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The dynamics of industrial energy consumption in Latin America
and their implications for sustainable development

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This article analyses the relationship between energy consumption in industry and industrial productivity and the implications of this for sustainable development. To this end, it presents a matrix characterizing economies as: (i) converging or diverging in terms of energy consumption per unit of value added, and (ii) catching up with or falling further behind the productivity level of the international frontier (the United States). On the basis of data from the industrial surveys of four Latin American countries (Brazil, Chile, Colombia and Mexico), it concludes that the region's evident specialization in natural resource-intensive sectors has contributed to a pattern of high energy consumption and slow productivity growth, and that while there is no productive convergence, there is evidence of energy sustainability in three of the four countries analysed.

I

Introduction

A central theme in current economic development discussions is the growing energy demands of industrial production systems and the environmental consequences that ensue. In particular, it is argued that developing countries cannot replicate the industrial processes followed by the developed economies, and that a sustainable structural shift is therefore needed to generate a process of virtuous development, given the negative environmental impacts generated by the most polluting energy-intensive processes and the clear upward trend of long-run energy prices.

It is thus important to analyse a country's industrial energy consumption in combination with the industrial structure prevailing there. While industrial energy consumption accounts for about 30% of the total in both the United States and Latin America, the importance of industry, with its traditional role in generating technical progress and spreading it to other sectors of the economy, makes it a crucial sector for the production of innovations that can offset environmental impacts and reduce energy consumption—both its own and that of other sectors.

The relationship between energy consumption in industry and the associated growth in industrial value added has been thoroughly discussed in the literature on the stages of the industrialization process in developed countries, and the issue is now becoming critical once again for developing economies as industry advances at the periphery.

The relationship between the amount of energy consumed and the development level attained by a society is neither unequivocal, one-directional nor universal. Disparities in timing and between different production spheres appear to be due, first, to technological choices that are critical to the sectoral structure of industry and, second, to the way resources are used. Thus, the technological choices of production agents affect both the amount of energy they consume and their levels of productivity and competitiveness. A twofold economic policy challenge thus arises, since the technological choices of individual countries' production systems ought to be efficient in terms of productivity while ensuring rational energy use.

Productive efficiency reflects the degree of technical progress and is usually described using the dynamic of labour productivity. The trend of energy consumption indicates the relationship between a country's energy usage and its economic development over time. When the growth of energy consumption in the production structure is decomposed, the technological factor that measures energy intensity by sector provides information about the quantity of energy required, directly and indirectly, to produce a unit of industrial value added (IVA). In turn, this relationship is affected by production scale and the different fuels used in the production process.

Although the energy industry reform and modernization processes that took place in the region subsequent to the debt crisis (starting in the mid-1980s in some cases and the 1990s in others) will not be analysed in detail for each country, it is necessary to be aware of them when seeking to explain decision-making by economic agents, and also when analysing the developments and processes involved in the substitution of energy sources. Thus, for the countries studied in this paper, the main reforms can be summarized as follows (OLADE/ECLAC/GTZ, 2003; Altomonte, 2010):

— There has been a complete restructuring of the electricity chain, from generation to distribution, in Chile and Colombia, and the same is true to a lesser extent of generation in Brazil and Mexico, which has been partially opened up to the private sector.

— In Chile, while locally produced oil is used in the energy matrix, the oil industry has not been privatized, and this is also the case in Mexico. In Brazil, although Petrobras is still State-owned and is one of the leading "trans-Latins" in the region, different parts of the industry have been opened up to private-sector participation, and this has also happened in Colombia.

This article aims to conduct a comparative analysis of industrial energy consumption by sector and of productive efficiency in Brazil, Chile, Colombia and Mexico relative to the technology frontier, with a view to ascertaining whether these countries are catching up with global best practice or falling further behind. These four countries were chosen in view of the data available, since only a few countries collect information on energy consumption by manufacturing sector in their

industrial surveys.[1] This dearth of data also limits the period of study, which will centre on the decade from 1997 to 2006.

This document is structured as follows. Section II presents a typology of productive development patterns by performance level and relationship with energy consumption, allowing the specific energy-use and sectoral trajectories of the countries studied to be compared. It also specifies the decomposition methodology employed to explain the different factors influencing the evolution of energy consumption. Section III analyses the dynamic of the industrial sector in Brazil, Chile, Colombia and Mexico and in the United States, which is the frontier. Section IV provides a description of the general energy situation in the four countries discussed. It also establishes the contribution of the dominant energy sources to CO_2 emissions. Section V carries out a more thorough analysis of the evolution of energy consumption in the industrial sector within the four Latin American countries, decomposing this sector into three groups of subsectors: engineering-intensive, natural resource-intensive, and labour-intensive. The final section sets out the general conclusions drawn from the analysis presented in the earlier sections.

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[1] The industrial surveys that will be used are as follows. Brazil: the Annual Survey of Industrial Companies carried out by the Brazilian Geographical and Statistical Institute (IBGE); Chile: the National Annual Manufacturing Industry Survey (ENIA) carried out by the National Institute of Statistics (INE); Colombia: the Annual Manufacturing Survey (EAM) of the National Administrative Department of Statistics (DANE); Mexico: the Annual Industrial Survey (EIA) of the National Institute of Statistics and Geography (INEGI); United States: the Survey of Current Business conducted by the Bureau of Economic Analysis (BEA) of the Department of Commerce.

II

General development patterns: the productivity gap and the energy gap

When the trajectory of Latin America is analysed from a long-run perspective, what emerges is that the region has not succeeded in reducing the per capita income differences separating it from the developed world. This has been a key concern at ECLAC from its earliest formulations right down to the most recent documents.

Increasing concern about the environment has thrown up new questions and challenges regarding the attainment of a more sustainable growth pattern. It has been argued that energy intensity ought to display a long-run evolution similar to a curve that is concave to the origin (an inverted U).

At the sectoral level, the basis for this evolution is that the industrialization process usually evolves from industries that are highly intensive in natural resources (such as the iron, steel and other metal industries) towards industries that are far more technology-intensive (the aeronautical industry, for example). Because of the technical characteristics of their production processes, natural resource-intensive industries are far more energy-intensive[2] than technology-intensive industries. Consequently, energy consumption ought to rise during the early stages of development (as natural resource-intensive industries prosper) before stabilizing and finally declining with the incorporation of more technology-intensive sectors, whereupon the industrialization process is complete.

At the level of agents, observation of the introduction of technological change in firms over the long term could also account for changes in energy intensity. Thus, the first wave of technological change would take the form of an automation process replacing labour by machinery (thus increasing energy consumption). Once automation of the stages in the production process was complete, however, the next technological leap would consist in digitalizing these and centralizing all information in a computer that improved the efficiency of the process. This improvement would be likely to yield energy savings as well. From this perspective, then, the pattern of innovation would also be associated with greater energy use in the early stages (automation) and lower (or at least not rising) use during the subsequent

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[2] Basic iron, steel and other metal industries are a clear example, as high temperatures (caloric energy) are needed to forge metal, so that these industries consume a great deal of energy and count as energy-intensive.

stages (digitalization) thanks to the optimization of production processes.

The production structure and the dynamic of productivity relative to the technology frontier is a recurring concern in the debate about the region's development. By focusing on sustainable productive development, this line of inquiry opens up a broader debate. What type of transformation in the production structure accompanies or leads to energy convergence or divergence? To what extent does the predominant structure in the region's economies tend to maintain not only the productivity gap relative to the frontier, but the energy gap too?

In relation to these questions, figure 1 distinguishes four situations:
— A virtuous development model: closing of the energy and productivity gap (catching up) (upper right-hand quadrant).
— Model in which the productivity gap narrows, but unsustainably: relative productivity catches up but with expanding energy consumption patterns (upper left-hand quadrant).
— Sustainable model with a widening productivity gap: this gap increases while energy consumption patterns converge (lower right-hand quadrant).

— Vicious development model: widening energy and productivity gaps (falling behind) (lower left-hand quadrant).

The problem the Latin American economies face will depend on where they are situated in these quadrants. To achieve a virtuous development pattern that is sustainable over time (upper right-hand quadrant of figure 1), there needs to be a process of structural change that narrows productivity differences (technical change) together with a path of lower energy consumption per unit of output. This structural change obviously does not always operate in the right direction, so that one of the other three possible trajectories may be followed instead.

The opposite situation to the virtuous pattern would involve a situation in which the production structure specializes in sectors that are technologically less dynamic, leading to a widening of the productivity gap and to higher energy consumption than in the developed economies (bottom left-hand quadrant). This creates the classic problem of productivity divergence with a pattern of energy consumption that is unsustainable over time.

A situation can also arise in which efforts are concentrated on modifying energy consumption patterns with a view to incorporating lower-intensity energies

FIGURE 1

Matrix of productive development and energy sustainability
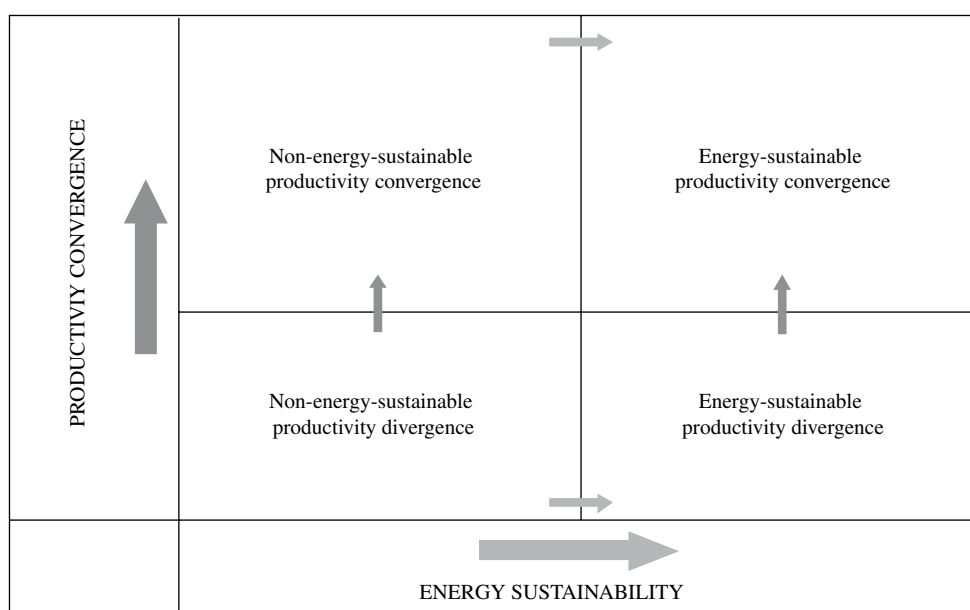
Source: prepared by the authors.

that are, however, less efficient in production terms, so that the productivity gap relative to the frontier widens (lower right-hand quadrant).

Lastly, there is the possibility of having a more technology-intensive specialization pattern that narrows the productivity gap but increases energy consumption (upper left-hand quadrant). An approach that is strongly geared towards production rather than energy goals results in this kind of trajectory. A situation of this type would call for higher spending on more energy-efficient technologies (oriented towards efficient recycling of materials, lower-emission technologies or both), resulting in lower energy intensity.

Thus, the schema put forward implies different development trajectories associated with two indicators: the productivity gap and the energy gap. This schema will be used in the sections that follow as an analytical reference framework to describe the energy and production situation of industry in the Latin American countries selected.

III

The dynamic of the industrial sector in Latin America

Between 2003 and 2007, Latin America experienced a period of high growth in a context of strongly rising raw material prices and a greater degree of openness in its constituent countries.[3]

As table 1 shows, total gross domestic product (GDP) expanded by 5.5% a year, while per capita GDP increased by 4.2% a year, a growth rate matched only in the 1970-1980 period.

At the same time, the manufacturing sector, which had lost its role as the "engine of development" since the 1970s, was more dynamic than agriculture and mining between 2003 and 2007 (see table 2). The result was a slowing of the downward trend in the industrialization coefficient that had been a characteristic of the region since the mid-1970s. Indeed, the share of industry in national value added has actually risen in a number of countries.[4]

This new dynamism in manufacturing presents some characteristics worth highlighting. The ongoing destruction of productive and technological capabilities and production linkages, together with a decline in research and development (R&D) spending and increased imports of high-technology goods over the 1980s and 1990s, gave rise to a new model of production organization.

