Published paper
Muñoz, P. and Hubacek, K. (2007) *Material implication of Chile's economic growth: combining material flow accounting (MFA) and structural decomposition analysis,* Ecological Economics, Volume 65 (1), 136 -144.

Material implication of Chile's economic growth: combining material flow accounting (MFA) and structural decomposition analysis (SDA)*

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Over the last three decades, the economic integration of the Chilean economy into global markets has happened at a fast pace. For example, in 1986, exports represented 29% of GDP while in 1996 they had increased to 38% of GDP. This period of time was characterized by strong economic growth with an average annual growth rate of about 10%. From a physical perspective, material requirements more than doubled from 220 to 500 million tons of direct material inputs (DMI) during the same decade (the rate of material growth requirements was around 13% per year).
The main objective of this study is to explain the changes in DMI by using a Structural Decomposition Analysis (SDA). The changes in material flow accounting (MFA) were broken down into the effects caused by changes in resource use per unit of output (material intensity effect), changes between and within sectors (structural change effect), changes in the composition of final demand (mix effect), changes due to shifting shares of domestic final demand and exports categories (category effect) and finally changes in the overall level of economic activities (level effects). The results, as percentage of the total level of DMI used in 1986, indicate that economic growth was the major source of material changes (109%). The material intensity and category effects explained 31% and 14% of the increase, respectively. The increase in the material intensity is mainly due to a declining quality of ores in copper production. However, these components were partly compensated by the structure (-14%) and mix (-13%) effects. Therefore, for a Southern American country such as Chile, the main causes of these changes in material consumption have been a combination of the nature of economic growth, increases in export production and increasing material intensity of production.

Keywords: Material Flow Analysis (MFA); Structural decomposition analysis (SDA); input-output analysis; economic growth; international trade; Chile.

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*An earlier version of the paper was presented at the IX Biennial Conference of the International Society for Ecological Economics on "Ecological Sustainability and Human well-being". 15-18 December 2006, New Delhi, India.

1 Introduction

Since the end of the 1960s, socio-economic systems have been studied as open systems which are embodied in a wider physical system, the environment (Ayres, 1969; Georgescu-Roegen, 1971; Boulding, 1973). From this point of view, "the economies are viewed, metaphorically, as living organisms. Industrial economies 'ingest' raw materials, which are "metabolized" to produce goods and services, and they 'excrete' wastes in the form of discarded materials and pollution" (Matthews et al., 2000, p.1). The study of exchange relationships of material and energy between socio-economic systems and the environment has been referred to as 'industrial metabolism' (Ayres et al., 1994) or 'society's metabolism' (Fischer-Kowalski, 1998). In spite of the relatively early ideas by Ayres, only recently, in the 1990s, has considerable progress been made with regards to accounting of materials used by economies (see for example Adrianse, 1997 or Schandl, 1998). More recently, have standardized and harmonised relevant concepts emerged providing a comprehensive framework for economy-wide material flow accounts and analysis (MFA) and material balances Eurostat (2001) [1].

The underlying concept of the material-based approach is the mass balance principle. This principle establishes that *all* 'inputs' going into the economy and coming from the environment will return, sooner or later, to the environment in the form of waste and emissions. On the one hand, all materials relate either to some form of scarcity of resources or a rate of regeneration or renewal. On the other hand, many environmental impacts are caused by material extraction, throughout the production processes, final consumption, and after disposal. Thus, the 'strength of an economy-wide MFA is that it provides a comprehensive and consistent picture of the quantity and composition of the metabolism of economies' (Bringezu, et al., 2003, p. 47); a weakness has been its ignorance of qualitative differences of various material flows and the explicit link to environmental damage (which is assumed rather than factually established).

However, one of the key issues when studying societal (industrial) metabolism is how the different socio-economic systems exchange materials and energy between them, specifically

[1] In this study we observe socio-economic systems at the country level.

how environmental goods as well as the environmental loads are distributed amongst different systems. A significant part of the literature has focused especially on the north-south relationship. According to this theory, the Southern countries provide the material and energy requirements for Northern countries to maintain and develop their socio-economic metabolism (Muradian and Martinez-Alier, 2001a, Giljum and Eisenmenger, 2004 and Perez, 2006). At the same time, the materials and energy imported by Northern countries often embody (or cause) large quantities of emissions and waste which remain in the exporting, usually Southern, countries (Muradian and Martinez-Alier, 2001b). A clear example of this situation is copper ore extraction: given the low copper content in minerals (around 1%), it is necessary to extract huge ore quantities in order to obtain a certain amount of pure copper output to be used in the economic process. We should note that Chile is the first copper supplier in the world (around 36% of the world market), with an output of 5.3 million tons of copper in 2006 (Procobre, 2006).

Some authors (Hornborg, 1998, Perez, 2006) have commented on how this appropriation of natural resources and the burden reallocation are related to different mechanisms such as prices, direct foreign investment and international trade, which facilitate natural resource extraction. These mechanisms have clear effects on the economic structure. Thus, having a comprehensive view of the dynamics of the economic structure is an important precondition when studying changes in material use. Hence, considering changes in the economic structure over time that govern material flows between producing industries, consuming households and exports is indispensable for solving the problems of both limited resource availability and pollution (Suh and Kagawa, 2005).

