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Energy and materials use in Italian and Chinese tile manufacturers: a comparison using an Enterprise Input-Output model

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Abstract

It is becoming evident that sustainable development methodologies, at the local and global level, are nowadays taken into account by governments and corporations of any country. More and more corporations are searching for an equilibrium among profit, local environment preservation, and energy consumption instead of profit on its own.

Tile manufacturing is a traditional industry and has an important place both in the Chinese and Italian economies. It is an industry which requires a great amount of energy and water. Therefore, monitoring energy, water, and raw materials use along with pollution levels in this sector are useful for various reasons. First, it can help plan local development strategies to render more efficient the supply chains under investigation. Second, it can help balance positive and negative impacts of production processes. In this paper, an enterprise input-output analysis based on production processes is used to investigate two tile manufacturers: one located in China and one in Italy. The aim of the work is to describe energy and material use and consequent pollution emissions, and also to make a comparison between supply chains that produce similar final products in these two countries.

1. Introduction

The modern technological society mobilizes and uses a very large number of materials. These substances are derived from natural resources and must undergo transformation before use. A large fraction of the materials is eventually returned to the environment. For the purpose of better understanding industrial development and potential environmental impact, it is important to know, even approximately, the elementary cycles of all materials adopted by modern technology. Recently, more and more managers realize that a focus on sustainability can provide strong returns while also meeting human needs and reducing the environmental footprint of their operations. Public administrators and firms are considering the relevance of sustainable development to combine production and environmental urges. The competitiveness and/or attractiveness of local areas have been in fact based on a balance between economy and ecosystem protection. However, countries with different development levels could imply contrasting technologies and different levels of attention regarding environmental concerns and sustainability.

A lack of quantitative approaches has been recognized to support local sustainability (Renn et al. 1998). In fact, the complexity of the concept of sustainability makes it very difficult to foresee the best policy to integrate environmental quality, economic growth and social needs without using appropriate models. It is therefore necessary to study the sustainable development of systems through analytical methods. In order to take effective actions and limit negative effects on the local environment, input-output modeling techniques have been proposed for

economic-energy-environment analysis using materials and flow data related to those supply chains, and to their associated locations (Albino et al., 2003).
Among a number of manufacturing sectors, tile manufacturing is an industry which typically uses a large number of materials and energy while producing both liquid and solid wastes. China and Italy are amongst the biggest tile production countries in the world (see Table 1). Tile manufacturing is a sector of utmost importance for the economy of these two countries, as will be described further.

Table 1. Production of ceramic tiles, by country, 1990, 1997, 2001 (Assopiastrelle, 2002).

	Annual output (million m^2)			Percentage of world production		
Countries	1990	1997	2001	1990	1997	2001
China	40	460	1062	2%	13%	23.4%
Italy	446	572	638.4	25%	17%	14%
Spain	219	485	638	12%	14%	14%
Brasil	190	383	473	11%	11%	10%
Japan	100	78	53	6%	2%	1.2%
Taiwan	50	68	45	2%	2%	0.9%
Germany	75	59	57	4%	1.7%	1.2%
France	45	44.7	39	2%	1.2%	0.85%
USA	50.8	58.5	54	3%	1.7%	1.2%
World total	1781	3462	4540			