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[3] The "degree of openness" can be measured by calculating the ratio between the sum of exports and imports and gross domestic product (GDP).

[4] These are Argentina, Colombia, Costa Rica, Ecuador, Nicaragua, Peru, the Plurinational State of Bolivia and Uruguay.

TABLE 1

Latin America (18 countries[a]): average annual growth rate, five subperiods

	1970-1980	1980-1990	1990-1997	1997-2003	2003-2007
Total GDP	5.9	1.2	3.7	1.4	5.5
Per capita GDP	3.3	-0.8	1.9	0.0	4.2
Total exports			8.7	5.1	8.4
Total imports			13.3	2.2	13.6

Source: Economic Commission for Latin America and the Caribbean (ECLAC).

GDP: gross domestic product.
[a]   Argentina, Bolivarian Republic of Venezuela, Brazil, Chile, Colombia, Costa Rica, Dominican Republic, Ecuador, El Salvador, Guatemala, Honduras, Mexico, Nicaragua, Panama, Paraguay, Peru, Plurinational State of Bolivia and Uruguay.

TABLE 2

Latin America: gross domestic product (GDP), three subperiods
(Average annual growth rate)

	1990-1997	1997-2003	2003-2007
Total GDP	3.7	1.4	5.5
Agriculture	2.4	3.3	3.5
Mining	4.2	1.3	1.5
Industry	3.3	0.5	5.4
Electricity	4.8	2.3	5.2
Construction	4.0	-0.8	8.2
Commerce	3.7	0.8	6.9
Transport	5.9	4.2	8.1
Financial institutions	3.1	2.3	6.3
Community and social services	2.3	1.7	3.3

Source: Economic Commission for Latin America and the Caribbean (ECLAC).

Although technology-intensive sectors have achieved higher growth rates than other groups of industrial sectors in a number of the region's countries, this good performance has not been enough to restore their share of the economy to what it was in periods prior to the 1980s. Furthermore, this loss of technological capabilities also seems to have gone along with a dramatic decline in institutional capabilities within the public sector (Katz and Stumpo, 2001).

Consequently, the production base associated with the growth process in the 2003-2007 subperiod was qualitatively very different from that which existed in the region in previous decades, as was the institutional production development context that might have accompanied and guided that process. The fact is that when some of the region's countries have tried to implement industrial development plans in recent years, they have encountered major difficulties at the design stage and insurmountable obstacles to implementation because of their loss of institutional capacity.

The countries where technology-intensive sectors have achieved a higher share (approximately 40% of industrial capacity) are Brazil and Mexico (see table 3). Despite their similarity, however, the policies applied have been profoundly different in the two cases: while industrial production in Brazil has been oriented towards the domestic market and its economy has become less open than it was, Mexico has opened up further and implemented a policy to encourage export manufacturing industry and integration into international production chains.

TABLE 3

Latin America (selected countries): industrial value added share of technology-intensive sectors, 1970-2007
(Percentages)

Country	1970	1980	1990	1997	2003	2007
Brazil	22.0	32.3	27.8	33.7	33.2	39.6
Chile	16.6	11.0	10.2	12.4	11.3	11.6
Colombia	11.3	11.3	10.4	12.4	11.2	12.3
Mexico	20.2	26.9	26.3	30.5	33.0	41.3

Source: prepared by the authors on the basis of the Industrial Performance Analysis Program (PADI) of the Economic Commission for Latin America and the Caribbean (ECLAC).

The almost total absence of active industrial development policies[5] in the stage of growth from 2003 to 2007, together with the profound transformation of the production base in earlier decades, meant that the rise in output achieved in technology-intensive sectors (and manufacturing more generally) was essentially quantitative, there being no true process of technological capacity-building.

The consequences of this situation can be appreciated in two quite different aspects. The first is a country's position in the world economy and its industrial trade balance, and the second is the evolution of productivity.

The increasing importance of the external sector has been reflected by a rise in industrial export and import ratios. In particular, the increase in the latter between 2003 and 2007 reveals how much the industrial production system is struggling to compete in most sectors. This is especially evident in the case of technology-intensive sectors, but is also true of labour-intensive sectors exposed to competition from new producers, especially in the Asian countries.

The result of this weakness is that, in a context of steadily rising domestic demand, industrial trade balances are presenting growing deficits or substantially lower surpluses (see table 4).

These deficits were offset in those years by high prices for the agricultural and mining products exported by the region. This situation is unlikely to be sustainable in the medium and long run, however, considering the openness of the region's economies and the volatility of raw material prices, something that has been confirmed by the international crisis which broke out in September 2008.

[5] The major exception in this case is Brazil.

TABLE 4

Latin America (18 countries[a]): industrial trade balance, 1970-2007
(Millions of current dollars)

Sector	1970	1980	1990	1997	2003	2006	2007
Technology-intensive sectors	-5 522	-28 686	-21 378	-56 934	-22 779	-66 752	-90 620
Natural resource-intensive sectors	2 092	2 726	17 818	1 446	8 283	37 527	31 058
Labour-intensive sectors	-530	-1 132	1 037	-8 928	-10 803	-22 035	-29 943
Total	*-3 960*	*-27 092*	*-2 523*	*-64 416*	*-25 299*	*-51 261*	*-89 505*

Source: Foreign Trade Data Bank for Latin America and the Caribbean (BADECEL) of the Economic Commission for Latin America and the Caribbean (ECLAC).

[a] Argentina, Bolivarian Republic of Venezuela, Brazil, Chile, Colombia, Costa Rica, Dominican Republic, Ecuador, El Salvador, Guatemala, Honduras, Mexico, Nicaragua, Panama, Paraguay, Peru, Plurinational State of Bolivia and Uruguay.

The phase of growth in the economy and the industrial sector over recent years does not seem to have translated into major structural changes, and the aspects mentioned in relation to the industrial trade balance are largely a reflection of this.

To gauge the outcome of the process of transformation in the production structure, consideration has been given, first, to the industrial value added (IVA) shares of the three categories of sectors into which the industrial production system has been subdivided (technology-, natural resource- and labour-intensive sectors) and, second, to the productivity of these groups of sectors. The changes made in some of the region's countries in the 1997-2006 subperiod have been compared with the changes that took place in the production structure of the United States over the reference period used by this study to analyse sectoral energy consumption.

Figures 2 to 5 show, first, that the productivity increases achieved by the United States were much greater than those achieved by the region's countries in all the groups of sectors considered, especially the technology-intensive ones. The differences are not confined to productivity increases, however, but also concern the composition of the production structure.

In the United States, technology-intensive sectors account for 53% of industrial value added (IVA), and in 2006 they had higher productivity than the other groups of industrial sectors. Technology-based industries create knowledge spillovers for the rest of the production structure, helping to increase the productivity of the whole industrial structure. As a result, the structural transformation in the United States has been associated with a general increase in productivity across the whole economy.

On the whole, the sectors that are most productive and contribute most to the creation of manufacturing value added are natural-resource intensive ones (with the
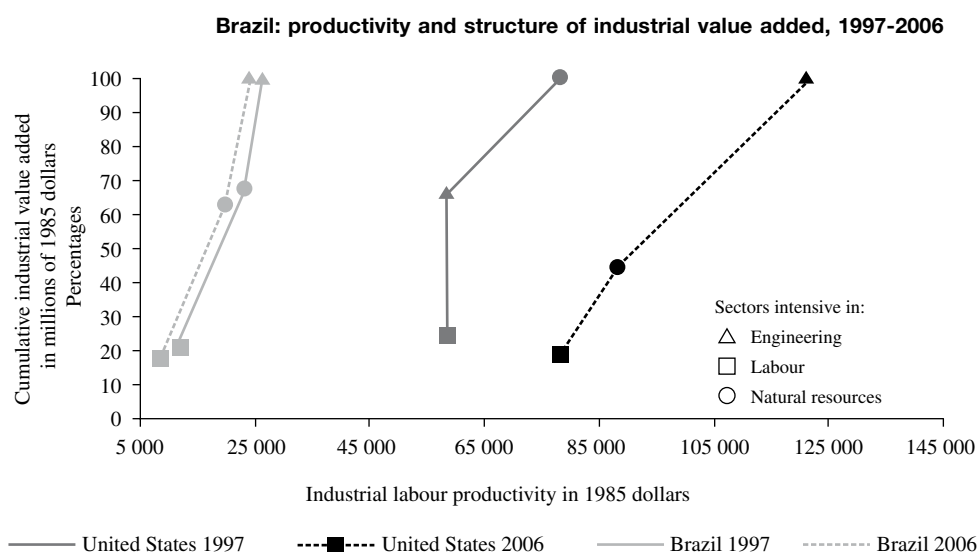
exceptions of Brazil and Mexico in 2006). Consequently, the production structure has not been favourable to growth in technological activities and those that spread knowledge and enhance technological capabilities.

Chile and Colombia have been increasing their productivity in all sectors, but the structure of their manufacturing value added has been much more concentrated in these natural resource-intensive sectors. Brazil and Mexico are partial exceptions because they present much less uniform productivity dynamics, and also because technology-intensive sectors still account for a large share of the industrial base, certainly by comparison with the other cases.

In the case of Brazil, the discouraging labour productivity results are due to the very large increase in the number of workers employed by industry, up from 4.9 million in 1997 to 6.5 million in 2006, reversing the labour expulsion trend that had been seen since 1986, a few years after the debt crisis. In addition, most Brazilian firms have oriented their restructuring processes towards greater efficiency, prioritizing modernization via imports of capital goods and the introduction of new organizational techniques. Willingness to invest in R&D has been quite limited, and in general the country's export profile has not undergone major changes, being still based mainly on the production of industrial commodities (Ferraz, Kupfer and Serrano, 1999).

In the case of Mexico, there has been a large rise in the productivity of engineering-intensive sectors, which became the most productive in 2006. These sectors appear to be closely associated with the integration of international production value chains, participating in links with lower value added and innovation capacity and having a clear efficiency orientation, but without producing spillover effects for aggregate industrial productivity. Despite the increasing weight of engineering-intensive sectors,
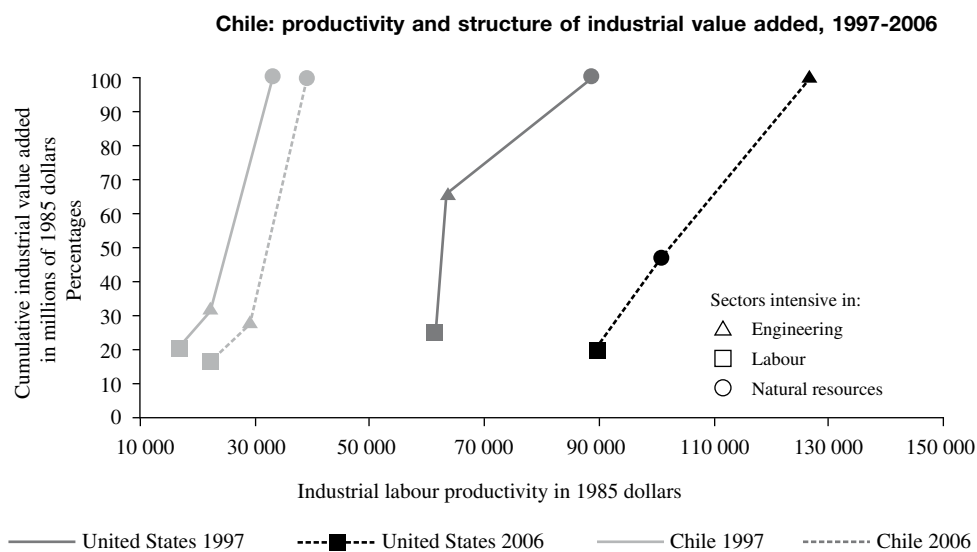
FIGURE 2

Brazil: productivity and structure of industrial value added, 1997-2006

Source: prepared by the authors on the basis of the Industrial Performance Analysis Program (PADI) of the Economic Commission for Latin America and the Caribbean (ECLAC).
Note: The horizontal axis shows labour productivity in constant 1985 dollars and the vertical axis the cumulative share of total industrial value added. The square represents labour-intensive sectors, the circle natural resource-intensive sectors and the triangle engineering-intensive sectors.

