacts caused by human activities. The scarcity of information on the amount and the quality of waste flows, from the economic system to the biosphere, makes the evaluation of environmental impacts and the choice of an adequate disposal system both very difficult (Ayres and Ayres 1997; Nakamura and Kondo 2002).

In this context, studies and research regarding, in particular, (a) the description of economic system material bases (MFA) and (b) the material flows between different economic sectors and from these to the biosphere, become more and more important (Kneese et al. 1970; Ayres 1978; Bringezu 1997; Strassert 2001; Brunner and Recheberger 2004).

In the first case (a) the objectives are: to detect the different materials used in different economic activities, to see how they are used and how they are transformed into waste. An analysis of this type, known as Material Flow Analysis (MFA), can be applied to the whole economy of a country, to a single industrial sector or to a single firm.

The second case (b) regards Physical Input-Output Accounting through which it is possible to illustrate intersectoral material and energy exchanges existing within

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different economic sectors and between these sectors and the biosphere. Generally, this analysis refers to an annual base and concerns the whole economy of the country.

Both of the analyses use the very useful tool of material and energy balance which is based on the principle of conservation of matter (materials and energy).

The first attempts to evaluate materials passing or circulating through the economy were made two centuries ago. These attempts were the first steps that eventually led to the Input-Output Analysis (IOA), the father of which was Wassily Leontieff. W. Leontieff was educated in the Soviet Union at a time when decision makers of the socialistic economy were improving tools and methodologies that could identify the materials, goods and energy, as well as their circulation, that were necessary to support that model of economic development (Nebbia 2000; Leontief 1970).

With this aim, the first intersectoral tables of the economy were constructed. However, because of the difficulties encountered, the IO table was based solely on monetary units. The result was an IO table that focused on material flows exclusively associated to the monetary units within the economic system. This type of elaboration implies the loss of certain information, in this case the flows from the technosphere to the biosphere that is essential for a full evaluation of environmental burdens caused by economic systems.

The explosion of concerns regarding the environment that took place after the Second World War led to a new interest about the description of material flows between the economic system and the biosphere. The first examples of the environmental extension of Input-Output Analysis were intersectoral physical input-output schemes later termed PIOT, Physical Input Output Table. Although these examples date back to the 1960s, a lot of methodological problems have yet to be resolved (Kneese et al. 1970; Daly 1968; Nebbia 1975) and this is one reason why the PIOT elaboration in physical units has proceeded with difficulty. However, it is important to underline that there is a renewed interest in studies of this type (Strassert 2000).

In the last few decades complete macroeconomic material flow accounts in the form of input-output tables have been presented by official statistical offices for Germany and Denmark and by researchers for other countries (Italy, Japan, Austria, USA) (Stahmer et al. 1997; Gravgård 1990; Nebbia 2003).

The principal aspect of these studies is the strong relationship between Material Flow Analysis and Input-Output Analysis since MFA is able to present figures needed to illustrate typical inputs and outputs of economic activities, and IOA records them as intersectoral exchange flows. However, one of the principal limits is the approach most used to collect this information, and that is to say top-down one. In this case the intersectoral physical units IO table is constructed starting from statistical information. The data are often incomplete and/or not based on material balance principle. As a consequence, the final result is a table able to give a general outline of a country's macroeconomic situation but not able to give a detailed flows outline regarding an economic sector or a homogenous group of economic activities. Thus, it becomes more difficult to use PIOT as a tool for the making of governmental choices.

In this paper, the approach chosen is the bottom-up approach which records in the intersectoral physical units IO table figures obtained directly from MFA of different industrial sectors. Therefore, in the section on Material Flow Analysis, we analyze two Italian industrial sectors, aluminum and sugar, and, after having applied MFA analysis to them, in the section Plot Construction we will attempt elaborate the PIOT with the bottom-up approach.

Material Flow Analysis

In this section, articulated in two separate sub-sections, we illustrate the MFA results regarding the Italian primary aluminum industry and the Italian sugar industry, with the aim of monitoring the material flows of these productive sectors. Detailed quantitative information concerning the amount of natural resources used and the amount of waste produced by the anthropic system are the basis for the evaluation of different production, consumption and recycling policies and for the construction of specific environmental impact idices. These, indeed, are the figures necessary to construct the PIOT.

The Primary Aluminum Industry

The present world consumption of aluminum is approximately 33 million metric tons (Mt)[1] per year, of which approximately 25 Mt are primary aluminum and 8 Mt are secondary aluminum. The European Union consumes less than 25% of the annual world consumption (8 Mt). Domestic aluminum consumption today totals approximately 1.7 Mt, making Italy one of the largest aluminum consumers in Europe.

As previously mentioned, aluminum is a much used metal in Italy. The domestic primary aluminum industry supplies more than 20% (190,000 t, about 1% of world primary aluminum production) of the Italian primary aluminum consumption, which is approximately 900,000 t per year. In Italy, the primary aluminum industry has just one alumina producing plant[2] and two smelting plants,[3] all owned by the American company Alcoa. Figure 9.1 illustrates the flow chart related to the production of 1,000 t of primary aluminum based on material balance data collected from international literature and companies.[4] Figure 9.1 also includes those activities, mining and transportation, which took place outside of Italy.

[1] All references to ton in this text refer to metric tons and Mt refer to millions of metric tons.

[2] The only alumina plant is located in Sardinia, at the locality of Portovesme. Its annual capacity is approximately 1 Mt per year.

[3] Also in Sardinia, there is one of the two smelting plants. The other one is in Fusina, near Venice.

[4] For a detailed study of MFA of the aluminium industry in Italy see (Lagioia et al. 2005; Amicarelli et al. 2004).

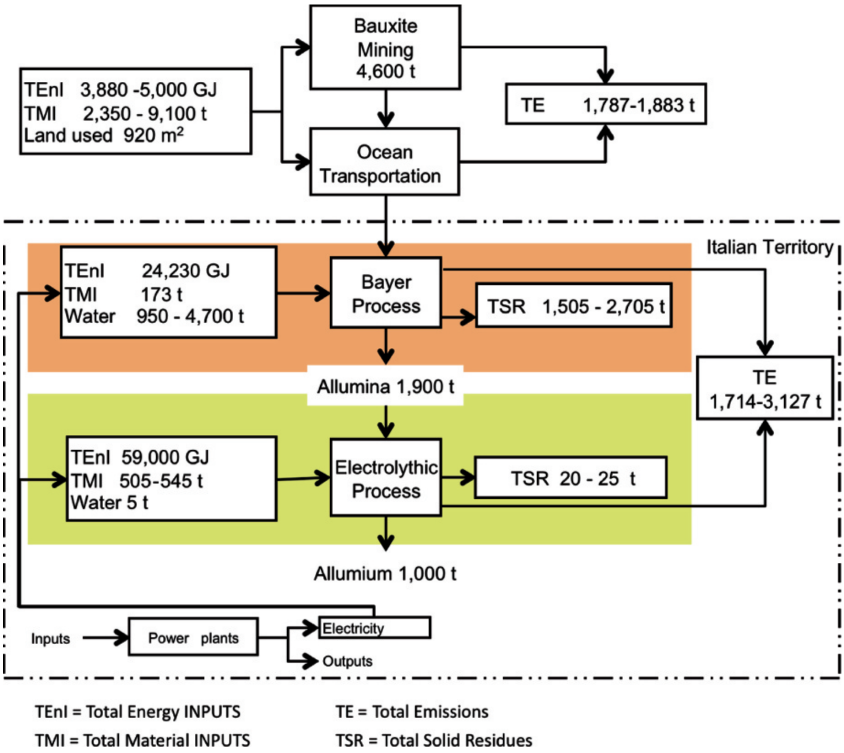

Fig. 9.1 Material Flows of Production of 1,000 t Primary Aluminum (Summary Chart)*

A synthesis regarding the material base of this Italian industrial sector and regarding the flows from and to other industrial activities and/or biosphere has been elaborated and recorded in Fig. 9.2. These quantitative figures allow the construction of the Input/Output table in physical units. The emissions of different phases have been calculated considering the emission factors processed by European and Italian Environmental Agency.