With 12.7 percent of the world's total China is the second largest emitter of energy-related carbon dioxide emissions after the United States. China's share of world carbon emissions is expected to increase in coming years, reaching 17.8 percent by 2025. China relies on coal for most of its industrial and household energy needs, and coal burning is one of its biggest environmental problems (Clay, 2002). Acid rain falls on an estimated 30 percent of China's total land area. Respiratory diseases are amongst the country's biggest health hazards. This is especially the case in major cities such as Beijing, where besides the threat posed by coal burning, 100,000 new vehicles take to the roads each year. In 2002, China ratified the Kyoto Protocol which internationally came into force in February 2005. China is a non-Annex I country under the United Nations Framework Convention on Climate Change, meaning it has not agreed to binding emissions reductions in the Kyoto Protocol.
Almost 60 percent of Italy's energy comes from oil, most of which is imported. Gas accounts for another 30 percent of energy use. Coal, hydro and renewables provide for most of the rest. Most electricity is generated with oil. Natural gas and, to a lesser extent, renewables are becoming important sources of power. Italy’s dependence on energy imports is about 90 percent. Italy also contributes 1.86 percent of world carbon emissions.
In 1997, Italy signed the Kyoto Protocol. Now, it is going to struggle to cut its greenhouse gases to comply with Kyoto targets, which could cost up to 3 billion euros (3.9 billion US dollars). Italy's Kyoto target is to reduce emissions by 6.5 per cent from 1990 levels, but in 2002 emissions had climbed 8.8 per cent instead. The Ministry of the Environment estimated that Italy's emissions would be 576 MtCO2e in 2010, down from the 613 MtCO2e it would have had without

abatement measures. Yet, that is still 101 MtCO2e above the 475 Mt target (Vagnoni, 2005).

In this paper, the enterprise input-output model has been applied to analyze the product data of two tile manufacturers: one located in Sassuolo, Italy, the other located in Foshan, China. The two have been compared the two in terms of energy/material flows. One of the reasons why these two countries were chosen (even though the topic of localization is not discussed in this paper) is because the internationalization process of enterprises represents a powerful factor that shapes and modifies the organizational model of industrial clusters. In particular, many Italian firms have located some production phases in China and there are already quite a few joint-ventures.

To summarize, the aims of this research are:

(1) To compare the product data and find similarities and differences on tile production;

(2) To improve the design and management of supply chains by evaluating how one can change the input mix and respect environmental constraints;

(3) To help plan local development strategies to render more green and/or efficient the supply chains under investigation, using possibly one as benchmark for the other;

(4) To determine the processes that contribute more to environmental pollution, and support investment decisions when substituting traditional energy technologies in favour of sustainable ones.

2. Literature review

2.1. Enterprise Input Output approach

Modeling at global and local levels includes a number of factors which can make it difficult. When the micro-scale of local development is considered, the analysis needs to be accurately disaggregated.

Lin & Polenske (1998) built a specific input output model for a generic steel plant based on production processes rather than on products or branches. Using a similar approach, Albino et al. (2002, 2003), and Albino & Kühtz (2003, 2004) have formulated enterprise input-output models to map production activities, and to interrelate and estimate flows of energy and materials, including the use and consumption of fuels and production of pollutants within the supply chain of a final product. They applied the model to production processes of Italian enterprises and industrial districts[1].

Defined as a production process the transformation of input flows in output flows, the **supply chain** is considered as a network of processes that procure raw materials, transform them into intermediate goods and the final product, and then deliver the product to customers through a distribution system. In particular, the original equipment manufacturer of a supply chain, can be the leader firm of an industrial district, fundamental cell of Italian economy and local development of regions.

This input-output approach can be used to analyse not only the flows (ie: raw materials, energy, products, pollution, imports and exports) relative to the processes of the chosen local supply chain, but also the relationships amongst these processes and those belonging to other enterprises or geographically localized elsewhere (global supply chain). This enterprise input-output approach based on production processes, as described in details by Albino et al. (2002, 2003) can be used:

[1] An **industrial district** is a production system of small-medium size, interdependent firms localised in a given geographic area, highly specialised on one or more phases of production processes, and co-ordinated through both market-like mechanisms and personal relationships based on mutual trust.

1. To recognize functional relationships amongst the flows of processes in a local and global supply chain;
2. To determine the processes that contribute more to environmental pollution;
3. To evaluate how one can change the input mix or the imports rate (for instance of energy sources) in order to respect environmental constraints (e.g. to reduce pollution, keeping other output flows constant).