Therefore, the objective of this study is to analyse the driving forces of material consumption in Chile over the time period of 1986 to 1996. We will mainly stress the effects of international trade and economic growth on environmental pressures. The analysis of these drivers, among others, gives us a comprehensive view about the material use during the observed time period in Chile, describing the material implications of changes in Chile’s economy and society.

In the next sections we proceed as follows: section two provides the economic context of Chile in terms of trade liberalization as well as a review of previous important work on material use. In section three we present the methodology for analyzing the socio-economic changes in Chile by employing a structural decomposition analysis. In section four we present the results and discussion of our findings, while in section five we provide final comments.

2 The Chilean case: antecedents

2.1 The economic perspective

Over the last three decades, one could observe an intensifying economic integration of the Chilean economy into global markets. During the same time period Chilean economic policies have emphasised economic stabilization and liberalization; for example a reduction of import tariffs from 105% in 1974 to a uniform tariff of 10% set in 1979 (Corbo and de Melo, 1987). During the 1990s, these policies were reinforced in the direction called for by the "Washington Consensus[2]" which is a "summary of the lowest common denominator of policy advice addressed by the Washington based institutions (including the World Bank) to Latin America" (Williamson, 2000, p. 251). Some of these policies considered in the "Washington Consensus" were: trade liberalization, liberalization of inflows of foreign direct investment, privatization, deregulation (to abolish barriers to entry and exit), and secure property rights, amongst others. Thus, in order to continue the trade liberalization path during this time period many free trade agreements took place between Chile and Canada (1996), the European Union (2002), the United States (2003), South Korea (2003), New Zealand, Singapore and Brunei Darussalam (2005) and other complimentary economic agreements with Latin American countries. Current negotiations are with China, Japan and India. Thus, exports as a percentage of GDP rose from 10% in 1973 to 40% in 2000 (Banco Central de Chile, 2001a). Today, Chile is widely recognized as having the most open, stable, and liberalized economy in Latin America (World Bank, 2001). In spite of achieved stabilization and economic growth there are a number of critical voices reflecting on social[3] and ecological dimensions (Quiroga and Van Hauwermeiren, 1996, Altieri and Rojas, 1999, Larrain et al., 2003).

[2] See for example Williamson (1990).

[3] According to Human Development Report Published by United Nations Development Programme (2004), Chile is one of the ten economies with the most unequal income distribution in the world.

2.2 The physical perspective

In the last decade, the awareness about national level material consumption has significantly increased. A recent EU-funded project (MOSUS[4]) provides estimations of domestic extraction[5] for all world regions and many of the world's economies (Behrens et al., 2005). The MOSUS data shows that the richest countries[6], which represented in 2000 14% of the world's population and 75% of the world's GPD, have extracted 34% of the world's materials. This means, of course, that the rest of the countries have extracted 66% of the direct material inputs, but have just generated 25% of the GDP for 86% of the world's population. From a conventional economic point of view these figures could be mainly explained by theories such as 'comparative advantage' referring to different levels of capital accumulation and availability of qualified labour in the richest countries. In the words of the world-system perspective, the 'global order' and their inherent properties such as prices, different economic structures and trade relationships lead to a progressive spatial separation of extraction, production and consumption. As a consequence, an uneven distribution of physical material use between the rich and poor countries (or core versus periphery) takes place (see Hornborg et al., 2007; Bunker, 2007).

Especially relevant for the case of Chile are MFA estimations by Giljum (2004) provided for the time period of 1973 to 2000. Figure 1 gives an overview of the use of different material categories for the last three decades showing an especially rapid increase in material use during the 1990s. This was mainly due to DMI triggered by resource-intensive exports from mining, fruit planting, forestry and fishery sectors.

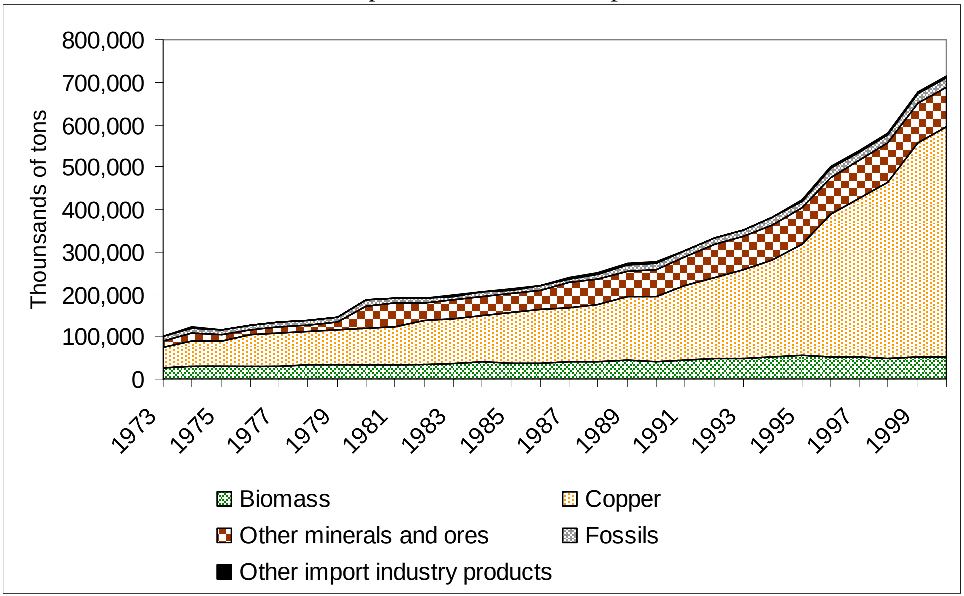
[4] A data base about MOSUS ((Modelling opportunities and limits for restructuring Europe towards sustainability) project results can be found at www.materialflows.net.