The primary aluminum industry obtains its raw materials from different types of mineral. The principal commercial source is Bauxite ($Al_2O_3 \cdot nH_2O$) the quality of which depends on the amount of alumina (40–45%) and silica (no more than the 5%) it contains.

In the year 2002, Italy imported more than 2.5 Mt[5] of Bauxite (from Australia and Guinea), all of which transformed into alumina. Approximately 37% of the alumina manufactured is destined to primary aluminum production whilst the remaining part is used in other sectors (the chemical industry for instance) or exported. Bauxite quarries cause the alteration of the ecosystems and an environmental impact due to operations such as (a) digging, necessary for the exploitation of opencast mines,

[5] This figure refers to minerals with 12% of humidity.

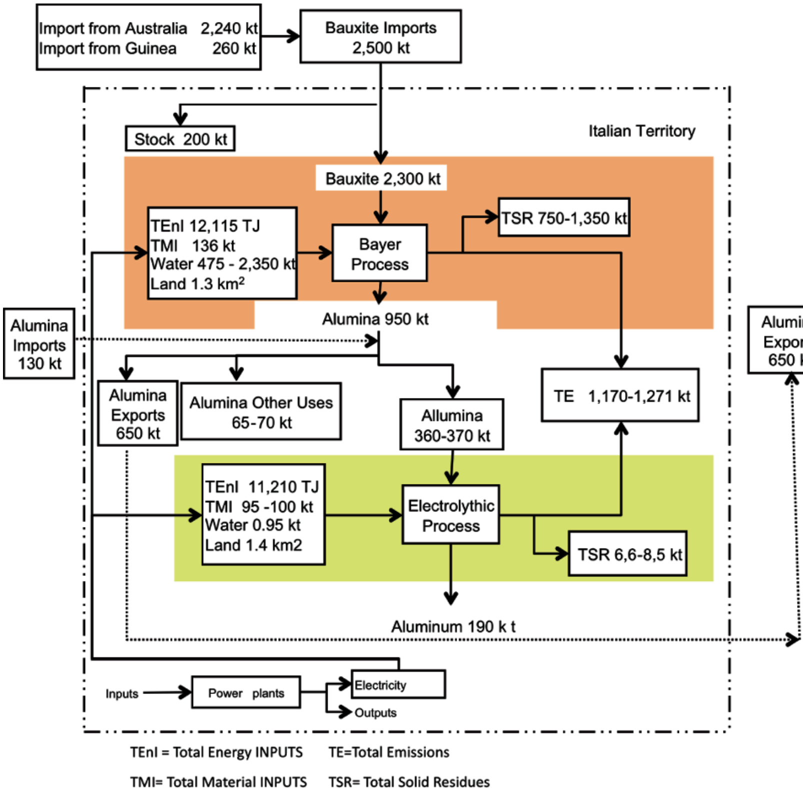

Fig. 9.2 Material Flows of Italian Primary Aluminum Production in the Year 2002 (Summary Chart)*

(b) fossil fuels used for local energy production, (c) water pollution due to waste water produced by washing-ore plants. Regarding this last point, water consumption has been reduced over the last 3 decades or so from 6 to 0.5–2.5 m^3/t thanks to enhanced natural resource saving policies.

Twenty days of navigation and over 40 cargo ships[6] per year are necessary to transport Bauxite to Italy, directly in the Sardinian Portovesme port. The estimated energy cost of this phase ranges from 0.7 to 0.8 GJ/t of transported Bauxite.

Aluminum metallurgy includes two distinct phases: one chemical and one electrolytic. In the first chemical phase, known as the Bayer process, the alumina is extracted from the Bauxite using a solution of caustic soda. To aid alumina extraction, small quantities of lime are often used. It is generally known that alumina production and lime consumption depend on the Bauxite quality. In the year 2002, the Italian aluminum industry used, on average, 2,400 kg of Bauxite, 40–50 kg of caustic soda and 40–50 kg of lime per each ton of alumina produced.

[6] Average cargo ship tonnage is estimated at approximately of 60,000 t.

The estimated fresh water use is approximately 5 m^3/t of alumina produced. Purification water systems reduce water consumption, as happens in the Sardinian Portovesme plant where it ranges from 0.5 to 2.5 m^3/t of alumina produced. Small quantities of flocculants agents (polyacrylate) and sulf acid are also used during the Bayer process.

As regards the energy consumptions of this phase, international values range from 8 to 30 GJ/t of alumina. The European, American and Italian averages are all approximately 13 GJ/t.[7]

The principal waste in the Bayer process is the red mud. Since this is non-toxic waste, it causes quantitative (from 300 to 500 kg/t of alumina produced) rather than qualitative disposal problems. At the Portovesme plant (100,000 m^2) the red mud is disposed of in a basin (1,200,000 m^2), about 3 km from the plant. The total of land used in 2002 covered approximately 1,300,000 m^2. In the near future the disposal area will be extended by 400,000–700,000 m^2.

The following step in the primary aluminum production chain is the electrolytic process known as the Hall–Héroult process, through which elementary aluminum is extracted. The Italian electrolytic covered cells, approximately 400 units, utilize precooked anodes. The cells are loaded with fused alumina and dissolved in a cryolite bath, which is needed to reduce the melting point. The current of electricity passing through the cells decomposes the alumina into aluminum and oxygen. The aluminum deposits on the cathode at the base of the cell and, the oxygen goes towards anodes where, combining with the anode carbon, it leaves the cell as carbon dioxide (CO_2). The fused aluminum, pure to 99.6%, is, periodically, extracted from the electrolytic cells and is used to prepare metal alloys or ingots.

The principal gases produced by electrolytic cells contain carbon dioxide (CO_2), carbon monoxide (CO), sulfur dioxide (SO_2) and volatile hydrocarbons and fluorides. Over the last 40 years atmospheric emissions, and particularly those of the dangerous fluorides, have been notably reduced thanks to the use of closed cells and to the introduction of dry gas purification systems. Today, emissions are estimated at 1–2 kg/t of aluminum produced.

Particular attention is required as regards the energetic inputs in the aluminum industry. Primary aluminum is an energy intensive production. The total energetic cost to obtain a ton of this non ferrous metal ranges from 145 to 180 GJ/t. The energy utilized is mainly electricity bought by the aluminum plants from the national electricity grid. This means that the primary energy cost for each kilowatt-hour produced, in terms of primary energy resources consumption and the environmental impacts, differs from country to country, from region to region, and from plant to plant. European and American Associations, analyzing the regional grids of all the aluminum manufacturing areas, have calculated the following conversion factors: respectively 8.3 and 7.6 MJ primary energy for each kilowatt-hour produced. In Italy, if we consider the national electricity grid, the conversion factor is 9 MJ/kWh,

[7] The Bayer process energy cost is 13 GJ of which approximately 2 GJ refers to primary energy used to obtain electricity (287 kWh) and 11 GJ refer to thermal energy directly used and produced in the plant by oil combustion (270 kg/t of alumina produced).