This is the approach which will be used in the course of this paper.

2.2. I-O in China

The path of the input-output model development in China at a macro level started in 1985, when it pursued a market research using the I-O model. An Input-Output table about Beijing's economy was compiled that same year. In 1987, some management departments completed their input-output tables, while some corporations tried to compile their enterprise input-output tables (Kuang 1994). In March 1987, the State Council of the People's Republic of China decided to carry out the input-output investigations on a national scale. The accomplishment of *The National Input-Output Table of 1987* marked a new step in developing the input-output technology. In 1992, the State Statistics Department created the input-output extension table based on the aforementioned *National Input-Output table of 1987*. In 1994 and 1995, the State Statistics Department compiled the national export value table which rested on the above input-output table of 1992 (Sun, 1994). These input-output investigations have been applied to the base data for some macro-decisions such as *85plan* and *95plan* of Beijing. In 1999, the national input-output table was compiled (Gong and Qu, 1994).

In 2000, Guo analyzed some important trends on change in the Direct Input Coefficient of China using the I-O model. The trends included the decrease of agriculture input coefficient, decrease of energy input coefficients in most sectors in the period of 1981-1995, increase of chemical input coefficients from 1981 to 1995, and the average input coefficients of machinery and electronics sectors increased drastically, as well as commerce input coefficients. Yet although remarkable, the above applications of input-output approach of China are concentrated on the macro scale. Polenske (1999) studied the importance of using regional input-output analyses for energy and environmental studies in China. With McMichael (2002), she illustrated how a process-flow IO model could be used for cokemaking in China.

Based on our current knowledge, the applications of the enterprise input-output approach is probably less mature in China than in the western countries. This article could represent some advances to improve the applications of the EIO approach in China.

3. The Chinese tile industry

In China, tile manufactures have developed very fast in recent years. In particular:

1. In the 1950s, the total number of tiles produced for buildings was 3000 m^2, and in 2003, this number raised to more than $2000 \cdot 10^6$ m^2
2. In 2002, the number of tile manufactures in the whole country was more than 3800. Their output increased quickly from 70-100 m^2 in 1980s to $2000 – 3000 \cdot 10^3$ m^2 and the output of the biggest tile corporation equaled approximately $10000 – 15000 \cdot 10^3$ m^2 in the last 3 years.
3. China is one of the largest tile production countries in the world (see Table 1).
4. There has been an increase in tile production exports in the recent years. The

international market occupation has enlarged 210 percent from 1997 until now. More recent data show that in 2003, China definitely became the leading producer of ceramic tiles (with around 1.8 million m^2 per year), followed by Spain, Brazil and Italy.

5. In China — which has in the space of a few years overtaken Italy in terms of quantity of tiles produced — the productive capacity installed was, until a short while ago, the result of investments in complete plants bought from the few Italian firms leading this market. For further expansion of the productive capacity in the already active factories, the Chinese tile producers turned directly to the Italian producers of single machines. However, it is more and more frequently the case that the Chinese ceramic firms purchase only one or a few machines from the Italian producers. Those machines are subsequently copied by Chinese producers and sold on the Chinese market, and even on the foreign market (Far East and Middle East) (Russo, 2003).

3.1. The Chinese tile district of Foshan

The Chinese production of tile**s** is destined mostly for the domestic market and is concentrated in five areas: Foshan, accounting for nearly half of China's output, Shanghai, Shandong, Fujian and Chongqing. Foshan is a historical city in the mid-south of GuangDong province. It is located in the Zhu River delta. Foshan measures a territory of 3813.64 square kilometers, and its population is 3.3 millions.