FIGURE 3

Chile: productivity and structure of industrial value added, 1997-2006

Source: prepared by the authors on the basis of the Industrial Performance Analysis Program (PADI) of the Economic Commission for Latin America and the Caribbean (ECLAC).
Note: The horizontal axis shows labour productivity in constant 1985 dollars and the vertical axis the cumulative share of total industrial value added. The square represents labour-intensive sectors, the circle natural resource-intensive sectors and the triangle engineering-intensive sectors.

FIGURE 4

Colombia: productivity and structure of industrial value added, 1997-2006
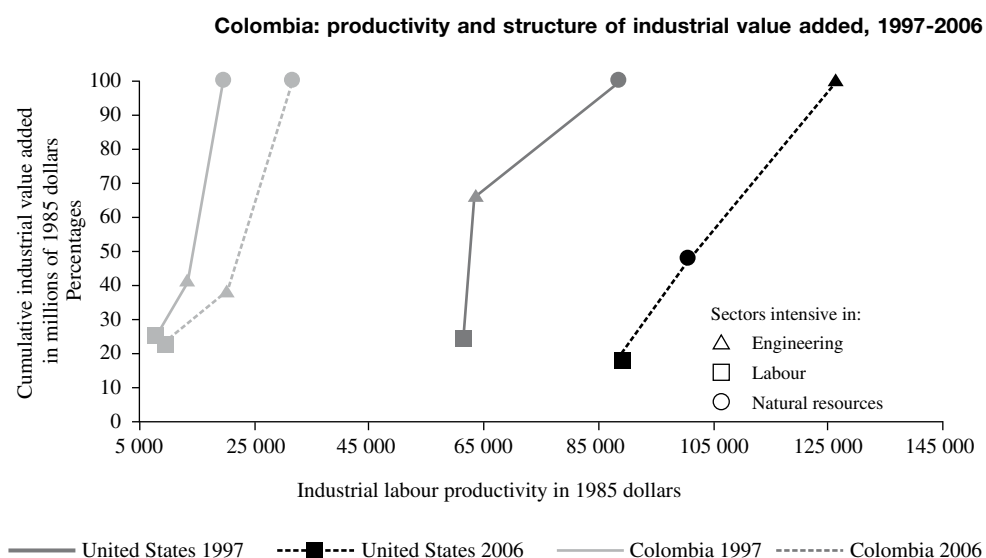

Source: prepared by the authors on the basis of the Industrial Performance Analysis Program (PADI) of the Economic Commission for Latin America and the Caribbean (ECLAC).
Note: The horizontal axis shows labour productivity in constant 1985 dollars and the vertical axis the cumulative share of total industrial value added. The square represents labour-intensive sectors, the circle natural resource-intensive sectors and the triangle engineering-intensive sectors.

FIGURE 5

Mexico: productivity and structure of industrial value added, 1997-2006

Source: prepared by the authors on the basis of the Industrial Performance Analysis Program (PADI) of the Economic Commission for Latin America and the Caribbean (ECLAC).
Note: The horizontal axis shows labour productivity in constant 1985 dollars and the vertical axis the cumulative share of total industrial value added. The square represents labour-intensive sectors, the circle natural resource-intensive sectors and the triangle engineering-intensive sectors.

the industrial fabric still includes a large percentage of natural resource-intensive sectors.

The aspects mentioned make it clear that technological change in industry in these Latin American countries has been limited and inadequate when set against the need for a production structure that is more open and integrated into international trade. This situation could become even more difficult in an international context where, for a number of years now, technologies and production methods have been changing because of increasing incorporation of information and communication technologies (ICTs) into production processes.
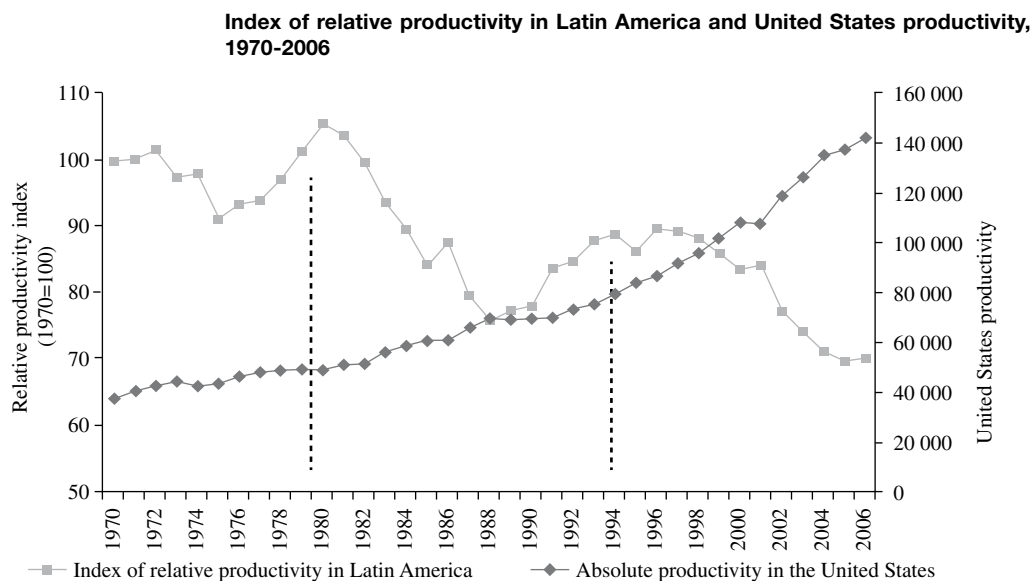
The comparison between productivity levels in the region's countries and in the United States gives some idea of the scale of the challenges ahead. The evolution of Latin America's relative labour productivity index[6] in the industrial sector shows that there was no

narrowing of the productivity gap throughout the period considered (see figure 6).

The productivity gap tended to widen in the 1980s, before narrowing in the 1990s. Since the mid-1990s, however, the relative productivity index has been falling again (meaning that the gap has widened). It should be noted that the decline was particularly pronounced in the last six years of the period studied, and there are two reasons for this. First, labour productivity in the industrial sector of the region's countries increased by 2% a year between 2003 and 2007, the worst performance for this indicator in the past 36 years, with the exception of the "lost decade" of the 1980s. Second, after standing at about 3% a year for 20 years, the productivity growth rate in the United States accelerated to some 5% a year in the mid-1990s. This second development, the faster pace of productivity growth in the United States, appears to be associated with the increasing incorporation of the new ICT paradigm into the country's production processes (Oliner, Sichel and Stiroh, 2007). Consequently, the "acceleration" of the productivity growth rate in the United States is mainly due to the transformation of the country's industrial structure and the incorporation of new paradigms into it, ICTs in particular.

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[6] This is an index (base 1970=100) constructed from the ratio between labour productivity in Latin America and labour productivity in the United States.

FIGURE 6

Index of relative productivity in Latin America and United States productivity, 1970-2006

— ■ — Index of relative productivity in Latin America   — ◆ — Absolute productivity in the United States

Source: prepared by the authors on the basis of the Industrial Performance Analysis Program (PADI) of the Economic Commission for Latin America and the Caribbean (ECLAC).

IV

The structure of energy consumption in Brazil, Chile, Colombia and Mexico

The industrial sector is the largest consumer of energy in Latin America, accounting for 37.1%, followed by the transport sector, with 35.4% of the region's total energy consumption in 2007. In the same period, the residential sector accounted for 17.4% and the other sectors for the remaining 10% of energy consumption (see table 5). In the United States, industry was also the largest user that year, being responsible for 33% of all energy consumption, while transport consumed 29%, residential users 21% and other users 17%. The country's consumption structure is thus slightly different from Latin America's, although the share of the industrial sector is around 33% in both economies (EIA, 2009).

To analyse the importance of industrial consumption in the region as a whole, and the selected countries in particular, it is necessary to take account of certain problems with the quantification of consumption associated with the manufacturing sector, since in many countries the sectoral allocation of energy consumption may be inaccurate. For example, mining and metallurgical complexes are aggregated, so that consumption in the primary production phases (mining) is not distinguished from consumption in the processing stage (manufacturing). The same can happen with some agro-industries. In any event, it can be seen that the energy consumption share of industry in the different countries compared is quite homogeneous, with the exception of Brazil. In this context, it is possible to characterize a specific group of countries where industrial energy consumption is below

the regional average, with transport taking a larger share. This is the case with Chile, Colombia and Mexico. Brazil is an example of the opposite, with industry exceeding the regional average and having the largest share of any sector of the economy.

The overview of energy consumption in the industrial sector specifies the matrix of the different energy source it uses, and thus provides valuable information on the energy variables determining both the sector's energy intensity and its carbon (CO_2) emissions. Consumption of primary energy has declined relative to that of secondary sources, but still accounts for about a quarter of the total.[7] Of all primary energy sources, the one most used in industry is natural gas, followed by wood and sugar cane. The predominant secondary sources are electricity together with petroleum derivatives (petrol, diesel and fuel oil) and coke, both the latter being major components of industrial consumption.

As regards total energy consumption, a number of processes of substitution between sources have taken place since 1980 (Altomonte, 2008). The reduction in primary energy consumption has been driven by substitution of biomass in general and wood in particular, and this drop has not been fully offset by the rise of natural gas, even

[7] By primary energy is meant the different energy sources as found in their natural state, whether directly (as in the case of hydraulic and solar energy, wood and other plant fuels) or after extraction, as in the case of oil, coal, geoenergy and others (OLADE, 2006).

TABLE 5

Latin America: structure of energy consumption, 2007
(Percentages)

Region/country	Transport	Industry	Residential	Commercial, public services	Agriculture, fishing, mining	Construction and other
Latin America and the Caribbean	35.4	37.1	17.4	4.9	4.9	0.3
Brazil	31.9	43.6	12.3	5.3	6.9	N/A
Chile	38.6	32.7	23.8	4.8	N/A	0.1
Colombia	40.3	25.0	23.1	5.4	5.4	0.8
Mexico	48.5	28.2	16.6	3.4	3.0	0.3

Source: prepared by the authors on the basis of data from Latin American Energy Organization (OLADE), "Energy-Economic Information System", April 2010.
N/A: Not available

though its share in the composition of final consumption has doubled (Altomonte, 2008). The expansion of natural gas has been due above all to the extensive substitution of fuel oil in the industrial sector and in electricity generation. It has also penetrated the residential sector, albeit to a lesser extent, owing to continuing urbanization and expansion of distribution networks.

The growth of electricity coverage and continuing urbanization account for the substantial penetration of electricity in the total consumption equation, with its share rising from just over 9% in 1980 to almost 16% in 2006 (see table 6). Lastly, there is the strong expansion of liquefied petroleum gas (LPG), whose share has almost doubled, and the "dieselization" of transport, especially cargo transport, which has driven the substantial rise in the share of diesel oil (categorized among other secondary sources).

As regards renewable sources, despite some interesting regulatory efforts to encourage their application, their share of the total energy supply held practically steady at 25.7% between 2002 and 2005. The predominant renewable sources are hydropower, wood and sugar cane products. For now, geothermal, wind and solar energy play only a marginal role.

As suggested earlier, the energy mix in each country is an important factor when it comes to assessing carbon emissions and energy intensity in industry. In other words, both energy intensity and its relationship to the environment are affected by the composition of the different fuels employed in the region's industries.

Table 7 presents the relationship between calorific power and the quantity of CO_2 emissions for each type of energy source. This table indicates that a barrel of oil (159 litres) emits 116.2 grams of CO_2. The same amount of energy could be obtained with 165.2 cubic metres of natural gas, which however would only produce 88.9 grams of CO_2.