Table 9.1 Energetic Cost of 1 t of Primary Aluminum in Europe, United State and Italy

	Bayer process		Electrolytic Process		Conversion factor	Primary energy cost	Energy cost [a]
	Thermal energy	Electricity	Thermal energy	Electricity			
	(A)	(B)	(C)	(D)	(E)	(F = (B × 1.9 + D) × E)	(G = A × 1.9 + C + F)
	GJ/t Al_2O_3	kWh/t Al_2O_3	GJ/t Al	kWh/t Al	MJ/kWh	GJ	GJ/t Al
US	<11	290	5	15.000	7,6[b]	>118	>144
Europe	<11	290	5	15.000	8,3[b]	>129	>155
Italy	<11	290	5	15.000	9[c]	>140	>165
Italy	<11	290	5	15.000	10[b]	>155	>180

[a] It does not include the energetic cost of Bauxite extraction and transport. For Italian aluminum industry this cost is estimated 5 GJ/t Al.
[b] Conversion factor of the specific regional grid of aluminum manufacturing area.
[c] Average conversion factor of the whole Italian national grid.

but if we refer to the regional situation, the kilowatt-hour primary energy cost increases to 10 MJ for kilowatt-hour produced. In Table 9.1 the different energetic costs necessary to produce a ton of primary aluminum are recorded.

In order to transfer energy figures from MFA analysis to PIOT we used the specific conversion factor for the aluminum manufacturing area. The Italian energy industrial system has "sold", per each ton of aluminum, 55 GJ of electricity (15,287 kWh) and approximately 30 GJ of thermal energy to the primary aluminum industry. This means that the electrical system has bought more than 155 GJ of primary energy resources.

Production Cycle of Beet Sugar

The production cycle of beet sugar, as we know, can be divided into three main phases: sugar beet cultivation, industrial transformation and commercial distribution of beet sugar (the final product). In the sweetener market, sugar is the most used for human nutrition. Sugar (saccharose) is mainly extracted from sugar cane and sugar beet. In the world, the land used for sacchariferous crops is about 27,000 km^2 and this permitted the production, in 2002, of 143 Mt of raw sugar, 30% of which came from sugar beets. In the European Union, Germany, France and Italy are the main sugar beet producers. In 2002, these three countries produced, respectively, 31, 26 and about 12 Mt. In Italy sugar beet cultivation is common throughout most of the country with a total of 2,220 km^2 dedicated to its cultivation. In 2002, 12 Mt of beets were produced and transformed into 1.4 Mt of sugar.

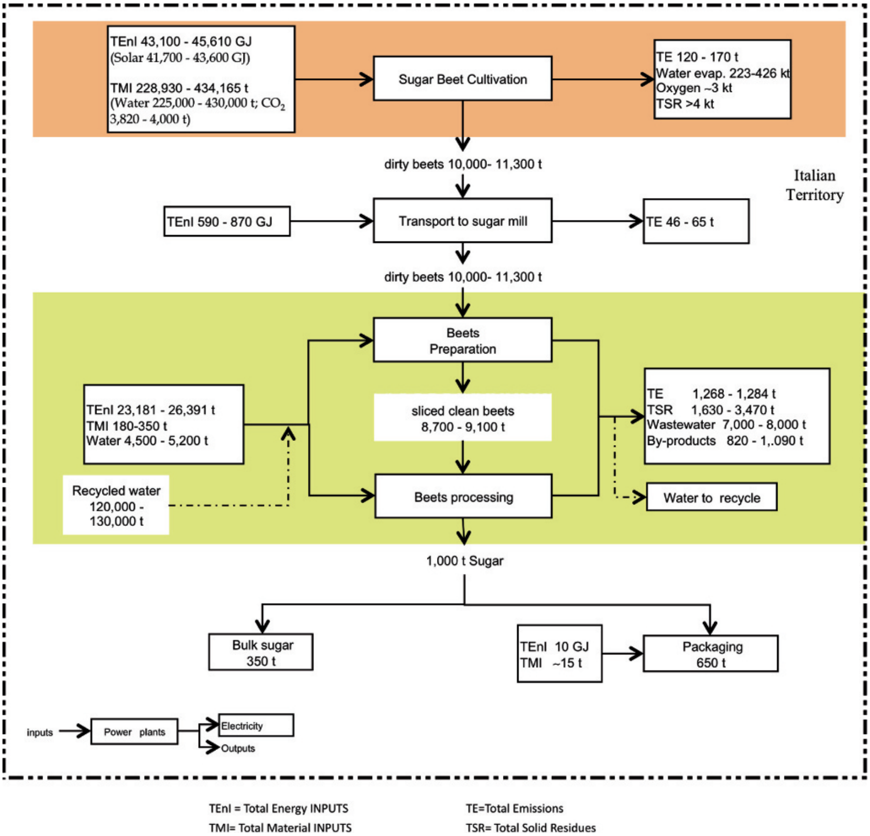

Fig. 9.3 Material Flows of Production of 1,000 t Sugar (Summary Chart)*

On the basis of the information obtained by the material flow analysis of cultivation, production and distribution of sugar in Italy, it has been possible to construct a flow chart for 1,000 t of sugar (Fig. 9.3) and the whole sugar Italian production in the year 2002 (Fig. 9.4).[8] The resulting data of this diagram allows us to retrace the exchange of materials between this sector and other industrial sectors as well as between the environment. This is all necessary to construct the intersectoral table in physical units (PIOT). Also in the case of sugar, emissions have been calculated considering the emission factors processed by the European and Italian Environmental Agencies.

As in the case of aluminum, we should pay particular attention to electricity consumption. The latter is converted into primary energy value (MJ) based on the national conversion factor of 9 MJ/kWh. In the case of sugar production, it is not

[8] For a detailed study of MFA of the sugar industry in Italy see (De Marco et al., 2002, 2003, 2004).

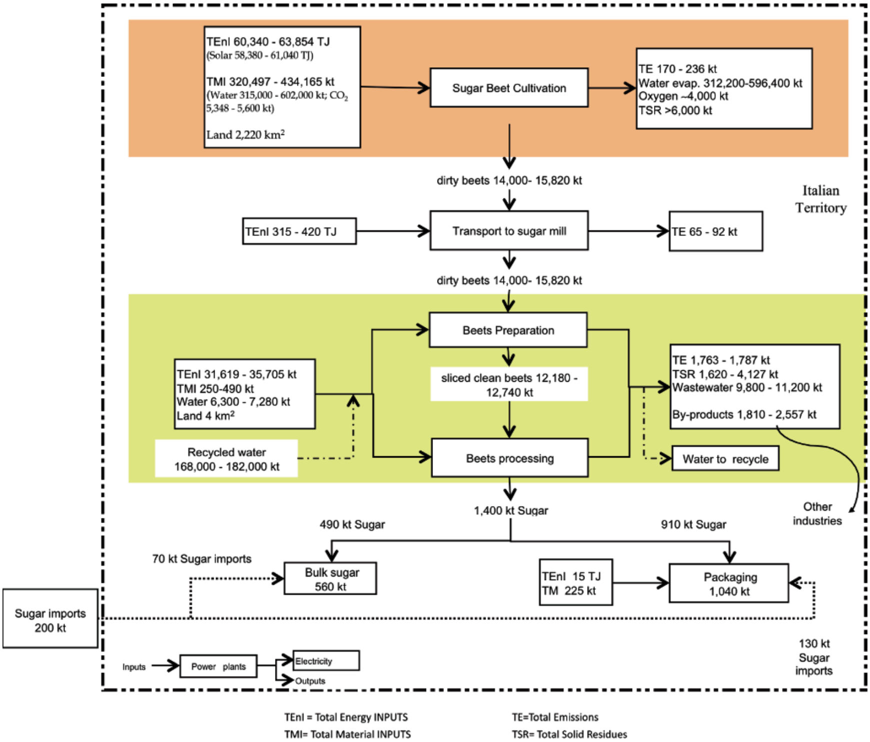

Fig. 9.4 Material Flows of Italian Sugar Production in the Year 2002 (Summary Chart)*

possible to consider specific regional references since sugar production and beet cultivation are so scattered throughout the country.