[5] Domestic extraction is defined as all solid, liquid and gaseous materials (excluding water and air but including e.g. the water content of materials) that enter the economy for further use in production or consumption processes. If it is added the material imports, then we obtain the Direct Material Input (DMI) indicator, which is equal to domestic extraction (DE) of material plus imports (Eurostat, 2001).

[6] Here represented by West Europe, USA, Canada and Japan.

Figure 1

Direct material inputs in Chile for the period 1973-2000



Source: Giljum 2004.

Note: Each material category includes domestic extraction and imports into the system.

Furthermore, we would like to highlight that most of the materials incorporated into the Chilean economy were required to produce exports. Using a static input-output approach results have shown that the Chilean exports caused around 80% of the DMI in 1996 (Muñoz and Roca, 2006). This approach not only considered those materials which were physically exported but also those direct materials that were necessary to produce exports.

So far, we have briefly described some physical, monetary and geopolitical position from this economy of the South. In the next section we present the methodology to study the driving forces that will be used to explain the changes over time.

3 Methodology

3.1 Structural Decomposition Analysis

Structural Decomposition Analysis (SDA) has widely been applied during the last three decades; the first formal derivation is attributed to Leontief and Ford (1972). SDA is used to explain the changes that occur in any variable over the time or space[7]. This technique has frequently been utilized to tackle topics related to the environment. For example, it has frequently been applied to energy (Lin and Polenske 1995, Mukhopadhyay, 1999, Jacobsen, 2000) and air pollution emissions (Casler and Rose, 1998, Wier, 1998, Haan, 2001, Mukhopadhyay and Forssel, 2005, and Roca and Serrano, 2006). Also, it is possible to find SDA application to others kinds of materials, for example, nitrogen (Wier and Hasler 1999). The most recent comprehensive summary has been provided by Hoektra[8] (2005) who, among others, also applied SDA to analyse the flows of iron and steel and plastics for the Netherlands. However, in spite of the increasing use and relevance of MFA over the last fifteen years, we just found one study combing SDA and MFA (see Moll et al., 1998).

We can describe SDA as decomposing the change of a variable over, at least, two points in time (or space). In order to do this, we have decomposed the variable under study according to our research objective. In a second stage, we take IO tables for two points in time to obtain the different component contributions (driving forces) to changes in material consumption between the two measurements.

3.2 The model

In a particular time period *t* the materials used by the economy can be written as follows:

$$M = \boldsymbol{m}^{q'} \times \boldsymbol{q} \qquad (1)$$

assuming a disaggregation of *n* commodities; *M (1x1*) are the amount of materials used by the socio-economic system in period *t*; the vector *q (nx1*) represents *n* commodities; $m^{q'}$ *(1xn)*

[7] SDA has also been used for a spatial analysis; see for example, Alcántara et al. (2004).
[8] For a full review of the literature see Hoektra's work who presents an extensive description of 31studies using SDA methodology.

represent the transposed vector of direct materials intensities which represent the materials used in each sector *m* per unit of output. Additionally, *q* can be replaced by the well-known Leontief inverse $(I\text{-}A)^{-1}$ times final demand *y*:

$$M = \boldsymbol{m}^{q'} \times (\boldsymbol{I} - \boldsymbol{A})^{-1} \times \boldsymbol{y} = \boldsymbol{m}^{q'} \times \boldsymbol{L} \times \boldsymbol{y} \qquad (2)$$

Where: *'y'* (*nx1*) correspond the vector of final demand by commodity; *I* (*mxm*) is the identity matrix; *A* (*mxm)* is the matrix of technical coefficient commodity-by-commodity and $(I - A)^{-1}$ is the Leontief inverse *L* which allows capturing direct and indirect effects triggered through changes in final demand *(y)*, such as exports, government or household demand.

Therefore equation 2 expresses total, direct and indirect, quantities of materials required to produce any final demand vector, given direct material intensities and a given economic structure.