Table 7 shows that the different energy sources can be classified into three major groups by CO_2 emissions level. The least polluting energies group includes natural gas, liquefied gas and electricity.[8] The intermediate group comprises all oil derivatives. Lastly, the most polluting energies group contains all products related to coal (including coke).

It can be deduced from the above that countries consuming more natural gas have lower industrial emissions than those relying heavily on energy sources derived from oil or coal. Consequently, the choice of energy sources will be a key factor, and it will depend not only on the calorific needs of industry, environmental regulations and policies and techno-economic paradigms,[9] but also on each country's endowment of energy resources and the supplies available from neighbouring countries.

Very little can be said about the different variants of these techno-economic paradigms within each country, as technological constraints vary substantially even within a single sector; from an economic point of view, furthermore, prices in the energy sector can also differ greatly from one country to another. Indeed, prices are very far from being set by free competition in the market, as they are very often determined by State intervention, whether in the form of regulation or subsidies or by public-sector enterprises, depending on the energy policy of each country.

Even so, the mix of energy sources or the extent to which they are used in each country's industrial energy matrix will be determined, at least in part, by the combination of relative prices between the

TABLE 6

Structure of consumption by source, 1980-2006

(Percentages)

Energy source	1980	1990	2000	2006
Natural gas	10.57	11.96	11.77	13.93
Coal	0.82	1.05	1.40	1.61
Wood	16.88	13.03	9.43	9.16
Other primary sources	0.69	0.98	1.18	1.24
Total primary sources	**28.97**	**27.02**	**23.78**	**25.94**
Electricity	9.38	12.71	15.80	15.92
LPG	3.91	5.52	6.69	5.73
Petrol	18.90	19.70	19.69	18.19
Fuel oil	11.57	7.07	4.76	3.06
Other secondary sources	27.27	27.98	29.29	31.17
Total secondary sources	**71.03**	**72.98**	**76.22**	**74.06**
Total (millions of BOE)	*1 966*	*2 382*	*3 043*	*3 676*

Source: Economic Commission for Latin America and the Caribbean (ECLAC), on the basis of Latin American Energy Organization (OLADE), "Energy-Economic Information System (SIEE)", August 2008.

BOE: barrels of oil equivalent.
LPG: liquefied petroleum gas.

[8] The amount of emissions deriving from the use of electricity is the average for Latin America and is a reference figure only. There are large differences in the CO_2 emissions of the different primary sources used to produce electricity.

[9] By techno-economic paradigms in this case are meant decisions taken by economic agents with a view to meeting their caloric needs at the lowest possible cost, given certain technological constraints and a particular level of relative fuel prices. It should be noted that three of the four countries analysed have large reserves of fossil resources, something that is certainly a factor in agents' decision-making. These countries are Brazil, Colombia and Mexico (although the oil reserves to production ratio is dropping rapidly in the last of these).

different sources at a given moment in time. In view of the importance of this subject, table 8 presents certain international trends in the prices of the main fuels. While these do not explain the specific context in each country, they do provide an appreciation of the general incentives affecting the employment of certain energy types, particularly the relative cheapness of more polluting energies as compared to cleaner ones, even though each country may operate explicit policies to subsidize the prices of certain fuels.

Indeed, table 8 suggests that coal is the cheapest fuel per unit of energy (measured in terms of final energy, without considering the performance of the equipment and processes using it), since in 2008 a unit of energy cost just over US$ 28 if produced with coal, but US$ 57.033 if produced with natural gas and US$ 97.035 if produced with oil. The relatively low price of the most polluting fuel type is a powerful incentive to use energy sources that are more harmful to the environment.

TABLE 7

Calorific power and CO_2 emissions by fuel type[a]

Energy source	Calorific power (amount needed to obtain one BOE of energy)		CO_2 emissions (grams of carbon emitted for each BOE of energy)
Oil	159.0	litres	116.2
Natural gas	165.2	m^3	88.9
Coal	205.7	kg	149.9
Electricity[b]	1.6	MWh	93.0
Petrol	178.9	litres	109.8
Kerosene	165.1	litres	113.3
Diesel	152.6	litres	117.4
Fuel oil	150.3	litres	122.6
Coke	206.9	kg	173.1
Sugar cane products[c]	1 297.9	kg	-
Liquefied gas	131.0	kg	99.9

Source: Latin American Energy Organization (OLADE), *Energy Statistics Report*, Quito, 2006; International Energy Agency (IEA), *World Energy Outlook 2008*, Paris, 2008; and *Voluntary Reporting of Greenhouse Gases*, Washington, D.C., 2007.
Notes:
[a] These figures are for reference only.
[b] Information provided by the International Energy Agency (2007) for South and Central America.
[c] Emissions from sugar cane production depend greatly on how much of this production is turned into ethanol and how much is employed as pulp, which is used to make paper or to fuel boilers.

BOE: barrel of oil equivalent.
MWh: megawatt hour.

TABLE 8

Prices of the main fuels, 1990-2008

			1990	1996	2000	2006	2007	2008
Oil	(average price)	(dollars/barrel)	22.99	20.37	28.23	64.27	71.13	97.04
Natural gas	(average price)	(dollars/1,000 m^3)	73.26	92.64	129.85	235.90	240.41	345.24
Coal	(average price)	(dollars/ton)	38.42	38.25	27.32	59.01	67.43	136.27
Petrol	(United States price)	(dollars/barrel)	29.84	25.02	34.98	76.53	85.47	103.49
			1990	1996	2000	2006	2007	2008
Oil	(average price)	dollars/BOE	22.99	20.37	28.23	64.27	71.13	97.04
Natural gas	(average price)	dollars/BOE	12.10	15.30	21.45	38.97	39.72	57.03
Coal	(average price)	dollars/BOE	7.90	7.87	5.62	12.14	13.87	28.03
Petrol	(United States price)	dollars/BOE	33.57	28.16	39.35	86.11	96.17	116.44

Source: International Monetary Fund (IMF), *International Financial Statistics*, Washington, D.C., 2010.
BOE: barrels of oil equivalent.

V

Sectoral patterns of industrial energy consumption in the region

Energy intensity is a commonly used indicator for measuring the relationship between energy use and a country's economic development over time. The evolution of this indicator, measured as the ratio between the amount of energy consumed and the country's GDP at a given time, provides information on the way energy is used, directly and indirectly, to produce a unit of output. Disparities in this indicator between different places and times reflect the structures of both energy systems and production systems, and thus can be seen to relate, first, to technological choices and, second, to differentiated forms of social and economic behaviour.

Energy analysts usually accept that energy intensity displays an upward evolution over time at the start of the early phases of development (mechanization of agriculture, development of energy-intensive industries such as chemicals, cement, metallurgy and paper) or when there is growth in energy-intensive primary sectors such as mining; then it levels off as these processes stabilize, before finally diminishing as technological innovations and know-how are introduced and as improvements are achieved in energy yields, transformation and consumption.

This concept can also be applied at the sectoral level. Thus, to take the industrial sector, the amount of energy consumed to produce a particular physical unit of output, such as kilocalories per ton of steel or cement, could be taken as an indicator of energy intensity. Given information availability and the need to analyse this indicator on a more disaggregated basis, this study will use two complementary methodologies:
(i) First, a distinction will be drawn between the different "effects" explaining industrial energy consumption.[10] Here, reference will be made to the energy intensity of the industrial sector in the aggregate, understood as the amount of physical energy (in calories) needed to produce a unit of value added, measured in constant money (calories/dollar of value added in constant 2000 dollars).
(ii) Second, to conduct a more disaggregated analysis of the manufacturing sector, the structure of industrial

consumption will be examined using the taxonomy of Katz and Stumpo (2001). In this case, use will be made of industry surveys, the great majority of which publish data not on physical energy consumption but on monetary expenditure on energy. Thus, in this second part of the analysis of the energy dynamic, a proxy for energy intensity will be used, namely the energy spending needed to produce a unit of value added, both values being measured in constant 2000 dollars.

It should be noted that the evolution of energy consumption as measured in physical quantities (calories) could be very different from the evolution of energy consumption as measured by monetary expenditure (in pesos or dollars). This difference derives from the fact that increasing monetary expenditure does not necessary entail a rise in physical consumption, and thus higher spending per unit of value added does not necessarily represent an increase in energy intensity.[11]

1. The United States

The United States is not only an industrial power, given the modernization of its industrial base and its high productivity, but also has very high energy standards, given the reduction of its industrial energy consumption and its specialization in less energy-intensive activities with high value added. For this reason, the United States has been taken as a proxy for the frontier, as it gives an idea of the best practices possible in production terms and also presents a large reduction in industrial energy intensity.

As table 9 shows, in the 1997-2006 subperiod there was a decline in both energy intensity (-0.1% a year) and in total energy consumption in the industrial sector (-0.8% a year). Taking a longer-term view, furthermore, in the three periods studied it can be seen that the structure

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[10] The methodology used to decompose the energy consumed in the industrial sector is set out in the Annex.

[11] An example of this could arise in a company or sector that modernized its energy consumption by making use of cleaner sources, switching from cheaper but more contaminating sources (such as coal or oil) to more refined and higher-yielding but costlier ones (such as gas or electricity). The shift from cheaper, more polluting sources to higher-yielding ones would surely entail higher (monetary) expenditure on energy, but not necessarily greater physical consumption or higher energy intensity, precisely because of the higher yield of the new sources.

TABLE 9

United States: evolution of the intensity, structure and activity effects in industrial energy consumption, three subperiods
(Percentages)

Subperiod	Intensity effect	Structure effect	Activity effect	Total
1980-1990	-0.3	-2.9	3.2	0.0
1990-1997	1.0	-2.4	3.0	1.5
1997-2006	-0.1	-3.8	3.1	-0.8

Source: prepared by the authors on the basis of United States Department of Energy/Energy Information Administration, *Monthly Energy Review*, June 2009; and Bureau of Economic Analysis, "Survey of Current Business", 2009.

of value added were the engineering-intensive ones, followed by labour-intensive sectors, which presented an intermediate intensity, and lastly by natural resource-intensive sectors, which were the most energy-intensive. The sectoral classification remained the same in 2006, almost a decade on, although energy consumption per unit of output was lower in all the sectors. Thus, from 1997 to 2006 the curve shifted from right to left in all sectors of industry, indicating that they now needed to expend a smaller amount of monetary resources on energy to generate the same unit of value added.

Where cumulative energy consumption is concerned, engineering-intensive and labour-intensive sectors in the United States are each responsible for between 15% and 20% and between 20% and 25%, respectively, of total industrial energy consumption, with natural resource-intensive sectors consuming the remaining 55% to 60%. Note that the United States is not an economy characterized by a specialization in natural resources; consequently, the high share of total industrial energy consumption accounted for by natural resources implies much greater relative consumption in these sectors (and this is indeed reflected in their higher consumption per unit of value added).