The sugar beet (*Beta vulgaris*, variety saccharifera L.) belongs to the class of Dycotiledons and to the family of Chenopodiacee. Proper soil preparation, which involves several phases, is required for this crop. The seed used, 25–40 g, is coated with geoinsecticides to protect it and the seedling from attacks of parasites and insects. After sowing, soil fertilization takes place; the dosage of fertilizer depends on the chemical–physical condition of the soil. It has been estimated that 50–60% of the nitrogen used for fertilizing is lost in the environment as nitrogen oxide.

After seed germination, photosynthesis starts and this allows the beet to grow and amass sugar substances in the pulpy root. It has been evaluated that, during the whole cultivation cycle, sugar beet crops absorb about 440 kg of CO_2, 180 kg of water,[9] 4.8 GJ of solar energy and release 320 kg of oxygen, to produce 1 t of roots.

[9] This amount of water refers only to water employed in photosynthesis, based on dry matter produced in the process.

Herbicide, fungicide and insecticide use depends on the presence/absence of serious plant infection. A useful tool to reduce specific plant illnesses could be the utilization of illness-resistant plants. Nevertheless, it has been estimated that the chemical spreading needs 2–13 MJ/t of beet.

Sugar beet cultivation requires a large absorption of irrigation water (25–52 m^3/t of beets) and about 90 MJ/t of energy to start up the irrigation devices (water raising pumps, nozzle movement, etc.).

Seventy days after sowing, sugar beets are harvested by mechanical means which are more efficacious, less expensive and require 28–36 MJ/t of beets. After harvesting, the sugar beets are taken to sugar mills[10] where they are cleaned and washed.

Thanks to water purification systems, the amount of water employed (to wash and to convey) in the whole sugar production cycle is about 0.3–0.4 t/t of roots. In the 1970s this amount was 0.6–0.9 t/t.

Clean beets are sliced into cossettes and sent for extraction. The countercurrent flow extraction takes place inside continuous extractors (drum or tower type) where cossettes and sugary juices move in opposite directions. Continuous extraction and dry transport permit further reductions in water consumption (0.7–0.8 t/t of beets).

Extraction produces exhausted cossettes and raw juice which contains about 13% of saccharose. The exhausted cossettes obtained are pressed, dried, and transformed into pellets and sent to the livestock industry. It has been estimated that in Italy in 2002 most of the sugar industry's by-products were used for animal feed.

Raw juice obtained by extraction is purified and treated with carbon dioxide, calcium oxide and sulfur dioxide. At the end of purification, thin juice, containing 1% of impurity, and filter cakes are produced. These cakes, after washing, can be used as fertilizer and this is another improvement in waste management. The thin juice, meanwhile, is evaporated, concentrated and, after cooling, centrifuged by water-centrifuge extractors to separate sugar crystals which are subsequently washed by water and steam. Centrifugation produces molasses and sugar, which is then dried and cooled. Molasses is used for the chemical industry to produce ethanol or chemicals such as inositol, glutamic acid, succinic acid, or together with dry pulp, to make animal feed. In 2002, 50% of the molasses produced was used for animal feed.

The sugar produced is distributed and sold in Italy as bulk (35%) or packaged (65%) sugar. Sugar is packaged in bulk bags (Big bag), paper shipping sacks, or disposable sugar mini bags. Generally kraft paper is used for paper shipping sacks because it is strong and cheap, and so suitable for a low added value product like sugar. The disposable mini bags are multilayer flexible packaging made of a combination of kraft paper and polyethylene. Big bags are made of plastic material (polypropylene tissue). The main characteristics of sugar distribution and its packaging are shown in Table 9.2.

[10] It has been calculated an average distance of 8–40 km from beets cultivation to sugar mills.

Table 9.2 The Main Characteristics of Italian Sugar Distribution in 2002

Sector	Package typology	Gross weight	Tare	%[a]
Industrial	Bulk (30 t tank truck)	–	–	50
Industrial	Paper kraft bag	25 kg	90–130 g	30
Industrial	Paper kraft bag	50 kg	165–175 g	15
Industrial	Big bag	500–1,000 kg	800 g	5
Wide consumption	Paper kraft bag	1 kg	7.5 g	96
Wide consumption	Other package	–	–	4
Ho.re.ca.	Multi-layers (Kraft-PE) disposable mini-bag	5–7 g	0.32 g	100

[a] Percentage of sugar used by each single sector per package typology.

PIOT Construction

As previously mentioned, the utility of MFA also provides the quantitative information necessary to construct the PIOT. The PIOT is a Physical Input-Output Accounting tool through which it is possible to measure material and energy flows passing through the economy of a country.

The idea of using a tool of this type is not new and over the years it has taken many paths (Kneese et al. 1970; Strassert 2001; Stahmer 2000). In any case, many studies relative to the construction of an Input-Output model of the economic systems require good knowledge, at the moment lacking, of the material flows of the various economic activities. Nevertheless, the impulse to Physical Input-Output Accounting was given by the introduction of the Material/Energy Balance Principle (Kneese et al. 1970; Strassert 2001; Nebbia 1975; Strassert 2000; and Chapter 4 [Giljum and Hubacek] of this handbook). The link between MFA and IOA, as here proposed, contributes to filling this gap.

In general a PIOT is a tabular scheme in which a certain number of economic activities or sectors are represented by their material input and output. Our PIOT construction is based on the Herman Daly matrix, one of the first examples of this methodology. It can be synthesized in the following table split into four different quadrants:

	Nature (i)	Technosphere (j)
Nature (i)	a_{ii}	A_{ij}
Technosphere (j)	a_{ji}	A_{jj}

where a_{ii} represents material flows within the biosphere, a_{ij} resources "sold" by the biosphere to the technosphere (water used in different processes, for example), a_{ji} material flows from the technosphere to the biosphere (waste disposed or emissions, for example), a_{jj} commodities, semis etc. exchanged between different technosphere sectors (electricity "sold" to the Bayer process, fertilizers used in sugar beet cultivations etc.) (Nebbia 1975, 2000; Daly 1968).

Generally, quadrant a_{ii} is left empty because the description of economic activities does not include the flows within Nature. In several analyses it is omitted (Strassert 2000).

To make the comparison and analysis between PIOT and MIOT (Monetary Input Output Table) easier, the columns and the lines concerning the technosphere are named using the codes utilized by the NACE 1.1 classification of the economic activities which is based on the last revision of the general nomenclature of the economic activities in the European Communities.

The biosphere sectors are given numerical codes, “1” for the air, “2” for the aquatic ecosystem, “3” for soil, and “4” for the natural deposits. Finally, another two sectors have been added: one, called *stock* (code AA), represents the material “contained” in each sector[11] and the other (code AB) represents the flows from and toward other countries. The line AB records importation whilst column AB records the exports.

In our case studies we use Italian aluminum and sugar MFA (Figs. 9.2 and 9.4), in order to individualize and quantify the type of intersectoral exchange and then attribute this exchange to corresponding PIOT box. The transfer of the quantitative information in MFA Figs. 9.2 and 9.4 to the PIOT boxes has been performed with the aid of the electronic spreadsheets.

The result of the transferral of MFA data to the PIOT is that the output produced by each production chain (that is the sum of final products, semis, by-products, waste, emissions and wastewater) is split among various columns, and each column refers to a specific economic sector and/or biosphere sector (soil, for instance). As a consequence, each column represents the figures related to the inputs received by a single sector. In this way the quantitative information relating to each economic sector is visualized in the form of intersectoral exchanges.