Furthermore, it is possible to break down final demand *y* in different components[9]:

$$\boldsymbol{y} = \boldsymbol{Y}_{Mix} \times \boldsymbol{Y}_{Category} \times \boldsymbol{Y}_{Level} \quad \textit{or in short} \quad \boldsymbol{y} = \boldsymbol{Y}_M \times \boldsymbol{Y}_C \times \boldsymbol{Y}_L \qquad (3)$$

where $\boldsymbol{Y}_{Mix}$ is also known as structure or composition effect of final demand, i.e. the percentage of every commodity in a respective final demand category (household consumption, public expenditure, exports, etc). The vector $Y_{category}$ gives the proportion of every category within aggregate final demand. Given the study's objective we have used two categories: the first one is 'domestic demand' including household consumption, public expenditure, investment and stock change; the second one is 'exports'. Finally, Y_{level} is a scalar which captures the changes in total volume demanded. Thus, the total decomposition is in the following factors:

$$\mathbf{M} = \mathbf{m}^{q'} \times \boldsymbol{L} \times \mathbf{Y_M} \times \mathbf{Y_C} \times \mathbf{Y_L} \qquad (4)$$

In this second stage, the underlying idea consists of taking into account the differences between, at least, two time periods in every one of the sources that explains the changes in materials, while the rest of the potential driving sources (decomposition factors) are kept

[9] This kind of final demand decomposition is attributed to Polenske and Los (1995)

constant. Then, we have decomposed for two periods of time (*0*) and (*1*) the material according to the former decomposition already shown in equation 4.

$$\boldsymbol{M_0 = m^{q'} \, . \, L \, . \, Y_M \, . \, Y_C \, . \, Y_L}$$
$$\boldsymbol{M_1 = m^{q'} \, . \, L \, . \, Y_M \, . \, Y_C \, . \, Y_L} \quad (5)$$

Thus, the difference between the two time periods can be expressed as:

$$\Delta \boldsymbol{M = M_1 - M_0 = M_1 L_1 Y_{M1} Y_{C1} Y_{Vt} - M_0 L_0 Y_{M0} Y_{C0} Y_{V0\,L}} \quad (6)$$

The difference between periods *1* and *0* can be generated by different possible combinations of the decomposition under study, in our case 5! (or in the general case n!). As Dietzenbacher and Los (1998, p.309) commented "there is no reason why one decomposition should be preferred to the others on theoretical grounds" thus recommending (Mukhopdlyay et al., 2005; Dietzenbacher and Los, 1998; amongst others) the use of two polar decompositions. This result should be close to the average of the full set of possible decompositions (5!). Then, following that procedure, we have considered the first polar decomposition, as usually, beginning with the final year *1*:

$$\begin{aligned}\Delta \mathbf{M} = \; & \Delta \mathbf{M}\, \mathbf{L_1}\, \mathbf{Y_{M1}}\, \mathbf{Y_{C1}}\, \mathbf{Y_{V1}} + \mathbf{M_0}\, \Delta \mathbf{L}\, \mathbf{Y_{M1}}\, \mathbf{Y_{C1}}\, \mathbf{Y_{V1}} + \\ & \mathbf{M_0}\, \mathbf{L_0}\, \Delta \mathbf{Y_M}\, \mathbf{Y_{C1}}\, \mathbf{Y_{V1}} + \mathbf{M_0}\, \mathbf{L_0}\, \mathbf{Y_{M0}}\, \Delta \mathbf{Y_C}\, \mathbf{Y_{V1}} + \\ & \mathbf{M_0}\, \mathbf{L_0}\, \mathbf{Y_{M0}}\, \mathbf{Y_{C0}}\, \Delta \mathbf{Y_V}\end{aligned} \quad (7)$$

This implies that the second polar decomposition should be starting with the base year ('0'):

$$\begin{aligned}\Delta \mathbf{M} = \; & \Delta \mathbf{M}\, \mathbf{L_0}\, \mathbf{Y_{M0}}\, \mathbf{Y_{C0}}\, \mathbf{Y_{V0}} + \mathbf{M_1}\, \Delta \mathbf{L}\, \mathbf{Y_{M0}}\, \mathbf{Y_{C0}}\, \mathbf{Y_{V0}} + \\ & \mathbf{M_1}\, \mathbf{L_1}\, \Delta \mathbf{Y_M}\, \mathbf{Y_{C0}}\, \mathbf{Y_{V0}} + \mathbf{M_1}\, \mathbf{L_1}\, \mathbf{Y_{M1}}\, \Delta \mathbf{Y_C}\, \mathbf{Y_{V0}} + \\ & \mathbf{M_1}\, \mathbf{L_1}\, \mathbf{Y_{M1}}\, \mathbf{Y_{C1}}\, \Delta \mathbf{Y_V}\end{aligned} \quad (8)$$