Furthermore, although this consumption structure has stayed roughly constant over time, there has been an improvement in engineering-intensive sectors, which

effect was negative, meaning that the industry share of output fell, while the opposite was true of the level of activity, meaning that economic growth contributed greatly to higher energy consumption in United States industry (see figure 7).
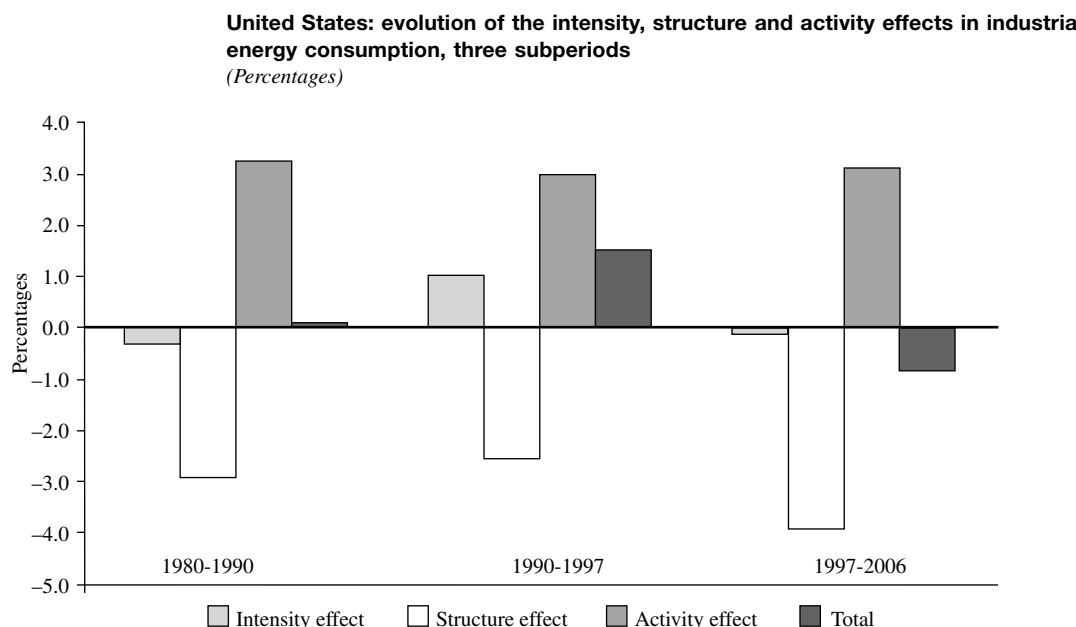
Figure 8 illustrates the share of cumulative energy consumption (vertical axis) and the energy spending needed to generate a unit of value added (horizontal axis) for the three manufacturing groups: sectors intensive in engineering, natural resources, and labour. In 1997, the sectors with the lowest energy expenditure per unit

FIGURE 7

United States: evolution of the intensity, structure and activity effects in industrial energy consumption, three subperiods
(Percentages)

Source: prepared by the authors on the basis of United States Department of Energy/Energy Information Administration, *Monthly Energy Review*, June 2009; and Bureau of Economic Analysis, "Survey of Current Business", 2009.

FIGURE 8
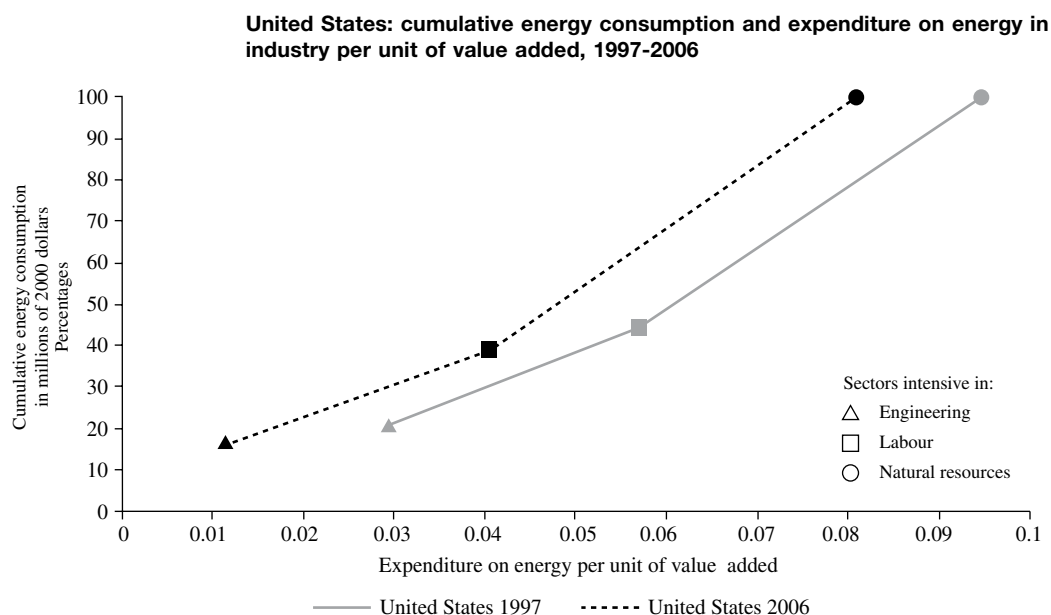
United States: cumulative energy consumption and expenditure on energy in industry per unit of value added, 1997-2006

Source: Economic Commission for Latin America and the Caribbean (ECLAC), on the basis of industrial surveys.
Note: Expenditure on energy per unit of value added is calculated as the ratio between industrial energy consumption (in millions of 2000 dollars) and industrial value added (in millions of 2000 dollars).

have succeeded in reducing their energy intensity sharply and decreasing their share of total energy consumption, this being a clear example of virtuous structural change. Thus, it can be seen that the reduction in energy intensity is explained not only by a fall in energy expenditure per unit of value added in all manufacturing sectors, but also by a shift in the composition of the production structure towards the least energy-intensive sectors, i.e., those that are engineering-intensive.

2. Brazil

The behaviour of energy consumption in the Brazilian industrial sector displays a worrying upward trend:

although consumption fell sharply in the 1980-1990 subperiod (-6.0%), it increased in the following subperiods (by 3.7% in 1990-1997 and by 3.5% in 1997-2006).

Much as in the United States, the structure effect has been systematically negative, while the activity effect has always contributed to higher energy consumption, a trend that can be attributed to the strong growth of the Brazilian economy over the past 15 years (see table 10 and figure 9).

In the case of Brazil, the rise in energy intensity can be seen both at the aggregate level, with a 1.2% annual increase in the 1997-2006 subperiod, and when the figures are disaggregated by groups of production sectors. In fact, the pattern in Brazil is the opposite of that

TABLE 10

Brazil: evolution of the intensity, structure and activity effects in industrial energy consumption, three subperiods
*(Percentages)*

Subperiod	Intensity effect	Structure effect	Activity effect	Total
1980-1990	-6.2	-1.3	1.6	-6.0
1990-1997	3.1	-2.3	2.9	3.7
1997-2006	1.2	-1.1	3.3	3.5

Source: prepared by the authors on the basis of CEPALSTAT and Ministry of Mines and Energy of Brazil, "Balanço Energético Nacional", 2009.

FIGURE 9

Brazil: evolution of the intensity, structure and activity effects in industrial energy consumption, three subperiods
(Percentages)
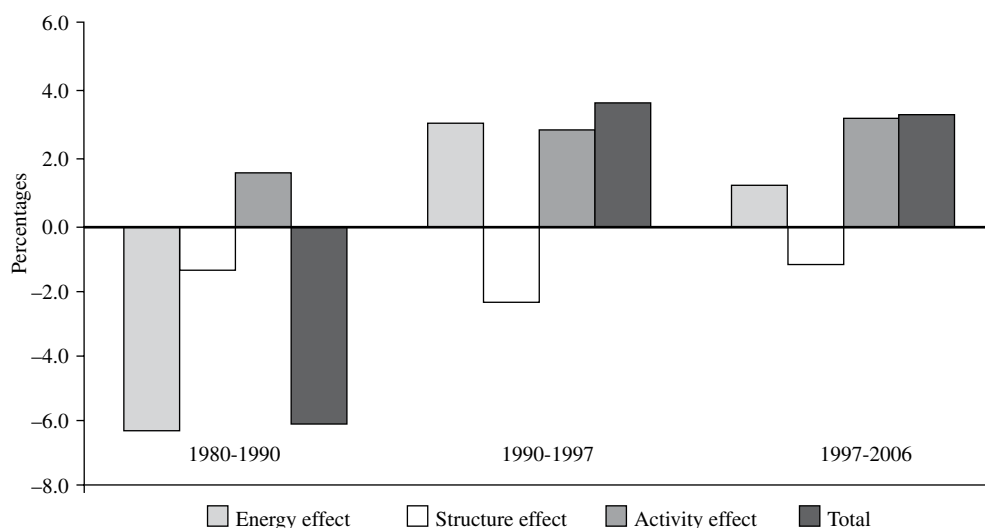
Source: prepared by the authors on the basis of CEPALSTAT and Ministry of Mines and Energy of Brazil, "Balanço Energético Nacional", 2009.

at the energy frontier, since the three sectoral groupings have registered a sharp increase in expenditure on energy per unit of value added during the period of study. Furthermore, the composition of energy consumption within the industrial sector has not been showing positive signals either, as the share of natural resource-intensive sectors (precisely the most energy-intensive) has risen (see figure 10).

One of the factors behind the worsening of energy intensity may lie in the changes that have occurred in the composition of consumption by energy source, as sources with a high energy yield have been replaced by others with a lower yield. Thus, between 1990 and 2006 the share of coal rose in Brazil (from 53% to 63%) and so did that of natural gas (these generally being sources used for calorific purposes) at the expense of electricity (down from 24% to 20%), which is usually employed in motive applications. Furthermore, the electricity crisis of the early 1990s led to a change in the pattern of energy behaviour with a view to making a greater reserve of electricity available in the form of power stations burning fossil fuels and more involvement by industrial and private-sector agents in producing their own electricity. This may be one of the explanations for the decline in the consumption share of electricity.

As is well known, electricity is the highest-yielding source, while processes that turn fossil fuels into caloric

energy present substantial losses and thus low yields (see table 11).

These trends in consumption by source (the increase in coal use especially) and the high level of industrial activity in Brazil have resulted in an unstable evolution of carbon intensity (CO_2 per unit of value added), but with a strong upward trend: from 0.6903 in 1990 to 0.8948 in 2006 (see table 12).

Although it might be concluded that the rise in industrial energy consumption and intensity[12] positions Brazil as one of the countries whose industrial growth model is not energy-sustainable, it needs to be considered that the tendency to seek energy self-sufficiency partially accounts for the increased use of locally produced fossil resources. Thus, in 2008 Brazil announced that it had achieved energy independence, and in the medium term (if the large underwater oil deposits that have been found are fully exploited) the country could become an exporter of hydrocarbons.

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[12] The rise in energy intensity is explained by a general increase in expenditure on energy per unit of output, the expanding share of natural resource-intensive sectors in total energy consumption and the replacement of sources with a high energy yield by others with a low yield.

FIGURE 10
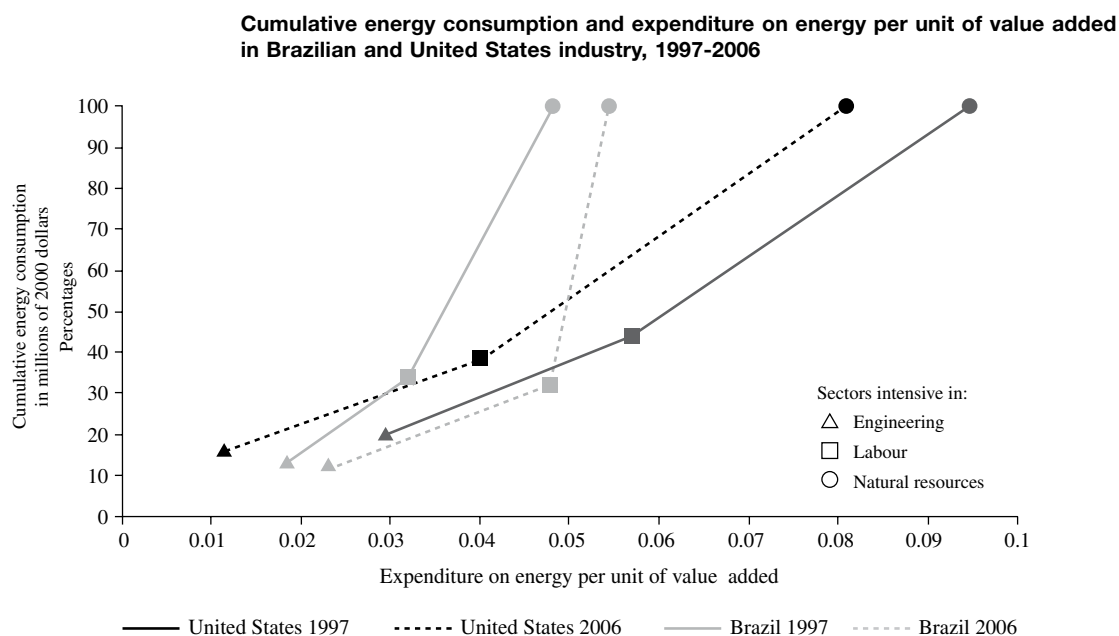
Cumulative energy consumption and expenditure on energy per unit of value added in Brazilian and United States industry, 1997-2006

Source: Economic Commission for Latin America and the Caribbean (ECLAC), on the basis of industrial surveys.
Note: Expenditure on energy per unit of value added is calculated as the ratio between industrial energy consumption (in millions of 2000 dollars) and industrial value added (in millions of 2000 dollars).