There are several kinds of natural resources in Foshan such as clay, rock, vitreous sand stone, rare metals, etc. The primary economy of Foshan is industry. In 2004, the GDP of whole city increased 16.3 percent beyond the previous year. As a result, the industrial output value occupied 65.8 percent. At present, there are about 30,000 industrial corporations. In Foshan, tile manufacture has a long history for more than 5,000 years. In 2003, the tile product of Foshan represented the 60 percent of the whole country's product. So, in a sense, Foshan is a "tile city". As the biggest global tile product base, there are more than 500 tile productive enterprises in Foshan, and in those enterprises, 298 have a big scale. There are 86,085 persons engaged in the tile production. There are more than 1,200 production lines in the whole city, and the production ability of wall-floor tiles can reach 1.5 billion m^2 (Huang 2003).

4. The Italian tile industry

In 2000, Italian firms produced around 600 million m^2 of ceramic tiles, almost 80 percent of which were produced by 190 firms in the ceramic tile industrial district of Sassuolo. The district is formed by ten municipalities in the provinces of Modena and Reggio Emilia in the North of Italy. Emerging at the end of the 1940s, large scale production of ceramic tiles increased rapidly - especially in the period 1960-80 which witnessed the increase of output from 37.8 million m^2 in 1960 to 355 million m^2 in 1980. In the same period the proportion of exports went up from 3.5 percent to 45 percent, giving Italy a clear lead in the world market.

4.1. The Italian tile district of Sassuolo

The Italian ceramic tile industrial district is located in ten municipalities in the provinces of Modena and Reggio Emilia in Northern Italy. In the whole, the area covers a surface of about 485 square kilometers with around 171,000 inhabitants. Only forty years ago, Sassuolo was an almost completely agricultural and depressed area challenging the strong specialization of Germany in tile production and machines for tile making. Germany gradually left off specialization in producing machines for tile making, extending its already vast presence in other fields in machinery manufacturing. Today, the district of Sassuolo could cope with the Chinese competition which occurs on several levels not so much through policies of patent protection or trade barriers, as by reinforcing its innovative capacity (Russo, 2003).

In the last forty years, output and labour productivity have increased continuously while the number of firms and employees has decreased. The main factors in the development of ceramic tile production in the industrial district have been the following: easy access to raw materials (different kinds of clays) in the mountains in that area; abundant labour force due to the depressed conditions in that area during the 1950s; and long and medium credit term facilities, which lasted till the middle of the 1970s for new enterprises in depressed areas.

To recover from the financial problems emerging at the end of 1970s, many ceramic tile firms formed groups based either on reciprocal shareholding or trading links. In general forty groups control 70 to 80 percent of the firms in the industry. The strategy of increasing the overall size is crucial in gaining all the economies of overall size, diversification and vertical integration control from raw material to sales organization. The district is Ecolabel certified and since 1970 has strongly believed in environmental management and control as competitiveness factors. It is a very innovative district because of its efficient use of resources such as water, energy and primary inputs. Between 1981 and 1985, the cost of energy was about the 25 percent of the district production total cost, whereas during the 1990s it dropped down to the 13–14 percent, due to energy policy strategies aimed at energy consumption, reduction, and optimisation (Nassetti et al., 1998). However after four decades of undisputed leadership on the world market for tiles, Italy has now sunk to fourth place behind China, Spain and Brazil. The enormous and rapid growth of China's tile production, driven by a domestic demand in strong expansion, was made possible by adopting avant-garde machinery produced in the ceramic district of Sassuolo. The district is a world leader in the production of machines for ceramic tile making as well as in the production of tiles themselves. Supported by strong intersectorial flows of knowledge in the field of machinery manufacturing and by a sharp increase of domestic demand, China is also beginning to produce machines for tile making, copying those developed in the Sassuolo district, which could also be destined for export (Russo, 2003).

The Sassuolo ceramic district thus finds itself in a transition phase where one of its success factors (the relations between the producers of machines for ceramic tile making and the users of those machines such as the producers of tiles), is also a condition for the success of other ceramic production systems. Additionally what is happening today with the Chinese system, in particular, is calling for changes of strategy on the part of the various actors in the Sassuolo district. This paper will not address the issue of these two systems.