These are so-called polar images with opposite weights with respect to time, "i.e. base year (0) versus end year (1) variables, attached to each of the corresponding change factors" (Haan, 2001, p. 186). Therefore, the average solution according to SDA methodology is:

$$\begin{aligned}\Delta\mathbf{M} = \; & \tfrac{1}{2}\,[\Delta\mathbf{M}\,\mathbf{L_1}\,\mathbf{Y_{M1}}\,\mathbf{Y_{C1}}\,\mathbf{Y_{V1}} + \Delta\mathbf{M}\,\mathbf{L_0}\,\mathbf{Y_{M0}}\,\mathbf{Y_{C0}}\,\mathbf{Y_{V0}}] + \\ & \tfrac{1}{2}\,[\mathbf{M_0}\,\Delta\mathbf{L}\,\mathbf{Y_{M1}}\,\mathbf{Y_{C1}}\,\mathbf{Y_{V1}} + \mathbf{M_1}\,\Delta\mathbf{L}\,\mathbf{Y_{M0}}\,\mathbf{Y_{C0}}\,\mathbf{Y_{V0}}] + \\ & \tfrac{1}{2}\,[\mathbf{M_1}\,\mathbf{L_1}\,\Delta\mathbf{Y_M}\,\mathbf{Y_{C0}}\,\mathbf{Y_{V0}} + \mathbf{M_1}\,\mathbf{L_1}\,\Delta\mathbf{Y_M}\,\mathbf{Y_{C0}}\,\mathbf{Y_{V0}}] + \\ & \tfrac{1}{2}\,[\mathbf{M_0}\,\mathbf{L_0}\,\mathbf{Y_{M0}}\,\Delta\mathbf{Y_C}\,\mathbf{Y_{V1}} + \mathbf{M_1}\,\mathbf{L_1}\,\mathbf{Y_{M1}}\,\Delta\mathbf{Y_C}\,\mathbf{Y_{V0}}] + \\ & \tfrac{1}{2}\,[\mathbf{M_0}\,\mathbf{L_0}\,\mathbf{Y_{M0}}\,\mathbf{Y_{C0}}\,\Delta\mathbf{Y_V} + \mathbf{M_1}\,\mathbf{L_1}\,\mathbf{Y_{M1}}\,\mathbf{Y_{C1}}\,\Delta\mathbf{Y_V}] +\end{aligned} \qquad (9)$$

Where:

$\Delta\mathbf{M}$: captures the change of the materials used per unit of output. This factor is called material intensity. Theoretically, it is expected to decrease over time reflecting efficiency gains through technical change, i.e. less material inputs per unit of outputs.

$\Delta\mathbf{L_{Vt}}$: measures the change in the commodity input structure.

$\Delta\mathbf{Y_M}$: identifies changes in the composition of final demand categories.

$\Delta\mathbf{Y_C}$: Capture changes between final demand categories;. in this particular case ‘domestic final demand’ and ‘exports’.

$\Delta\mathbf{Y_{Vt}}$ measures the changes in total volume of final demand. It can be seen as an economic growth proxy as it equals changes in GDP.

3.3 Data

The data utilized corresponds to two time periods: 1986 and 1996. It is an interesting period to analyse given the rapidly increasing rate of resource extraction (see figure 1) alongside a period of strong economic growth. A more pragmatic reason for this choice is due to the fact that Chile’s last available monetary input-output table (MIOT) is for 1996. Therefore, the corresponding materials data was also restricted to this time period.

Monetary IO tables were developed and provided by the Central Bank of Chile (Banco Central de Chile, 1993 and 2001b). The MIOTs are commodity-by-industry and we have used a commodity-by-commodity formulation under the industry-technology assumption. Furthermore, we have used the MIOTs in basic prices and domestic transactions. Subsequently, the tables were deflated using the output vector in constant prices available for 26 commodities for the years 1986 and 1996.

The materials data are based on the estimations made by Giljum (2004) for the two years under study. We have used direct material input (DMI) as indicator for materials *(M)* used and consumed in the economy. It is important to mention that the DMI used in this study does not take into account water and air. Furthermore, the DMI indicators were disaggregated according to the commodities provided in the MIOT.

However, with regards to the combination of biophysical and economic data we face a certain level of uncertainty. We have disaggregated the biophysical data by product according to products description (see for example Banco Central de Chile 2001a) as proper product classification, such as ISIC, was not available. Consecutively, we adopted a commodity-by-commodity formulation in order to account for products produced (or extracted) by a secondary industry to be allocated on the basis of the primary commodity by using the industry's technology assumption[10]. Another issue worth noting is with regards to the allocation of material imports; we have allocated physical material imports based on monetary information coming from the import matrix available in the MIOTs. This does represent an inconsistency to the idea of extended input-output analysis but is of minor importance in our case. In 1996, around 68% of the material imports were fossil fuels used by petroleum refineries. That means that we have reallocated 32% (7 millions of tons) of the products imported, which represent 1,5% of the total DMI using monetary information in 1996 (an analogous procedure was used for the year 1986).