In synthesis, the phases of elaboration involve (a) the displaying of the MFA results of the entire industrial sector so that they are ready to be transferred to the PIOT; (b) identification of the NACE codes of the origin and destination sectors of the various material flows reported in Figs. 9.2 and 9.4; (c) construction of the PIOT for each single sector, in this case aluminum and sugar (Figs. 9.5 and 9.6);(d) designing a PIOT that summarizes the results of the case studies (Fig. 9.7). In order to improve PIOT reading the charts have been reorganized representing, whereas there are no exchanges, only the column related to the section.

It should be noted that since the various boxes may contain several material flows the PIOT has an appendix which gives the details of each individual box. This is important especially when the results of the studies of several sectors are grouped together (Fig. 9.7). For example, box “X(D-DJ-27.42.0),(1)” of Fig. 9.7 indicates the total of the emissions (1,170–1,271 kt) generated by the aluminum industry. The details of these emissions would risk being lost if there were no link with the MFA (Fig. 9.2). Only with MFA does it emerge, for example, that the principle flow of emissions is due to the release of 1,130–1,185 kt of CO_2.

[11] For example this box represents the amount of bauxite ore imports and the amount stored in alumina plants.

Since PIOT concerns only the flows inside the national territory, not all the values of MFA, which focuses on the entire material base, are recorded in the PIOT. For instance, inputs and outputs associated to the Australian Bauxite mining or the energy consumption for its transport are included in MFA analysis but, since they occur outside national territory, the related flows are not included in the PIOT table. In this case only the amount of mineral imported will be recorded in the line AB.

One of the most important aims of analyses of this type is to evidence the amount of waste that the economic activities generate and send into the environment. It is therefore important to observe the way these flows are recorded and this represents one of the main problems in designing a PIOT. In our cases, all the waste was considered as outputs of the various economic activities and is, therefore, split amongst the various columns/sectors of destination in correspondence with the line/sector of origin. As regards this point, there are two possibilities: (a) the waste may flow directly from the economic sector to the biosphere and (b) the waste may pass through "intermediary" economic sectors of treatment, reuse, recycling or disposal and consequently do not flow directly into the biosphere.

In the first case, the waste is easily identifiable as negative pressure indicators of the economic activities since it is recorded in the quadrant a_{ji} which illustrates all the flows of the technosphere towards the natural environment. For example, box "X(D-DJ-27.42.0),(1)" of Fig. 9.5 reports the emissions of CO_2, CO etc. "directly" flowing from the aluminum sector (code D-DJ-27.42.0) to the atmosphere (code 1). It is therefore easy to reconstruct that in Italy the production of 1 t of Al in 2002 generated a flow towards the environment of 6.1–6.7 t of emissions. This can then be easily compared with all the other sources of emissions and to the total amount of emissions. It is possible to see clearly the contribution of the aluminum industry to this total.

In the second case, the negative output (the waste) is not directly disposed of in the environment due to the input of other economic activities (treatment, recycling, etc.). It becomes more difficult, therefore to evidence the amount produced by each single sector. This can be seen, for example, in box "X(D-DA-15.83.0),(O.90.02.0)" of Fig. 9.6, which reports the waste produced by the sugar mills and then passed on to the systems of treatment. Here, however, it appears as an exchange within the economy. The final "sale" of the waste from the technosphere to the biosphere (box "X(O.90.02.0),(3)") would therefore be only indirectly linked to the sector under study. This point is also discussed in another chapter of this handbook (see Chapter 7 by Dietzenbacher et al.) and in the literature (Nakamura and Kondo 2002; Suh 2003; Giljum et al. 2004; Giljum and Hubacek 2004). The building of the intersectoral tables often entails the recording of the various flows in just one box, as in the case of waste which flows from the economic sector to the environment, and this leads to the loss of information of the quality of the materials and of the substances that have been disposed. The integrated reading of the MFA results and the PIOT appendices allow us to understand the nature of these flows and so to express a more complete evaluation, also qualitative, of the environmental problems associated to the sector under consideration. An example of this can bee see in the already mentioned box "X(D-DJ-27.42.0),(1)" of Fig. 9.5.

a

Section (S)				*S*	1 Air	2 Water	3 Soil	4 Natural Stock	A .. C
Subsection (Sb)				*Sb*					....
Division, Group, Class (DGC)				*DGC*					......
Description (Des.)				*Des.*					......
S		*Sb*	*DGC*	*Des.*					
1	Air								
2	Water								
3	Soil								
4	Natural Stock								
A	Agriculture	....	....	.....					
B	Fishing	....	.....	.....					
C	Minerals	....	.....	.....					
D	Manufacturing	DF	23.20.1	Manufacture of refined petroleum products					
		DG	24.13.0	Manufacture of other inorganic basic chemicals					
			24.14.0	Manufacture of other organic basic chemicals					
			24.16.0	Manufacture of plastics in primary forms					
		DI	26.52.0	Lime production					
		DJ	27	Metals products					
			27.42.0	Primary Aluminium industry	X		X		
E	Energy and water		40.11.0	Production of electricity	X	X			
			41.00.2	Collection, purification of water					
F ... Q	....	....	....	.....	X				
AA	Stock	....	....	.....					
AB	Import	....	....	.....					
				Totals (min)	4.669	383.560	759	0	0
				Totals (MAX)	4.770	832.510	1.361	0	0
			Land use (km²)						

Fig. 9.5 Input-Output Table of Primary Aluminum Industry (Nace Code 27.42.0) in Italy in 2002 (Summary Chart)*

Another important block of information, the recording of which poses particular methodological problems, is the quantity of land used by the different economic sectors. This voice cannot be inserted among the other voices of the PIOT on account

b

D Manufacturing			E Energy and water		F … Q	AA Stock	AB Export		
DG	DJ				……	….	….		
24	27	27.42.0	40.11.0	41.00.2	……	….	….		
Manuf. of chemicals	Metal products	Industry Primary Al	Prod. of electricity	Collection, purification of water	…..	…..	…..	Totals min	Totals MAX
		X	X					2.238	2.322
			X	X				383.580	834.405
								0	0
								0	0
								0	0
								0	0
								0	0
		X	X					1.082	1.082
		X						48	52
		X						22	26
		X						0	0
		X						43	43
								0	0
X	X					X	X	3.034	3.742
		X						387.315	836.265
		X						476	2.351
								0	0
								0	0
		X						2.630	2.630
65	190	4.172	385.727	476	0	200	650	780.468	
70	190	6.139	834.677	2.351	0	200	650		1.682.918
		3							

Fig. 9.5 (continued)

of the different units of measurements used. We have, therefore, as also proposed by others (see Chapter 7 from Dietzenbacher et al. In this handbook; Suh 2003; Giljum et al. 2004), inserted a final line after the totals in order to express in square meter the quantity of land used by each column/sector in such a way as to be able to build the relative indicator of the land used by each sector examined.

a

Legend: Section (S); Subsection (Sb); Division, Group, Class (DGC); Description (Des.)