What this paper is particularly interested in is materials/energy flows. In the Sassuolo district, the reuse of heat flows, increase of energy efficiency in some processes (i.e. the cooking process), and the optimisation of processes management have been adopted for more than twenty years now. Innovation is indeed still the key to understanding the continuing expansion of the Sassuolo district. Because new technologies keep arising to improve the energy efficiency of all the diverse machinery used, in the near future there might be margins for improvement and further energy reductions in the district.

5.The EIO model

This model is based on an input-output table which gathers materials and energy flows data related to the production processes of the enterprises investigated. It also allows for the quantity of resources use and consequent pollution emissions, as done in Albino Dietzenbacher & Kühtz (2003) for clusters. Flows of materials and energy, measured in physical terms, are inputs and outputs of processes composing the supply chains within the enterprises. A production process is considered as a function that transforms inputs (resources including energy) into outputs (wastes, by-products and product) (Figure 1). In Figure 2, a simplified processes supply chain is presented.

The model can also be used as a planning tool to help foresee possible development scenarios. For example, it is possible to compute changes of the input flows if the final demand changes or if a technological innovation occurs (e.g. efficient energy use) to respect environmental constraints (e.g. reduce pollution keeping final demand flow constant).

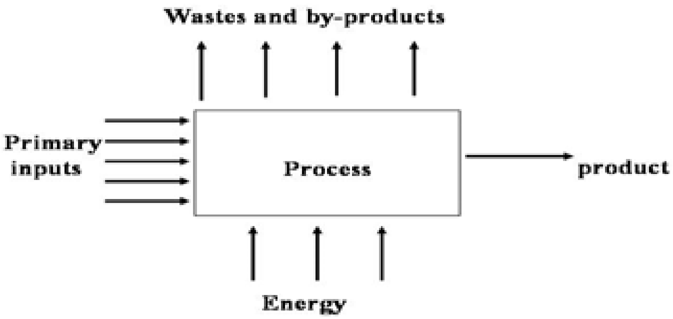

Figure 1. A production process transforms inputs into outputs.

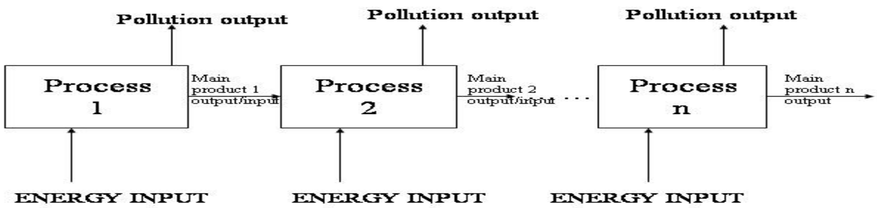

Figure 2. Simplified process supply chain composed of n processes.

We suppose that there is only one main product per process. Let $\mathbf{Z_0}$ be the matrix of 'domestic' main products (to and from processes in the enterprise investigated), intermediate deliveries, $\mathbf{f_0}$ is the vector of final demands and $\mathbf{x_0}$ the vector of gross outputs. In the empirical cases examined, as showed further, we consider the production of *single firing* tiles for which five processes are distinguished (for a generic supply chain we have instead a number α of production processes). Each of these processes may require intermediate inputs from the other ones, but not from itself, so that the entries on the main diagonal of the matrix $\mathbf{Z_0}$ are zero. Of course, other inputs are also required for production. These are β primary inputs (i.e. intermediate inputs of products not produced by one of the five processes) and λ types of energy. The processes also produce by-products and waste. Define the intermediate coefficient matrix **A** as follows $\mathbf{A} \equiv \mathbf{Z_0}\ \hat{x}_0^{-1}$ where a 'hat'is used to denote a diagonal matrix. The result is: $\mathbf{x_0} = \mathbf{Ax_0} + \mathbf{f_0} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{f_0}$.