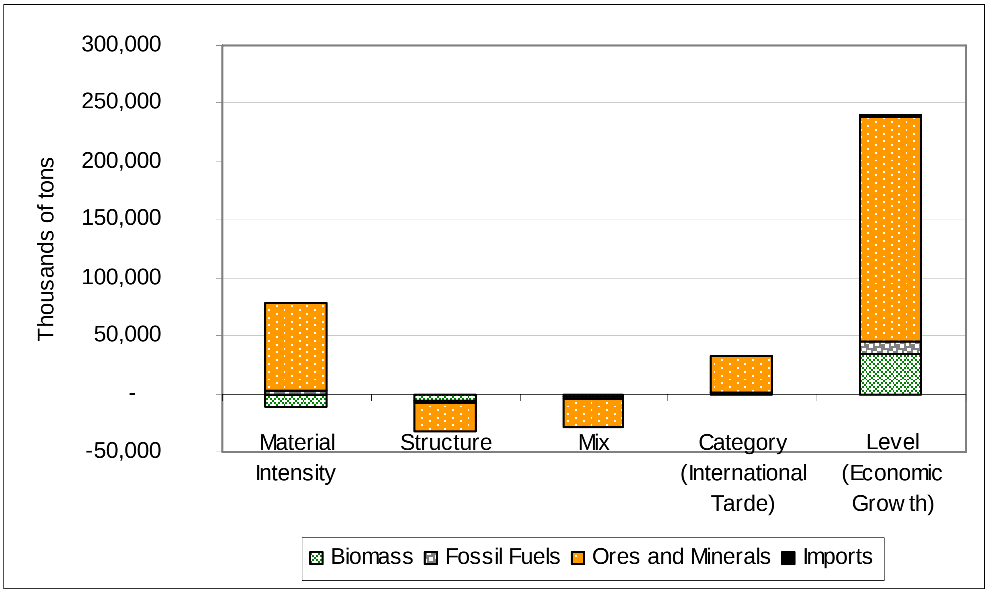
[10] For a more detailed explanation about commodity-by-commodity (or industry-by-industry formulation see Miller and Blair, 1985.

4 Results and Discussion

Previous studies on the Chilean socio-economic metabolism have shown that material requirements have increased from 221 million tons in 1986 to 500 million tons in 1996 (see Figure 1). In this section we present the contribution of the different components (material intensity, structure, mix, category and level) by commodity groups to material changes. Figure 2 gives a first overview of the contribution of the different components according to different kinds of materials. The net addition of the components is equal to the total changes in material consumption between 1986 and 1996.Furthermore, table 1 gives a comprehensive view on material changes with regards to the decomposition effects and different commodity groups for direct material inputs.

Figure 2

Contribution of different components to change in materials: 1986-1996



Note: The total change of direct material inputs was 279 millions, i.e. 500 million tons in 1996 minus 221 million tons in 1986.

Source: own calculations.

Table 1: Direct material inputs decomposed according to different driving forces and commodity groups for Chile, between the years 1986 and 1996.

Cod	Description	M. Intensity	Structure	Mix	Category	Level	Total	M. Intensity	Structure	Mix	Intern. Trade	Level	Total
		Thounsands of tons						As % of DMI used by the economy in 1986 (220.57 millions of material tons)					
1	Agriculture	389	- 1,472	- 1,224	- 61	3,385	1,016	0.18%	-0.67%	-0.55%	-0.03%	1.53%	0.46%
2	Fruit plantation	- 233	- 891	258	215	1,918	1,267	-0.11%	-0.40%	0.12%	0.10%	0.87%	0.57%
3	Livestock and forestry	- 1,520	- 269	- 735	159	4,937	2,573	-0.69%	-0.12%	-0.33%	0.07%	2.24%	1.17%
4	Fishing	- 1,219	- 235	2,093	36	1,115	1,791	-0.55%	-0.11%	0.95%	0.02%	0.51%	0.81%
5	Cooper	46,851	- 3,708	- 11,016	26,689	148,721	207,536	21.24%	-1.68%	-4.99%	12.10%	67.42%	94.09%
6	Other mines	15,560	- 2,269	- 19,531	5,572	29,629	28,962	7.05%	-1.03%	-8.85%	2.53%	13.43%	13.13%
7	Food, beverages and tobacco	- 3,797	- 9,705	- 5,023	28	22,040	3,543	-1.72%	-4.40%	-2.28%	0.01%	9.99%	1.61%
8	Manufacture of: wearing, dressing, leather and footwear	335	- 836	- 637	- 61	915	- 285	0.15%	-0.38%	-0.29%	-0.03%	0.41%	-0.13%
9	Wood products and furniture	- 187	852	103	67	1,242	2,078	-0.08%	0.39%	0.05%	0.03%	0.56%	0.94%
10	Manufacture of paper and printing products	103	- 347	- 74	105	902	690	0.05%	-0.16%	-0.03%	0.05%	0.41%	0.31%
11	Chemical, refined petroleum, rubber and plastic products	2,337	- 6,251	751	- 160	4,712	1,389	1.06%	-2.83%	0.34%	-0.07%	2.14%	0.63%
12	Other non-metallic mineral products	163	- 15	190	- 3	271	605	0.07%	-0.01%	0.09%	0.00%	0.12%	0.27%
13	Basic metals	361	- 519	607	147	925	1,520	0.16%	-0.24%	0.28%	0.07%	0.42%	0.69%
14	Metal products, machinery and equipment	533	- 1,282	- 286	- 20	1,315	261	0.24%	-0.58%	-0.13%	-0.01%	0.60%	0.12%
15	Other manufactures industries	16	- 39	36	1	30	45	0.01%	-0.02%	0.02%	0.00%	0.01%	0.02%
16	Electricity, gas and water supply	738	- 803	58	- 59	883	818	0.33%	-0.36%	0.03%	-0.03%	0.40%	0.37%
17	Construction	3,998	1,025	3,988	- 464	7,960	16,506	1.81%	0.46%	1.81%	-0.21%	3.61%	7.48%
18	Commerce, hotels and restaurants	1,015	- 1,522	2,313	- 114	3,686	5,378	0.46%	-0.69%	1.05%	-0.05%	1.67%	2.44%
19	Transport	1,121	- 1,699	325	94	1,837	1,679	0.51%	-0.77%	0.15%	0.04%	0.83%	0.76%
20	Communications	40	- 15	113	- 1	82	219	0.02%	-0.01%	0.05%	0.00%	0.04%	0.10%
21	Financial intermediation	316	94	- 249	- 37	689	813	0.14%	0.04%	-0.11%	-0.02%	0.31%	0.37%
22	Activities of private households	335	- 316	- 442	- 51	726	251	0.15%	-0.14%	-0.20%	-0.02%	0.33%	0.11%
23	Education	120	16	- 180	- 24	362	294	0.05%	0.01%	-0.08%	-0.01%	0.16%	0.13%
24	Health	216	- 526	- 76	- 51	728	290	0.10%	-0.24%	-0.03%	-0.02%	0.33%	0.13%
25	Other service activities	181	- 448	- 131	- 35	493	60	0.08%	-0.20%	-0.06%	-0.02%	0.22%	0.03%
26	Public Administration	488	- 523	- 702	- 82	1,158	339	0.22%	-0.24%	-0.32%	-0.04%	0.52%	0.15%
Total		68,262	- 31,704	- 29,471	31,890	240,662	279,638	30.95%	-14.37%	-13.36%	14.46%	109.11%	126.78%