S		Sb	DGC	Des.	1 Air	2 Water	3 Soil	4 Natural Stock	A Agriculture	B	C	D Manufacturing			
Sb										....	....	DA	DA	DA	DG
DGC									01.11.3	....	....	15	15.7	15.83.0	24
1	Air								X					X	
2	Water								X					X	
3	Soil								X						
4	Natural Stock								X						
A	Agriculture		01.11.3	omissis	X	X	X								
B	Fishing	....	....												
C	Mineral extraction	CB	14.12.2											X	
D	Manufacturing		15												
		DA	15.83.0		X	X			X				X		X
		DD	20.40.0												
		DE	21.21.0												
		DF	23.10.1											X	
		DF	23.20.1						X						
		DG	24.13.0											X	
		DG	24.15.0						X						
		DG	24.20.0						X						
		DH	25.22.0												
		DI	26.52.0						X						
E	Electricity, Gas &		40.11.0		X	X								X	
E	Water		40.21.0											X	
F	Costruction	....	....												
G	Wholesale and ...		51,2						X						
H	Hotels and restaurants	....	....												
I	Transport,...		60.24.0		X							X		X	
J	Financial intermediation	....	....												
K	Other....		74.82.1												
L-N	....	....	....												
O	Other community, ...		90.02.0				X								
P	Family														
Q	... service activities	....	....												
AA	Stock														
AB	Import														
			Totals (min)		8.236	393.034	8.014	0	326.404	0	0	560	959	21.307	189
			Totals (MAX)		8.587	784.687	10.740	0	616.277	0	0	560	1.253	24.443	273
			Land use (km^2)						2.220					4	

Fig. 9.6 Input-Output Table of Sugar Beet Cultivation (Nace Code 01.11.3) and Sugar Industry (Nace Code 15.83.0) in Italy in 2002 (Summary Chart)*

Another problem we encountered with the methodology that we adopted is that tables are usually partially incomplete since the material flows of a specific analyzed economic sector do not involve all the sectors present in the technosphere or in the biosphere. This is the reason why often a lot of boxes in the tables are left empty (see Figs. 9.5–9.7). However, it is observed that this is a frequent situation when

b

E Electricity, …	F	G Trade	H	I Transport, …	J	K Other…	L-N	O Other …	P Family	Q	AA Stock	AB Export		
	....		....		....		....			....				
40.11.0	....	51,2	....	60.24.0	....	74.82.1	....	90.02.0		....				
omissis													Totals	Totals
													min	MAX
X				X									8.335	8.569
X													406.520	799.500
													1.260	3.640
													1.390	1.453
				X									324.359	611.966
													0	0
													252	490
									X				560	560
				X		X		X					16.375	20.770
						X							11	11
						X							10	10
													12	23
X				X									122	156
													1	2
													70	144
													0	2
						X							1	2
													78	83
						X							85.412	190.444
													720	803
													0	0
													0	0
													0	0
													14.625	16.472
													0	0
									X				1.040	1.040
													0	0
													1.924	4.371
													0	0
													0	0
													0	0
				X		X							200	200
85.375	0	0	0	14.613	0	1.062	0	1.924	1.600	0	0	0	863.277	
190.400	0	0	0	16.457	0	1.064	0	4.370	1.600	0	0	0		1.660.711
									+		+	+		

Fig. 9.6 (continued)

only one sector is analyzed but, using MFA results it will be possible to compile the whole intersectoral table if studies like the ones we have carried out will be carried out for all the sectors of an economic system.

The approach we used is named 'bottom-up' on account of the fact that we aggregate the details and specific information regarding each economic sector in order

a

Legend
Section (S)
Subsection (Sb)
Division, Group, Class (DGC)
Description (Des.)

S		Sb	DGC	Des.	1 Air	2 Water	3 Soil	4 Natural Stock	A Agriculture	B	C	D Manufacturing							
Sb										....	....	DA	DA	DA	DG	DG	DG	DJ	DJ
DGC									01.11.3	....	....	15	15.7	15.83.0	24	24.15.0	24.20.0	27	27.42.0
Des.									omissis										
1	Air								X					X					X
2	Water								X					X					
3	Soil								X										
4	Natural Stock								X										
A	Agriculture		01.11.3	Omissis	X	X	X												
B	Fishing	....	....																
C	Mineral extraction	CB	14.12.2											X					
D	Manufacturing	DA	15																
		DA	15.7																
		DA	15.83.0		X	X			X				X		X				
		DD	20.40.0																
		DE	21.21.0																
		DF	23.10.1											X					
		DF	23.20.1						X										X
		DG	24.13.0											X					X
		DG	24.14.0																X
		DG	24.15.0						X										
		DG	24.16.0																X
		DG	24.20.0						X										
		DH	25.22.0																
		DI	26.52.0						X										X
		DJ	27.42.0		X		X								X			X	
E	Electricity, Gas & Water		40.11.0		X	X								X					X
			40.21.0											X					
			41.00.2																X
F	Costruction	....	....																
G	Wholesale		51,2						X										
H	Hotels and restaurants	....	....																
I	Transport, storage ..		60.24.0		X							X		X					
J	Financial ...	....	....																
K	Other.....		74.82.1																
L-N	....	....	....																
O	Other		90.02.0				X												
P	Family																		
Q	... service activities	....	....																
AA	Stock																		
AB	Import																		X
			Totals (min)		12.905	776.594	8.773	0	326.403	0	0	560	959	21.308	254	0	0	190	4.172
			Totals (MAX)		13.357	1.617.547	12.102	0	616.278	0	0	560	1.253	24.444	343	0	0	190	6.139
			Land use (km^2)						2.220					4					3

Fig. 9.7 Input-Output Table of Aluminum and Sugar Industry in Italy in 2002 (Summary Chart)*

to have an overall and complete picture of all the exchanges that characterize the economic system. The PIOT of Fig. 9.7 is an example of the a single table for both sectors analyzed and in which it is possible to find the union of flows.

One consequence of this method is that the indirect flows are visualized only when the exchanges of materials of related sectors are inserted. For example, the use of caustic soda in the Bayer process (box(D-DG-24.13.0), (D-DJ-27.42.0) of

b

0		F .. H	I	J	K	L-N	O	P	Q	AA	AB		
Electricity, Gas & Water			Transport …		Other …		Other, etc.	Family		Stock	Export		
		....		....		....			....				
40.11.0	41.00.2	....	60.24.0	....	74.82.1	....	90.02.0		....			Totals min	Totals MAX
omissis													
X			X									10.573	10.892
X	X											790.100	1.633.905
												1.260	3.640
												1.390	1.453
			X									324.359	612.316
												0	0
												252	490
								X				560	560
												0	0
			X		X		X					16.375	20.770
					X							11	11
					X							10	10
												12	23
X			X									1.203	1.238
												49	54
												22	26
												70	144
												0	0
												0	2
					X							1	2
												121	126
										X	X	3.034	3.742
					X							472.729	1.026.710
												720	803
												476	2.351
												0	0
												0	0
												0	0
												14.625	16.472
												0	0
								X				1.040	1.040
												0	0
												1.924	4.371
												0	0
												0	0
												0	0
			X		X							2.830	2.830 -
471.102	476	0	14.614	0	1.062	0	1.924	1.600	0	200	650	1.643.746	
1.025.077	2.350	0	16.457	0	1.064	0	4.370	1.600	0	200	650		3.343.981
								+		+	+		

Fig. 9.7 (continued)

Fig. 9.5) implies that the economic sector is indirectly linked to the flow "X(C-CB-14.40.0), (D-DG-24.13.0)". This box should report the quantity of salt sold by salt mines to the alkaline substances industry (sector "D-DG-24.13.0"). In the present study we have, nevertheless, deemed it opportune not to ignore the principle indirect flows (consumption of primary resources and emissions) associated with the use of electrical energy.

This means that the figures represent not only the quantity of energy that flows from the electricity sector to the examined sectors but also all the primary energy resources used to produce electricity. The fuel sector, for instance, sells to the electricity sector 768–773 ktoe[12] of thermal energy. After the transformation the electricity sector sells to the aluminum and sugar industries, respectively, 257 and 22–24 ktoe of electricity and "offers" to the biosphere 489–492 ktoe of heat losses.

Conclusion

In the present chapter we have analyzed two Italian productive sectors: the aluminum and sugar industries. Utilizing the material balances, the MFA methodology applied has allowed the description of all the phases of these two production chains taking place in or outside the domestic territory (Figs. 9.1–9.4). Then, with the MFA results, the PIOT has been constructed for each of the two sectors. Figures available in literature often have to be confirmed by companies and this makes MFA analysis rather painstaking. In the study cases presented it has been possible to collaborate with Italian aluminum and sugar firms (Comalco Limited 2004, personal communication; Alcoa Portovesme Alumina Plant 2004, personal communication; Sadam Zuccherifici S.p.A. 2004, Jesi Plant, personal communication; S.F.I.R. S.p.A 2004, Foggia Plant, personal communication) and we hope for a greater collaboration between universities and the business world to improve this type of study.