Where the matrix notation indicates:

A = $[A_{ij}]$= matrix of intermediate input-output coefficient (i.e. output of product i per unit of output of product j);

f = $[f_i]$= vector of the final demand (deliveries leaving the enterprise to the final client);

x = $[x_i]$ = vector of the gross output;

I = $[I_{ij}]$ = identity matrix.

A change in the final demand vector induces a change in the gross outputs and subsequently changes in the input of energy and primary products, and changes in the output of by-products and waste. Suppose that the final demand changes into f' and that the intermediate coefficients matrix A is constant (reasonable in the short-run), then the output changes into $\mathbf{x'} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{f'}$. Given this new output vector, the requirements of primary inputs and of energy, and the output of by-products and waste are given as follows:

$$\mathbf{r'} = \mathbf{Rx'}$$
$$\mathbf{e'^{d}} = \mathbf{Ex'}$$
$$\mathbf{w'} = \mathbf{Wx'}$$

Where **r'**gives the β×1 vector of primary inputs, **R** the β×α matrix of primary input coefficients with element r_{kj} denoting the use of primary input k (= 1,..., β) per unit of output of product j, $\mathbf{e'^{d}}$ gives the λ×1 vector of demand for the λ energy types; **E** is the λ×α matrix of energy input coefficients with element e_{kj} denoting the input of energy of type k (= 1,..., λ) per unit of output of product j; **w'**is the β×1 vector of by-product or waste types; **W** is the β×α matrix of wastes output coefficients with element w_{kj} denoting the output of by-product or waste of type k (= 1,..., β) per unit of output of product j. Note that the coefficient matrices **R**, **E** and **W** are numerically obtained from observed data and kept constant when the final demand vector is changed.

6. Case Studies

The case examples presented in this section refer to actual supply chains. In Italy, it has been easier to get the data, because the firms in the district are organized so to refer to a *super partes* association, Assopiastrelle, which monitors constantly firms' performances. In Italy, the original equipment manufacturer chosen is a leader firm in the world market of tiles and is located in the fore-mentioned Italian industrial district of Sassuolo. It produces different types of tiles, but only the *single firing* line of production is being considered in this case.

The corresponding tiles corporation located in China, Foshan, is a big tile corporation which produces different types of tiles and only the *single firing* line was considered for this paper. Since its foundation in August 1998, the corporation has introduced ISO9001 Quality Control System and ISO14001 Environment Quality Control System. In both cases the first stage of the production process is the preparation of the raw materials by a drying process of grinding the clay into a fine powder that is then moistened and pressed into tile shape. There is then a difference because the Chinese *single firing* chain produces polished tiles and the Italian one produces glazed tiles.

6.1. The Chinese tile company

The staff of this manufacturing company (the only one that responded out of ten companies contacted during this part of the research) opened its doors to its whole production processes by giving a guided tour. The main production processes that compose the company supply chain (Table 2 and Figure 3) are as following:

• *Mixing process*: The clay, crude wastes reused and other materials (that depend on the type of tiles to be produced) are grounded and sifted and mixed with water and mud.

• *Pressing and drying process*: The mixed clay is first pressed and then dried to obtain crude dried tiles.

• *Cooking process*: It is a continuous process that has the scope to consolidate the tiles; it is composed of preheating, cooking and cooling.

• *Polishing:* Tiles are polished first roughly and then finely.

• *Selection and packaging process*: Tiles are selected according to quality and colour and are then packaged with machines that automatically put the tiles in boxes.

In terms of outputs, each process is characterized by a single main product (a specific intermediate or final product), and by waste, pollution and by-products.

Based on the local supply chain indicated in Fig. 3, a materials/energy balance table can be completed (Table 3), it represents the actual material/energy accounting of the company supply chain. The present data (in physical units) for the five process company supply chain are distributed in four sections: main products, imports, purchased inputs, by-product and waste outputs. The last line is a recall of the main products of each process and is comprised of the diagonal elements of the matrix of the first section. The data in the table refer to year 2004.