Source: own calculations.

The results give us an assessment about the physical dimensions of the driving forces by commodity group. For the study period, the level effect was the main driver. Note that the level component can be seen as a proxy variable of ‘economic growth’. Thus, if the Chilean economy had been grown with the identical levels of material intensity, structure, mix, and category than it had in 1986 the material use would have increased by 240.66 million tons (or 109% as a percentage of material used in 1986); Copper (67%), Other mines (13%), Food, beverages and tobacco (10%), Construction (3,61%), Livestock and forestry (2%) and Chemical, refined petroleum, rubber and plastic (2%). These commodities together explain 99% of the 109% of the increase in material use since 1986 (see table 1).

This matches with findings of other studies reporting the level effect as the major driving force. For example, for the Netherlands, the change of CO_2 emissions between the years 1987-1998 was mainly due to the level effect explaining 35% of the change (De Haan 2001). In the case of Germany, the level component explains 13% of the changes in total material requirements for the period 1980-1990 (Moll et al., 1998)[11].

For the case of Chile the direct material inputs by economic growth (240.66 million tons) during that time period was larger than the all material required to sustain the socio-economic metabolism in 1986 (220.57 million tons). In other words, the production level has more than doubled with a growth rate of around 10% annually. As we have mentioned in section 2 this has been strongly encouraged by a set of liberalization measures. While GDP was increasing by this high annual growth rate, the material inputs required to sustain this economic growth have also increased by about the same rate. Despite the inherent relationship between economic growth and environmental stress (see for example Arrow et al., 1995) and one to one link between economic growth and environmental destruction is not given and various extends of linking and delinking of growth and destruction can be observed for countries during different development stages and contexts (see the extensive literature on the EKC, e.g. Selden and Song, 1994; Roca et al., 2001; Seppälä et al., 2001). Thus, the policy context is of

[11] The economic growth for these economies, Netherlands and Germany, was on average of 3.1% and 2.3 for the periods under study, respectively.

considerable importance - economic policies oriented towards economic growth can lead to an intensification of resource use, as seen in the case of Chile, if the growth is not accompanied by appropriate environmental legislation. The policy context is not only important for stirring economic growth and its environmental implications but for other decomposition elements as well.

The trend described above has been reinforced by 'category effects', which have contributed 31.89 million tons of material use during this time period. It means that, exports explain 14% of the change in material consumption. This situation is mainly caused by the following industries: Copper (12%) and Other mines (2%).

Nevertheless, we would like to highlight that it does not mean that just 31.89 millions of material tons are necessary to supply to foreign demand. As we have mentioned before, the Chilean exports caused 80% (399 millions of materials) of the direct material inputs into the economy in 1996 (Muñoz and Roca, 2006). It is important to note that the "category effect" (or international trade effect) measures only the change of the share of exports within total final demand for 1996 with respect to the base year, in this case 1896[12]. The empirical results showed that the share of exports within final demand increased for the period under study. Thus, the material consequences of these changes required 31.89 millions of material tons, which is an increase of 14% in the material consumption as a percentage of material used in 1986.

On the other hand, these effects were partly compensated by 'mix effects' due to changes in final demand composition which decreases the material pressure by 29 million tons (14% as a percentage of materials used in 1986). The material decrease described by the mix effect is mainly caused by reduction in the share of Copper, Other mines and Food, beverages and tobacco commodities in total final demand. This material savings are partly compensated by increases in the consumption of other materials, which are triggered by the following commodity sectors: Construction, Commerce, hotels and restaurants and Fishing.