Nevertheless, the MFA results utilized to compile material balances illustrate the degree of efficiency the considered sectors have reached compared to the previous years and to the international situation in general, particularly as regards the use and saving of resources and the reutilization or the disposal of waste produced. It is noted, for example, that energy consumption for each ton of Bauxite quarried is now at the lowest level possible. It is also noted that the Italian Bauxite/alumina ratio is very close to the European and American averages. Also the water consumption in both analyzed industries shows substantial changes due to the reduction in water use and to water recycling. At the same time, modern soil fertilization techniques have reduced the total amount of fertilizers used. Unsolved is still the disposal management of red mud, the principal aluminum industry waste.

Based on figures obtained from the MFA analysis of the aluminum and sugar industries, PIOT tables have been constructed using the bottom-up approach. The

[12] In the elaboration of the data for the construction of the PIOT, the energy consumptions have been converted in toe.

tables illustrate the material flows that took place between these sectors and the others (technosphere and biosphere) in the year 2002 in Italy. Figures 9.5 and 9.6 illustrate, respectively, the two analyzed sectors whilst Fig. 9.7 summarizes the figures related to them. The transposition of the flow figures into the intersectoral PIOT allows us to synthesize direct and indirect input and output associated to the various productive sectors. It is possible, for example, to calculate that, in 2002, the industrial sector (from DA to DJ PIOT sections) sold the aluminum sector approximately 0.9 Mt of direct material Input and the electricity sector approximately 0.3 Mtoe. If we consider also the flows related to the electricity sector (NACE code 41.00.2), it is obvious that the indirect inputs of the aluminum industry are approximately 0.7 Mtoe and 400–820 Mt of cooling water used to produce electricity.

The complete illustration of the total of indirect inputs can be achieved only if all productive sectors are recorded. Although the top-down approach does not have this limitation, it does, however, lack the details regarding a single sector or single commodity.

Based on these coefficients it is possible to construct scenarios which would be useful to individuate the effects caused by shifts in business and/or government policy and to evaluate benefits of technological innovations. If the aluminum plant were located in an area characterized by a better efficiency of the local electricity plant (conversion factor 8.5 MJ/kWh instead of 10 MJ/kWh) it should be possible to reduce energy consumption by approximately 0.1 Mtoe and reduce the related environmental impacts.

The utility of this tool is also to unite the monetary indicators (GDP)[13] and the material indicators (GMP)[14] in order to achieve better planning policies aimed at sustainable development.

Obviously, the environmental extension of Input-Output Analysis (quadrants a_{ij} and a_{ji}) allows us to know also the details regarding waste or emissions associated to each industrial sector.

In this way, it is possible to point out the role of one specific sector compared to the country's total emissions. This detailed information is lacking in the monetary analysis of an economic system.

The direct contribution of the aluminum industry to the total Italian CO_2 emissions, for instance, is approximately 0.13% but if we consider indirect CO_2 emissions (those associated to the electricity sector), the aluminum industry's contribution passes from 0.13% to over 0.8%. Furthermore, the aluminum PIOT shows that, from a quantitative point of view, apart from the wastewater flows, the aluminum industry flow is represented by solid waste (particularly red mud) going into the ground. To evaluate the environmental impacts of these flows it is, nevertheless, necessary to analyze the quality of these flows. Because the PIOT construction entails the summing of materials which are often very heterogeneous, it is difficult

[13] GDP is Gross Domestic Product.

[14] GMP, Gross Material Product is a physical indicator capable of illustrating the whole mass of materials absorbed by the final consumers, services, stocks, and plus exports minus imports (Nebbia 2003).

to illustrate the effects that each flow has on the biosphere (air, water, and ground). MFA results can help overcome this flaw since they can detail what is summarized in the PIOT box.

The principal limitation of the bottom-up approach is that it is laborious and a long time is required to obtain an overall picture of the intersectoral exchanges within the whole economy. Moreover, to achieve the latter, it is necessary to aggregate information of many different MFA analyses and for this, as stated before, a greater collaboration between researchers and the world of business would be necessary (De Marco et al. 2001; Nebbia 2003; ANPA 2001, 2002).

Furthermore, from a methodological point of view, it would be better to follow a standardized scheme to assign material flows to different production branches, or to consumption, or to stocks. In this way it may be possible to obtain a tool that offers more truthful and verifiable results. The MFA studies presented, as shown in Figs. 9.1 and 9.3, allow us to illustrate the coefficients related to the inputs and outputs used. The transparency of the figures could favor comparison with analyses made in other countries. If we had similar analyses from other industrial sectors, it would be possible to obtain detailed data able to illustrate direct and indirect effects of the many changes taking place in the economy. The great benefit of this system is that it would provide the user with a very flexible tool that offers many types of aggregations. If, for example, decision-makers want general information on, let’s say, waste disposal in Italy, it is sufficient to refer to the waste disposal section of the PIOT. If, however, they want more detailed information they simply have to enlarge the PIOT to be able to consult the details in the subsections.

In conclusion, we stress the necessity of uniting MFA analysis and IO analysis since a better understanding of the physical flows within an economy (or technosphere) and between the technosphere and the biosphere could illustrate the relationship between economic activities and the environment; and this, as every knows, is at the heart of the environmental problem (De Marco et al. 2001; Kytzia, 2004; Bailey et al. 2004).

End Note

*The complete charts are available from the authors by request. They can also be found at http://www.dgm.uniba.it/Docenti/Lagioia/pubblicazioni.htm

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Appendix 1
Primary Aluminum Industry PIOT (27.42.0 NACE Code)

We supposed that the electricity, used to produce 1 t of primary aluminum, was obtained by thermoelectric plants located close to the domestic primary aluminum industries. Considering that Italian primary aluminum (190,000 t) is produced for 75% in Portoscuso (Sardinia) plant and for the other 25% in Fusina (Venetia) one, we applied the same bipartition to calculate material base (primary energy, emissions, etc.) associated to thermoelectric plants. We did the same hypothesis to calculate the amount of water (cooling and industrial water) used in thermoelectric plants. Thermoelectric production efficiency calculated is more than 35.5% for Sardinia (10.1 MJ/kWh) and more than 36.5% for Venetia (9.8 MJ/kWh).

X (1), (D-DJ-27.42.0) 328–413 kt – Oxygen for fuel combustion in aluminum plant (only Aluminum Oxide plant).
X (1), (E-40.11.0) 1,910 kt–Oxygen for fuel combustion in power plant.
X (2), (E-40.11.0) 383,104–832,054 kt – Cooling water (128–278 L/kWh) and industrial water (0.3 L/kWh) used by power plant.
X (2), (E-41.00.2) 476–2,351 kt – Water pass from natural system to water distribution industry.
X (D-DF-23.20.1), (D-DJ-27.42.0) 369 ktoe – Petroleum coke and fuel oil (thermal energy, as toe) used by aluminum industry.
X (D-DF-23.20.1), (E-40.11.0) 713 ktoe – Fuel used by power industry to manufacture electricity.
X (D-DG-24.13.0), (D-DJ-27.42.0) 48–52 kt – Caustic soda; Acids and fluoride used by aluminum industry.