Table 2. Production processes and related products.

Production process	Main product
Mixing, A	Clay mixture, CM
Pressing and drying, B	Dried Tiles, DT
Cooking, C	Semi-product, SP
Polishing, D	Polished tile, PT
Selection and packaging, E	Final product, FP

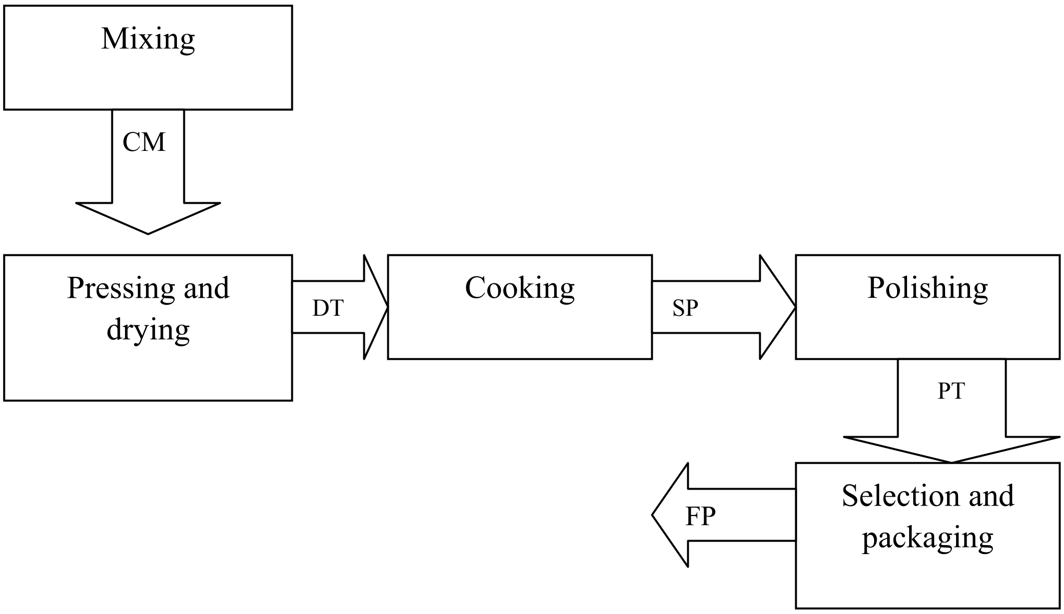

Figure 3. Chinese company processeses and its main products.

Table 3. Balance table for the Chinese tile company considered in the case example.

		Production processes					
		A	B	C	D	E	
P. processes and products	Units per year 10^4	Intermediate consumption of main products z_{ij}					Finaldemand $\mathbf{f}_i$
A – Clay mixture	t	0	16.30	0	0	0	0
B – Dried tiles	t	0	0	15.60	0	0	0
C – Cooked tiles	t	0	0	0	15.13	0	0
D – Polished tiles	t	0	0	0	0	14.74	0
E – Packaged tiles	t	0	0	0	0	0	14.76
Types of purchased inputs	Units 10^4	Primary inputs					Total
1-Clay	t	16.8	0	0	0	0	16.8
2 – Water	m^3	Not measured	0	0	NM	0	NM
Types of energy inputs	Units 10^4	Energy inputs					Total
Electric power	MWh	1.26	0	1.11	1.40	0.04	3.81
Heavy oil	kcal	4387224	0	0	0	0	4387224