TABLE 11

Brazil: evolution of the industrial consumption structure, by source, 1990-2006
(Millions of TOE and percentages)

Brazil		Electricity	Natural gas	Oil and derivatives	Coal and other	Total
1990	10⁶ TOE	9.66	2.45	6.85	21.20	40.15
	Percentage	24.05	6.10	17.06	52.79	100.00
2000	10⁶ TOE	12.61	5.51	7.31	31.53	56.96
	Percentage	22.14	9.68	12.83	55.35	100.00
2006	10⁶ TOE	15.60	9.65	3.96	49.27	78.48
	Percentage	19.88	12.30	5.05	62.78	100.00

Source: prepared by the authors on the basis of Ministry of Mines and Energy of Brazil, "Balanço Energético Nacional", 2009.

TOE: tons of oil equivalent.

TABLE 12

Brazil: carbon intensity of industry, 1990-2006

	1990	2000	2005	2006
Millions of tons of CO_2	57.5	94.0	99.5	105
IVA (millions of 2000 dollars)	83 293	96 131	110 925	117 463
Kg CO_2/IVA	0.6903	0.9778	0.8970	0.8948

Source: prepared by the authors on the basis of Energy Information Administration (2007), *Voluntary Reporting of Greenhouse Gases*, Washington, D.C., United States Department of Energy, 2010; and Economic Commission for Latin America and the Caribbean (ECLAC), *Time for Equality: Closing Gaps, Opening Trails* (LC/G.2432(SES.33/3)), Santiago, Chile, 2010.

IVA: industrial value added.

Kg CO_2/IVA: kilograms of carbon per unit of industrial value added.

3.   Chile

Industrial energy consumption in Chile has been growing at a steady 2% a year or more, with much faster growth of 8.7% a year in the 1990-1997 subperiod. As in the cases of Brazil and the United States, the structure effects displays negative values while the activity effect is invariably positive (see table 13 and figure 11). This reveals the declining share of industrial sector value added in the economy as a whole and the scale of the activity effect, especially in the last two subperiods.

Energy intensity, meanwhile, has continued to fluctuate, showing a slight decline (-0.7% a year) during the last subperiod studied. When groups of activities are taken, contradictory trends are seen. Whereas natural resource-intensive sectors have increased their expenditure on energy per unit of value added, while also increasing their already high share of overall consumption, labour- and engineering-intensive sectors have reduced their consumption per unit of value added (see figure 12).

The reduction in aggregate energy intensity and the higher expenditure on energy in the most energy-intensive sectors could be partly explained by examining the copper industry, which is particularly important in Chile because of the country's profound specialization in that sector. The copper industry has yet to exploit all its potential for raising energy efficiency; however, since the 1980s its energy consumption in physical quantities per unit of

TABLE 13

Chile: evolution of the intensity, structure and activity effects in industrial energy consumption, three subperiods
(Percentages)

Subperiod	Intensity effect	Structure effect	Activity effect	Total
1980 -1990	0.0	-0.3	2.9	2.6
1990 -1997	2.4	-1.9	8.2	8.7
1997- 2006	-0.7	-0.9	3.6	2.0

Source: prepared by the authors on the basis of Ministry of Energy, "Balance nacional de energía", Santiago, Chile, 2009; CEPALSTAT; and Economic Commission for Latin America and the Caribbean (ECLAC), *Time for Equality: Closing Gaps, Opening Trails* (LC/G.2432(SES.33/3)), Santiago, Chile, 2010.

FIGURE 11

Chile: evolution of the intensity, structure and activity effects in industrial energy consumption, three subperiods
(Percentages)
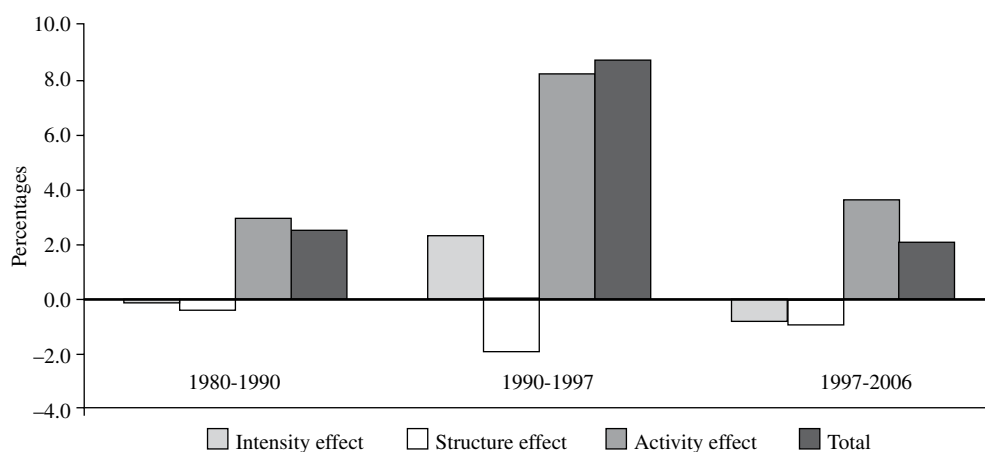
Source: prepared by the authors on the basis of Ministry of Energy, "Balance nacional de energía", Santiago, Chile, 2009; CEPALSTAT; and Economic Commission for Latin America and the Caribbean (ECLAC), *Time for Equality: Closing Gaps, Opening Trails* (LC/G.2432 (SES.33/3)), Santiago, Chile, 2010.
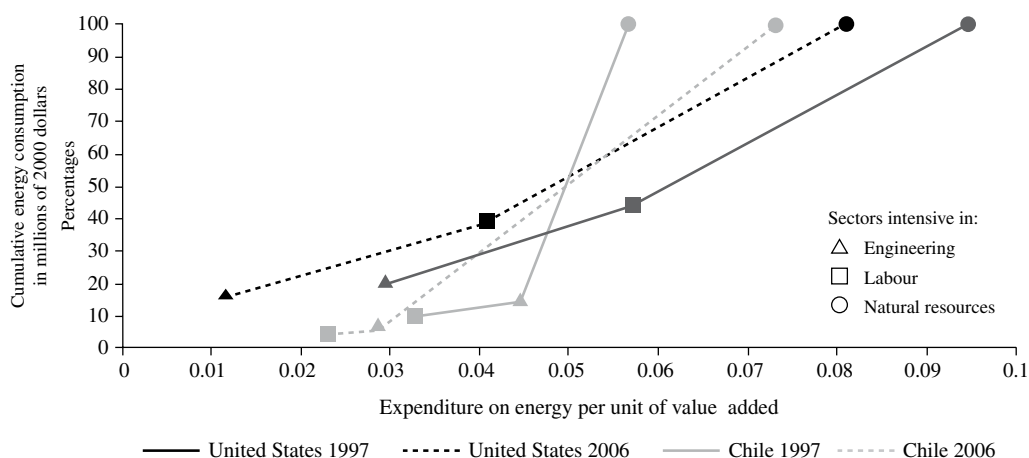
FIGURE 12

Energy consumption shares and productivity in the manufacturing sectors of Chile and the United States, 1997-2006

Source: Economic Commission for Latin America and the Caribbean (ECLAC), on the basis of industrial surveys.
Note: Expenditure on energy per unit of value added is calculated as the ratio between industrial energy consumption (in millions of 2000 dollars) and industrial value added (in millions of 2000 dollars).

value added has declined steadily, owing particularly to technological changes designed to replace lower-cost, lower-yielding sources with higher-cost, higher-yielding ones. Thus, for example, the use of hydrometallurgy for refining copper oxides has made strong inroads at the expense of the traditional pyrometallurgical process, while many of the reverberatory furnaces used to smelt copper (characterized by high energy consumption) have been replaced, although they are still in use at some major workings. These changes in the production process have reduced energy intensity in the copper industry by 13% (Maldonado, 2007).

While there is no similar information or research for other industries as conclusive as that for copper, it can be seen that the "technology" effect presents periods with changing signs. In any event, it can be deduced that only in recent years has industry, like national energy policy generally, begun to assign importance to energy efficiency. The results of the efforts made by the National Energy Efficiency Programme (PPEE) since its creation and the impact of the sustained rise in energy prices since late 2008 have not translated into an aggressive energy efficiency policy leading to a reduction in intensive energy use.

Again, variations in the energy intensity ratio have occurred in parallel with a complex process of substitution between sources. The preponderance of imported energy sources has left Chile quite exposed not only to supply risks but also to the repercussions of international price

increases and volatility. This dependence on external sources has been aggravated by reliance on an almost exclusive provider, as happened with the natural gas imported on a large scale from Argentina until 2004. Since 2005, however, the situation has begun to shift back in favour of more polluting energies, the rise in coal consumption being a case in point, so that there has been a gradual return to the consumption pattern prior to 1998 and high fuel consumption (see table 14).

In turn, this substitution process has been reflected in the fluctuating behaviour of carbon intensity, with a large increase of 71% in CO_2 emissions per unit of value added between 1990 and 2000 being followed by a reduction of 11% between 2000 and 2005 and a fresh rise of 20% between 2005 and 2006 (see table 15).

It could be concluded that the reduction in energy intensity (which is explained by lower expenditure on energy per unit of output in labour- and engineering-intensive industries and the decline in intensive energy use in the copper industry) leaves Chile quite well placed in energy terms, although the growing share of coal raises questions about the future.

4. Colombia

From 1980 onward, total energy consumption in Colombian industry presented a worrying upward trend, but this was reversed during the last subperiod (1997-2006). Thus, growth was 5.3% a year in the 1990-1997

TABLE 14

Chile: evolution of the industrial consumption structure, by source, 1990-2007

(Millions of TOE and percentages)

		Electricity	Natural gas	Oil and derivatives	Coal and other	Total
1990	10^6 TOE	0.88	0.18	1.43	1.39	3.87
	Percentage	22.61	4.69	36.94	35.76	100.00
2000	10^6 TOE	2.21	0.98	2.14	1.96	7.28
	Percentage	30.32	13.45	29.37	26.86	100.00
2007	10^6 TOE	1.39	0.47	2.95	2.16	6.96
	Percentage	19.95	6.70	42.33	31.01	100.00

Source: Ministry of Energy, "Balance nacional de energía", 2009, Santiago, Chile, 2009.

TOE: tons of oil equivalent.

TABLE 15

Chile: carbon intensity of industry, 1990-2006

	1990	2000	2005	2006
Millions of tons of CO_2	8.62	14.78	15.75	17.78
IVA (millions of 2000 dollars)	7 811	12 131	14 560	15 135
Kg CO_2/dollar of IVA	1.10	1.22	1.08	1.17

Source: prepared by the authors on the basis of International Energy Agency (IEA) and Economic Commission for Latin America and the Caribbean (ECLAC).

IVA: industrial value added.
Kg CO_2/IVA: kilograms of carbon per unit of industrial value added.

subperiod, followed by decline of -1.9% in the following one (see table 16 and figure 13). It is important to stress that while economic growth in Colombia is still contributing to higher energy consumption, the downward trend of the structure effect was also reversed in the last subperiod, implying a rise in the industry share of total national output and thus an increase in its energy consumption. The positive contribution of these two effects during the last subperiod (1997-2006) makes the reduction in total energy consumption even more striking, as it was only made possible by the fall in energy intensity (-5.1% a year), offsetting the 4.7% annual increase in the previous subperiod.

At a more disaggregated level, opposing trends can be seen. While natural resource-intensive and labour-intensive sectors have increased their expenditure on energy per unit of value added, energy-intensive sectors have dramatically lowered it, thus reducing yet further their already small share of Colombian industry's total energy consumption (see figure 14).