Table 9.3 Emission Factors of Electricity (g/kWh)

CO_2	889–944
SO_2	1.30–2.40
Particulate	0.04–0.03
NOx	0.75–1.17
CO	0.10

X (D-DG-24.14.0), (D-DJ-27.42.0) 22–26 kt – Pitch and cathodes used by aluminum industry.
X (D-DG-24.16.0), (D-DJ-27.42.0) 0.05 kt – Flocculants used by aluminum industry.
X (D-DI-26.52.0), (D-DJ-27.42.0) 43 kt – Lime used by aluminum industry.
X (D-DJ-27.42.0), (1) 1,170–1,271 kt – Emissions produced by aluminum industry.
X (D-DJ-27.42.0), (3) 759–1,361 kt – Dry red mud, sand, sodium oxalates, spent lining pot, other solid residue produced by aluminum industry.
X (D-DJ-27.42.0), (D-DG-24) 65–70 kt – Alumina sold to chemical sector.
X (D-DJ-27.42.0), (D-DJ) 190 kt – Aluminum sold to metal products industry.
X (D-DJ-27.42.0), (AA) 200–200 kt of Bauxite ore stored.
X (D-DJ-27.42.0), (AB) 650–630 kt of alumina exports.
X (E-40.11.0), (1) 3,499 kt – Air emission from power industry based on factors showed in the following table (Table 9.3). Industrial water (0.3 L/kWh) realized by power industry.
X (E-40.11.0), (2) 383,560–832,510 kt – Heat loss and plant cooling water (128–278 L/kWh) realized by power industry.
X (E-40.11.0), (D-DJ-27.42.0) 256.5 kt – Power used by aluminum industry.
X (E-41.00.2) (D-DJ-27.42.0) 476–2,351 kt – Water from water distribution industry to aluminum industry.
X (AB), (D-DJ-27.42.0) 2,630–2,500 kt of Bauxite ores and 130 kt of alumina imported from aluminum industry.

Appendix 2 Sugar Industry PIOT (01.11.3 and 15.83.0 NACE Code)

X (1), (A-01.11.3) 8,200–8,400 kt – CO_2 for beet production.
X (1), (I-15.83.0), 1 kt – Oxygen for fuel combustion in sugar mill.
X (1), (E-40.11.0) 100–120 kt – Oxygen for fuel combustion in power plant.
X (1), (I-60.24.0) 34–48 kt – Oxygen for fuel combustion in trasportation service.
X (2), (A-01.11.3) 315,000–602,000 kt – Fresh water for sugar beet cultivation.
X (2), (D-DA-15.83.0) 6,300–7,280 kt – Fresh water for sugar mill.
X (2), (E-40.11.0) 85,220–190,220 kt – Cooling and industrial water for power plants.

X (3), (A-01.11.3) 1,260–3,640 kt – Soil stuck to beets.
X (4), (A-01.11.3) 1,390–1,453 ktoe – This figure (as ktoe) is the solar energy used in photosynthesis.
X (A-01.11.3), (1) 6,069–6,326 kt – Oxygen from photosynthesis, atmospheric emissions from agricultural machinery.
X (A-01.11.3), (2) 298,200–583,450 kt – Water released from cultivation for evapotranspiration.
X (A-01.11.3), (3) 6,090–6,370 kt – Leaves and epicotyls.
X (A-01.11.3), (I-60.24.0) 14,000–15,820 kt – Dirty beets.
X (C-CB-14.12.2), (D-DA-15.83.0) 252–490 kt – Limestone.
X (D-DA-15), (P) 560 kt – Sugar contained in food products sold to the family.
X (D-DA-15.83.0), (1) 1,745–1,785 kt – Air emission from sugar mill.
X (D-DA-15.83.0), (2) 9,800–11,200 kt – Wastewater from sugar mill.
X (D-DA-15.83.0), (A-01.11.3) 358–487 kt – Filter cake sold to sugar beet cultivation. It is assumed 35–40% of total filter cake output.
X (D-DA-15.83.0), (D-DA-15.7) 959–1,253 kt – Molasses (270–390 t/1,000 t of sugar) and dry pulp (550–700 t/1,000 t of sugar) used in animal feedstock. It is assumed that 50% of molasses output is sold to this industrial sector.
X (D-DA-15.83.0), (D-DG-24) 189–273 kt – Molasses (270–390 t/1,000 t of sugar) used by chemical industry. It is assumed that 50% of molasses output is sold to this industrial sector.
X (D-DA-15.83.0), (I-60.24.0) 490 kt – Bulk sugar transported to food industry.
X (D-DA-15.83.0), (K-74.82.1) 910 kt – Bulk sugar to food packaging industry.
X (D-DA-15.83.0), (O-90.02.0) 1,924–4,371 kt – Soil and stone (900–2,600 t/1,000 t of sugar) removed in sugar beet preparation phase. Filter cake (730–870 t/1,000 t of sugar). This is the 60–65% of filter cake not re-used in sugar beet cultivation.
X (D-DD-20.40.0), (K-74.82.1) 11.2 kt–Wood pallets.
X (D-DE-21.21.0), (K-74.82.1) 9.6–10.4 kt – Containers of paper (Kraft) and carton board.
X (D-DF-23.10.1), (D-DA-15.83.0) 12–23 ktoe – Carbon coke (as toe) for lime kiln.
X (D-DF-23.20.1), (A-01.11.3) 47–67 ktoe – Diesel fuel for cultivation equipment.
X (D-DF-23.20.1), (E-40.11.0) 55–60 ktoe – Primary energy (as toe) to manufacture electricity used in sugar industry.
X (D-DF-23.20.1), (I-60.24.0) 20–29 ktoe – Diesel fuel for transport (as toe).
X (D-DG-24.13.0), (D-DA-15.83.0) 1–2 kt – Sulfur dioxide for sugar purification phase.
X (D-DG-24.15.0), (A-01.11.3) 70–144 kt – Nitrogen fertilizer (as N), phosphorous fertilizer (as P_2O_5), potassium fertilizer (as K_2O).
X (D-DG-24.20.0), (A-01.11.3) 0.49–2.38 kt – Herbicides, insecticides, fungicides.
X (D-DH-25.22.0), (K-74.82.1) 0.85–1.65 kt – Polyethylene and polypropylene containers.

Table 9.4 Emission Factors of Electricity (g/kWh)

CO_2	550–580
SO_2	0.2–1.9
Particulate	0.01–0.06
NOx	0.4–0.7
CO	0.07

X (D-DI-26.52.0), (A-01.11.3) 78–83 kt – Lime used by sugar cultivation.
X (E-40.11.0) (1) 357–383 kt–Emissions from power plant related to electricity used in sugar industry based on factors showed in the following table (Table 9.4).
X (E-40.11.0) (2) 85,034–190,037 ktoe – Heat loss and plant cooling water (128–278 L/kWh) realized by power industry.
X (E-40.11.0), (D-DA-15.83.0) 21.3–23.3 ktoe – Electricity (as toe) sold to sugar mill.
X (E-40.11.0), (K-74.82.1) 0.4 ktoe – Electricity (as toe) sold to sugar packaging activities.
X (E-40.21.0), (D-DA-15.83.0) 720–803 ktoe – Natural Gas (as toe) to manufacture water vapor and thermal energy in sugar mill.
X (G-51.2), (A-01.11.3) 0.28–0.42 kt – Seeds of beet.
X (I-60.24.0), (1) 65–92 kt – Atmospheric emissions from transport.
X (I-60.24.0), (D-DA-15.83.0) 14,000–11,520 kt – Dirty sugar beet transported to sugar mill.
X (I-60.24.0), (D-DA-15) 560 kt–Bulk sugar for food industry.
X (K-74.82.1) (P) 1,040 kt – Packaged sugar sold to the family.
X (O-90.02.0), (3) 1,924–4,371 kt – Waste disposal to landfill. We consider landfill on the outside of technosphere.
X (AB), (I-60.24.0) 70 kt – Sugar imports.
X (AB), (K-74.82.1) 130 kt – Sugar imports by food packaging activities.