[12] If we were measure this component in 1996 with respect to 1973, when the first liberalizations measures took place and the exports represented 10% of the total final demand, the international trade effects would have been considerably different and most probably larger.

The ‘structure effect’, reflecting on changes in the intermediate production structure of the Chilean economy, has also shown important savings in materials use of 31.7 million tons (14% as a percentage of materials used in 1986). These material savings are mainly explained by the following commodity groups: Food, beverages and tobacco, Chemical, refined petroleum, rubber and plastics, Copper, and Other mines. It is interesting to note that over time the productive processes have been reducing the inputs requirements in various industries.

Finally, the ‘material intensity effect, reflecting on the change in material requirement per unit of output, has contributed to the increase in material consumption most significantly by adding 68 millions tons or 31% during this time period. This is mainly due to developments in the Copper and Other mine commodities. This very interesting finding is due to the fact that metal concentration in the minerals has been decreasing, that means that larger quantities of ore are necessary in order to produce a certain level of useful materials. Our suggestion is that further decomposition is needed for this specific case. However, when focusing the analysis on specific material categories, for example biomass, we find that considerable reductions took place in most commodities for biomass consumption per unit of output, especially Food, beverages and tobacco (a reduction of 5.7 million of biomass tons, i.e. 15%, as percentage of biomass used by the economy in 1986, 38.93 millions of tons), Livestock and forestry (1.6 million of biomass tons), and Fishing (1.2 million of biomass tons).

5. Final Comments

During the time period from 1986 to 1996 Chile's socio-economic systems required an additional 279 million tons of materials and thus more than doubled its metabolism (increase of 127%). At the same time we could observe a strong economic growth (with an average rate of 10% annually) thus leading to an increase of income per capita from 2,910 US$ in 1986 to 5,310 US$ in 1996.

These findings have shown the driving forces behind increasing material consumption: economic growth, international trade as well as increase in material intensity. It was mainly the nature of this economic growth with a focus on primary commodities. The increase in material intensity was due to the fact that the quality of metal ores, especially copper, is decreasing and more materials are needed per unit of useful ores and thus per unit of output.

These resource intensification trends were partly offset by the net mix effect in final demand, indicating a change towards more environmentally friendly commodities: for example, reducing the share of Copper and Other mine commodity groups in total final demand, but at the same time partly compensated by shifts towards biomass-intensive commodities such as Fishing or Fruits plantation.

Similarly, also the structure effect contributed to some delinking of production and material consumption. This decoupling trend for the structure effect can be observed in almost all commodity groups. This can partly be contributed to the competitive pressure increasing efficiency but also to specific economic incentives which are designed to increase material efficiency and thus help to achieve material savings.

Considering the periods from 1997 to 2005, it is important to note that the Chilean economy has been growing on an average of 3.94 % per year; a considerable number of free trade agreements took place during that time period (see section 2.1). Both of these factors likely had a major effect on the environment. However, there were no data available to analyze the past decade. To face the future, it is necessary to formulate policies considering both economic and environmental aspects in order to alleviate environmental pressures.

The usefulness of environmental extended Input-Output (EEIO) analysis for analyzing environmental issues has received increasing attention in the recent past (see for example Tukker et al., 2006). Static EEIO has been used, amongst other purposes, to identify the so-called 'hot spots', which are those product groups that use relatively large quantities of material-energy in comparison to other product groups. Thus, this information should inform integrated product policies in order to reduce environmental pressures (material consumption) caused by the production and consumption of these products. Furthermore, through combining SDA and material flows it is possible to understand the underlying driving forces which cause changes in material use at the product group level. This knowledge about driving forces by product groups offers additional relatively detailed information about variables and their environmental impacts over time.

Two strategies are often recommended to lead an economy towards less material intensive economic growth: vertical diversification, which calls for downstream processing of raw materials by increasing the created value added per resource unit (Bocoum-Kaberuka, B., 1999); and horizontal diversification (Zhang, L., 2003), which mainly refers to producing a growing range of (preferable less material intensive) commodities within a given economy (e.g. switching to tourism, financial or other services sectors). In order to assess one the potential paths, it is necessary to take into account theses indicators, in physical units, as a part of a sustainable development strategy considering environmental and economic affairs. In addition other indicators, social, economic and environmental need to be included in the analyses to allow for a more complete evaluation of these strategies and policies.

Finally, it is important to mention that the latter strategies ignore the fact that this probably only involves a shift of the environmental effects to those countries that then end up providing the more material intensive products. The former strategy intends to shift higher end production from other countries to the resource extracting economy. On a global scale both strategies are only part of a zero-sum situation that can only be improved by shifts in lifestyles and improvements in resource efficiency. Thus despite the holistic view of monetary combined with biophysical input-output analysis one needs to maintain the larger picture and consider environmental effects beyond the boundary of the respective country.

Acknowledgment

We would like to thank especially Stefan Giljum and two anonymous referees for their helpful comments and suggestions. Pablo Muñoz thankfully acknowledges the scientific and technical support provided during his research period at the School of the Environment at University of Leeds. In addition, we would also like to thank Andy Dougill from the School of the Environment for graciously removing all administrative hurdles.

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