The decline in energy intensity can largely be explained by the introduction of more efficient processes in Colombian manufacturing, such as the use of alternative energies (UPME, 2008).

Certain industries underwent major changes, although by international standards they still seem to have scope to improve their performance in terms of specific consumption values for both energy and water.

Different industries made heavy use of coal, crude oil (known in Colombia as Castilla oil) and fuel oil, while the use of waste was low and that of gas fuels only incipient. In the paper industry, for example, comparative analysis of the findings reveals great potential for energy savings, depending on the technologies and production scales used: a special feature of non-integrated firms in the medium-sized industry sector is their use of rotating drum technology for forming sheets. Only one of the firms surveyed consumed thermal energy in the process; the others carried out the drying process with atmospheric air. The specific energy consumption of these industries is not comparable with international indices, given low production volumes and the type of technology used in Colombia.[13]

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[13] Average specific consumption for integrated firms is of the order of 0.9 megawatt hours per ton (MWh/ton), equivalent to 3.2 gigajoules per ton (GJ/ton), and 5,731.8 megacalories per ton (Mcal/ton), equivalent to 23.9 GJ/ton, for electrical and thermal

TABLE 16

Colombia: evolution of the intensity, structure and activity effects in industrial energy consumption, three subperiods

(Percentages)

Subperiod	Intensity effect	Structure effect	Activity effect	Total
1980 -1990	0.2	-0.5	3.4	3.1
1990 -1997	4.7	-3.5	4.0	5.2
1997- 2006	-5.1	0.4	2.8	-1.9

Source: prepared by the authors on the basis of Mining Energy Planning Unit (UPME), "Sistema de información minero energético colombiano 2010" [online] http://www1.upme.gov.co/index.php?option=com_wrapper&view=wrapper&Itemid=108.

FIGURE 13

Colombia: evolution of the intensity, structure and activity effects in industrial energy consumption, three subperiods
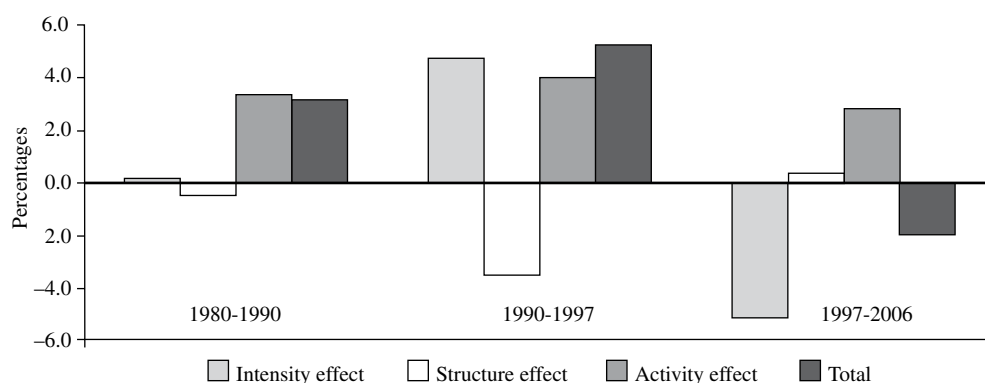
Source: prepared by the authors on the basis of Mining Energy Planning Unit (UPME), "Sistema de información minero energético colombiano 2010" [online] http://www1.upme.gov.co/index.php?option=com_wrapper&view=wrapper&Itemid=108.

The policy of large-scale natural gas use implemented in Colombia came up against some obstacles to expansion in the domestic market in the form of competition
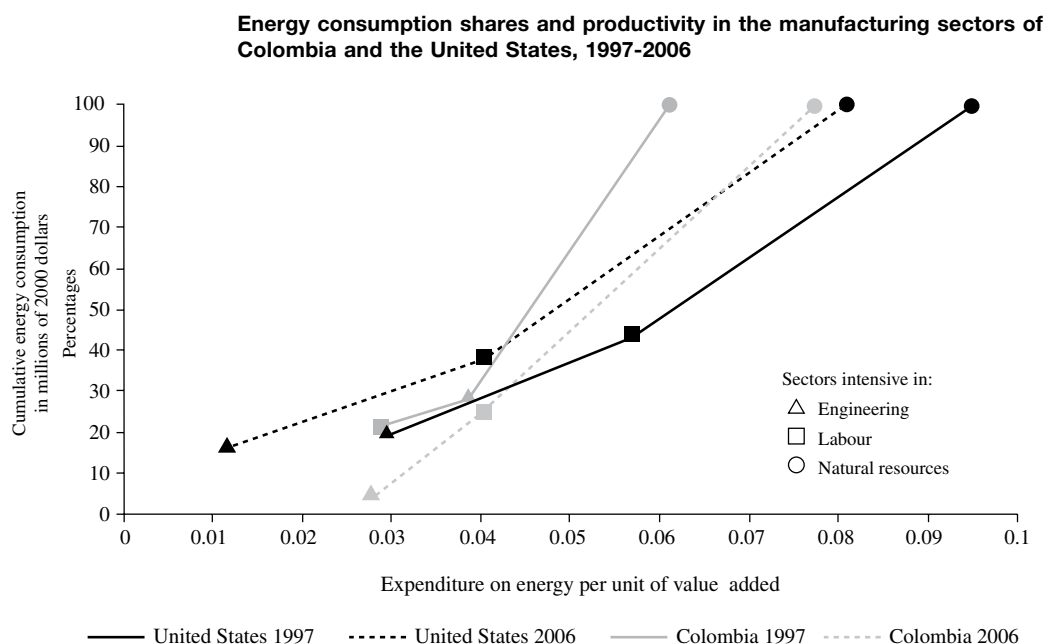
energy, respectively, and 27.1 GJ/ton for total energy (electrical plus thermal). Overall, specific consumption is vastly greater than the internationally reported figure of 16.7 GJ/ton for firms of the same type, so that there is potential for a 60% reduction in specific consumption. For non-integrated firms, average specific consumption is of the order of 0.9 MWh/ton (3.2 GJ/ton) for electrical energy, 3,487.5 Mcal/ton (14.6 GJ/ton) for thermal energy and 17.8 GJ/ton for total energy. Overall, specific consumption is slightly higher than the internationally reported figure of 15.5 GJ/ton. This represents a potential specific consumption saving of 15%. Specific consumption of water may stand at around 40m³/ton, and be as low as 8 m³/ton in plants with totally closed systems. Some firms have water recovery and recirculation systems in certain processes. This figure serves as a benchmark for firms that exceed it, as they have great scope for saving by reusing water in their own processes, as well as reducing the environmental impact caused by waste water containing pollutants and solids.

from substitutes and the relative price structure.[14] The share of natural gas in the national energy matrix rose steadily; in the particular case of the industrial sector, it increased from 18.39% to over 31% in 20 years. Together with electricity, natural gas was the source with the greatest penetration (see table 17).

Although total emissions grew from 10.3 million to 16 million tons between 1990 and 2006, the downward trend in carbon intensity reflects this process of substitution between sources, with a reduction from 1.36 to 1.06 kilograms of carbon per unit of industrial value added (see table 18).

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[14] Colombia has large coal resources, with 92 years of reserves at current production levels, and its reserves of hydrocarbons are also substantial, although the reserves to production ratio is somewhat lower: 34 years for natural gas and 25 to 30 for oil. It also has abundant water resources. See UPME (2010).

FIGURE 14

Energy consumption shares and productivity in the manufacturing sectors of Colombia and the United States, 1997-2006

Source: Economic Commission for Latin America and the Caribbean (ECLAC), on the basis of industrial surveys.
Note: expenditure on energy per unit of value added is calculated as the ratio between industrial energy consumption (in millions of 2000 dollars) and industrial value added (in millions of 2000 dollars).

TABLE 17

Colombia: structure of energy consumption in the industrial sector, 1990-2006

	Electricity	Natural gas	Oil and derivatives	Coal and other	Total
1990: millions of TOE	0.68	0.94	1.04	2.46	5.11
Percentage	13.27	18.39	20.31	48.03	100.00
2000: millions of TOE	0.98	1.16	1.03	3.53	6.71
Percentage	14.65	17.27	15.42	52.65	100.00
2006: millions of TOE	1.14	1.90	0.62	2.40	6.06
Percentage	18.75	31.32	10.26	39.67	100.00

Source: prepared by the authors on the basis of Ministry of Mines and Energy, "Balance energético", and of Mining Energy Planning Unit (UPME), "Sistema de información minero energético colombiano 2010" [online] http://www1.upme.gov.co/index.php?option=com_wrapper&view=wrapper&Itemid=108.

TOE: tons of oil equivalent.

TABLE 18

Colombia: evolution of carbon intensity in the industrial sector, 1980-2007

	1980	1990	2000	2005	2007
Millions of tons of CO_2	10.3	12.3	20.9	19.1	16
IVA (millions of 2000 dollars)	7 558	10 102	10 617	12 967	15 173
Kg CO_2/dollar of IVA	1.36	1.22	1.97	1.47	1.06

Source: prepared by the authors on the basis of International Energy Agency (IEA) and Economic Commission for Latin America and the Caribbean (ECLAC).

IVA: industrial value added.
Kg CO_2/IVA: kilograms of carbon per unit of industrial value added.

The potential for further reducing industrial energy intensity while making more substantial progress with natural gas will depend on the latter remaining competitive for low-capacity industrial diesel boilers (light industry) and on changes to the diesel oil pricing policy (the influence of subsidy) that is preventing it from being adopted for high-capacity industrial diesel boilers. Natural gas may also be uncompetitive for certain industrial uses where fuel oil and coal are alternatives, something that may cause industrial consumption not only to grow per unit of value added in future, but to become more polluting.

Despite this prospect, it can be concluded that Colombia presented one of the region's most sustainable energy patterns during the 1997-2006 subperiod studied, given the large decline in energy intensity there and the fall in total industrial consumption.

5. Mexico

In a longer-term perspective, the path of Mexico's industrial energy consumption has been variable. Between 1980 and 2006 it rose, having grown slightly between 1980 and 1990 and then more rapidly in the 1990-1997 subperiod, before declining during the 1997-2006 subperiod. This may owe something to a reduction in the structure effect between 1997 and 2006 altering the upward trend of the two earlier subperiods, but was essentially due to the systematic drop in the "technology" effect, whose rate of decline accelerated to -3.9% a year during the 1997-2006 subperiod (see table 19 and figure 15).

It is intriguing to note that while energy intensity declined in manufacturing as a whole in the 1997-2006 subperiod, the three manufacturing groups greatly increased their (monetary) consumption of energy per unit of output (see figure 16). Notwithstanding, there are two trends that help explain the reduction in energy intensity across Mexican industry as a whole. First,

there was a favourable shift in composition within the industrial structure, with engineering-intensive sectors considerably increasing their share of energy consumption, from 10.1% to 13.8%. Second, much of this decline in the "technology" effect was driven by the industrial consumption matrix itself, with as much as 13% of fossil energy (which is normally less efficient, but cheaper) being replaced by more expensive but higher-yielding electricity.

It should be noted that a large proportion of export value added was generated by activities that consume more energy in motive than in calorific applications, which might go some way towards explaining the process of substitution between sources that arose in recent years, particularly up to 2000, and might also be one of the factors behind the decline in energy intensity. Although the process of fossil energy substitution had already been observable since the 1970s, it intensified to encompass 28% of total industrial consumption by 2000, a figure that remained stable until 2006. In other words, substitution of sources has taken place, and this has involved not only the substitution of lower-yielding sources (fuel oil) by electrical energy, but the increasing application of these sources to more efficient uses, as motive applications generally present yields in excess of 80%, whereas calorific applications rarely attain yields as high as the 50% to 60% range (see table 20).

The overall effect of these changes in the composition of the consumption structure was a downward trend in carbon intensity, which virtually halved from 0.87 kilograms of carbon dioxide per unit of value added in 1990 to 0.43 Kg CO_2/VA in 2007. In other words, electricity penetration cushioned the undesirable effect of the substitution which took place between fossil fuels, replacing natural gas and its derivatives (down from almost 75% in 1990 to 56% in 2006) with coal, whose share rose from 13% in 1990 to 26% in 2006-2007 (see tables 20 and 21).

TABLE 19

Mexico: evolution of the intensity, structure and activity effects in industrial energy consumption, three subperiods

Subperiod	Intensity effect	Structure effect	Activity effect	Total
1980-1990	-0.2	0.2	1.8	1.8
1990-1997	-0.4	0.9	2.8	3.3
1997-2006	-3.9	-0.5	3.3	-1.1

Source: prepared by the authors on the basis of Mexican Ministry of Energy, *Sistema de Información Energética (SIE)*, 2010 [online] http://www.sener.gob.mx/webSener/portal/Default.aspx?id=1429.

FIGURE 15

Mexico: evolution of the intensity, structure and activity effects in industrial energy consumption, three subperiods

Source: prepared by the authors on the basis of Mexican Ministry of Energy, *Sistema de Información Energética (SIE)*, 2010 [online] http://www.sener.gob.mx/webSener/portal/Default.aspx?id=1429.
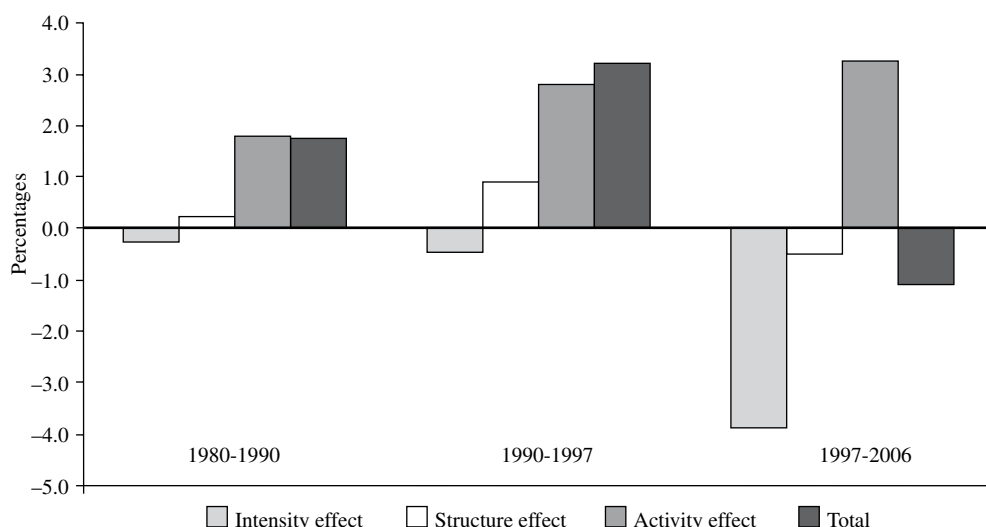
FIGURE 16

Energy consumption shares and productivity in the manufacturing sectors of Mexico and the United States, 1997-2006
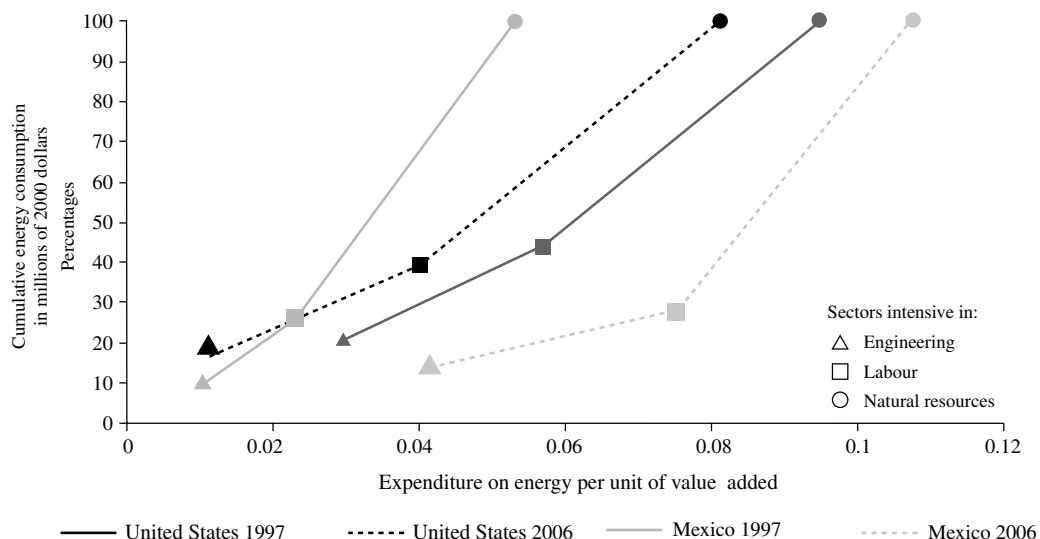
Source: Economic Commission for Latin America and the Caribbean (ECLAC), on the basis of industrial surveys.
Note: Expenditure on energy per unit of value added is calculated as the ratio between industrial energy consumption (in millions of 2000 dollars) and industrial value added (in millions of 2000 dollars).

TABLE 20

Mexico: evolution of the industrial consumption structure, by source, 1980-2006
(Millions of TOE and percentages)

	Electricity	Natural gas	Oil and derivatives	Coal and other	Total
1980: millions of TOE	2.46	10.5	5.3	3.1	21.3
Percentage	11.6	49.2	24.7	14.5	100
1990: millions of TOE	4.42	10.8	7.8	3.3	26.3
Percentage	16.8	41.2	29.5	12.5	100
2000: millions of TOE	8.04	9.1	6.8	4.7	28.6
Percentage	28.2	31.8	23.8	16.3	100
2006: millions of TOE	8.78	10.2	4.7	7.8	31.5
Percentage	27.8	32.4	15.0	24.8	100

Source: prepared by the authors on the basis of Mexican Ministry of Energy, *Sistema de Información Energética (SIE)*, 2010 [online] http://www.sener.gob.mx/webSener/portal/Default.aspx?id=1429.

TOE: tons of oil equivalent.

TABLE 21

Mexico: industrial sector CO_2 emissions, 1990-2007

	1990	2000	2005	2007
Millions of tons of CO_2	73.9	67.8	58.5	62.7
IVA (millions of 2000 dollars)	85 152	131 376	133 212	143 846
Kg CO_2/IVA	0.8679	0.5161	0.4391	0.4357

Source: prepared by the authors on the basis of International Energy Agency (IEA) and Economic Commission for Latin America and the Caribbean (ECLAC).

IVA: industrial value added.
Kg CO_2/IVA: kilograms of carbon per unit of industrial value added.

In the case of Mexico, it might be concluded that the reduction in energy intensity –which is explained by a favourable change in composition in the production structure, but essentially by the replacement of lower-yielding (cheaper and more polluting) sources with higher-yielding ones, electricity in particular– suggests that the country is in a positive situation in energy terms, particularly since, having traditionally been a net exporter of oil, it has seen a sharp drop in reserves since the middle of the last decade. New prospecting means that this tendency could be reversed in the not too distant future.

VI

Final results and conclusions

The analyses of the production and energy dynamic presented in sections III and IV are summarized in table 22.

Table 22 summarizes the information set out in the earlier sections, showing that during the 1997-2006 subperiod none of the four Latin American countries could show productivity growth rates similar to those of the technology frontier where, after holding steady at approximately 3% for 20 years, they rose to extraordinarily high levels (close to 5% a year) thanks to the incorporation of ICTs (Oliner, Sichel and Stiroh, 2007). Consequently, all these countries have fallen behind where productivity is concerned, in some cases by a long way, as in Brazil, where strong labour absorption has actually caused labour productivity to fall at a rate of -1.5% a year, or with less of a relative decline, as in Colombia, where

strong productivity growth (3.7%) a year has still been 1.5 percentage points below the frontier.

Meanwhile, the majority of the countries studied have converged on greater energy sustainability, the exception being Brazil. The case of Colombia once again merits particular attention, as a large fall in energy intensity (by -5.1% a year during the 1997-2006 subperiod) has left it better placed than any of the other countries in terms of energy sustainability. Thus, the productive development and energy sustainability matrix falls into the following pattern (see figure 17).

It should be emphasized that while natural resource-intensive sectors are the most energy-intensive, it has been shown that a specialization in these sectors is no bar to improving energy efficiency. Similarly, a greater specialization in engineering-intensive sectors is no guarantee of energy sustainability.

By comparison with the Latin American countries analysed in this study, the United States presents a virtuous development pattern, specializing in activities with higher productivity, high technology content and lower energy consumption. Latin America has been specializing in natural resource-intensive sectors, which are characterized by their low technology content and slow productivity dynamic; furthermore, these are the most energy-intensive sectors, and greater specialization in them thus entails a rising demand for energy.

Accordingly, it is assumed that improving both productive efficiency and energy efficiency would involve a process of structural change, which would not only entail a narrowing of the productivity gap between the Latin American economies and the frontier but would also reinforce a growth pattern with greater energy sustainability over time. From the analysis conducted in this paper it can be deduced that the greatest challenge lies in the sphere of productivity, given how slowly it is rising in these Latin American countries. It should not be forgotten, however, that unless the region's specialization pattern changes, higher industrial growth will entail expansion of the most energy-intensive sectors, and thus

TABLE 22

Selected countries: productive development and energy sustainability, 1997-2006

Country	Productivity of labour	Energy intensity	Productive convergence	Energy convergence
	Π	EI	$\Pi_i - \Pi_{US}$	$EI_{US} - EI_i$
Brazil	-1.5	1.2	-6.8	-1.3
Chile	2.6	-0.7	-2.6	0.6
Colombia	3.7	-5.1	-1.5	5.0
Mexico	2.8	-3.9	-2.4	3.8
United States	5.3	-0.1	0.0	0.0

Source: prepared by the authors.

FIGURE 17

Productive development and energy sustainability matrix
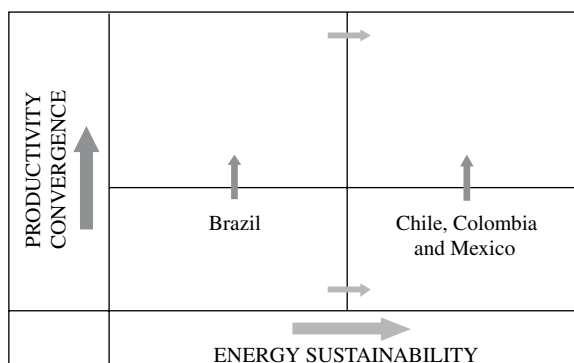
Source: prepared by the authors.

increased energy consumption. To bring about sustainable structural development, in other words, it is necessary to shift the industrial structure towards the sectors that are the most knowledge-intensive and dynamic in terms of productivity growth where these have the potential to replace other sectors that are less dynamic and more energy-intensive, thereby altering the region's current specialization path.

(Original: Spanish)

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ANNEX[15]

Industrial energy consumption can be broken down into four effects: a technology effect, a structure effect, an activity effect and second-order effects. The decomposition method is detailed below:

Ej: the amount of energy consumed in industrial sector j.
VAj: value added in industrial sector j.
GDP: gross domestic product.

    The amount of energy consumed by the industrial sector, then, can be written as:

_____

[15] See Jacques Percebois (1989), chapter II, pp. 75-100.

$Ej = [Ej/VAj]\ [VAj/GDP]\ GDP$

and consequently the growth rate of industrial consumption can be decomposed into three effects:

$$\Delta\,Ej = \quad \Delta[Ej/VAj]\ [VAj/GDP]\ GDP \qquad \text{intensity or “technology” effect}$$

$$+$$
$$[Ej/VAj]\ \Delta[VAj/GDP]\ GDP \qquad \text{structure effect}$$
$$+$$
$$[Ej/VAj]\ [VAj/GDP]\ \Delta GDP \qquad \text{activity effect}$$
$$+$$
$$\varepsilon \qquad \text{second-order effects}$$

CHART