Diesel oil	kcal	0	0	1848000	0	0	1848000
Natural gas	kcal	0	1203846.8	7932425.8	0	0	9136272.6
by-products & waste outputs	Units 10^4	Output of by-products and waste					Total
1- Crude wastes	t	0	0.702	0	0	0	0.702
2-Washing mud	t	0.504	0	0	0	0	0.504
3- Cooked wastes	t	0	0	0.234	0	0	0.234
4- Polished crude wastes	t	0	0	0	0.197	0	0.197
5- Polished wastes	t	0	0	0	0.039	0	0.039
6- Selected wastes	m^3	0	0	0	0.0151	0.0147	0.0298
7 – CO_2	kg	1385.11	324.4	2680.1	1.12	0.036	4408.77
8 – Packaged wastes	t	0	0	0	0	0.442	0.442
9 – flowing water	m^3	NM	0	0	NM	0	Not measured
Gross output of main products	x_j	16.30	15.60	15.13	14.74	14.66	

6.2. The Italian tile company

The company chosen is a leader firm in the world market of tiles and is located in the fore-mentioned Italian industrial district of Sassuolo (basically all the companies contacted responded, but for this work we chose the biggest in the area) (Albino & Kühtz, 2004).

Table 4. Production processes and related products for the Italian company.

Production process	Main product
Mixing, A	Clay mixture, MC
Pressing and drying, B	Dried Tiles, DT
Glazing, C	Glazed tiles, GT
Cooking, D	Cooked tiles, CT
Selection and packaging, E	Packaged tiles, PT

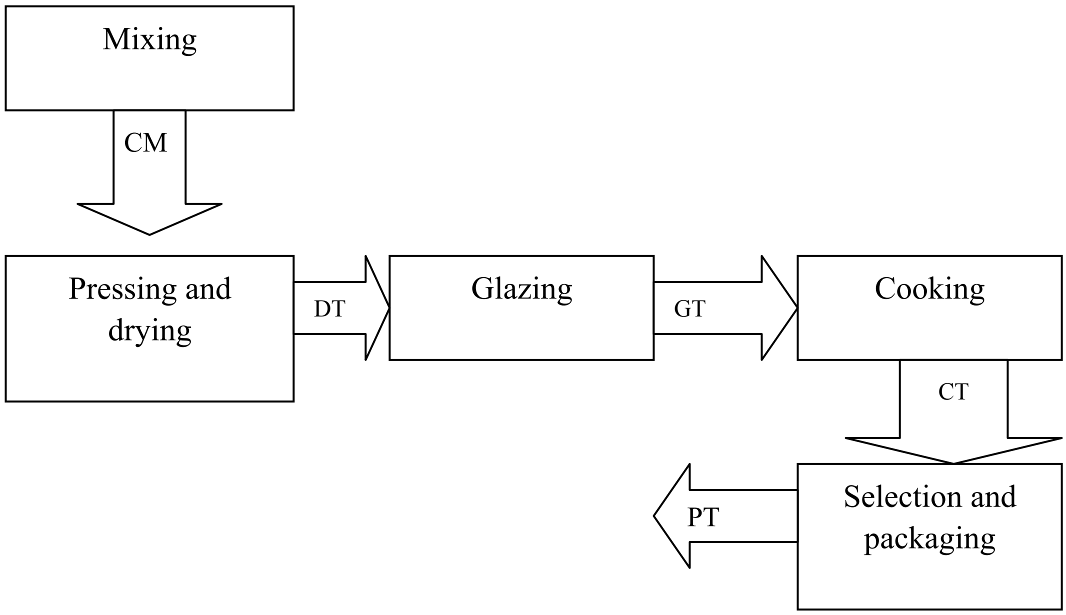

Figure 4. The Italian tile company processes considered in the case example and its main products.

The main production processes that compose the company supply chain (Table 4 and Fig. 4) are: *Mixing process*: The clay, crude wastes reused and other materials are grounded and sifted and mixed with water and mud; *Pressing and drying process*: The mixed clay is first pressed and then dried to obtain crude dried tiles that are then decorated in the *glazing process*; *Cooking process*: It is a continuous process that has the scope to consolidate the tiles and fix the glazing. It is composed of preheating, cooking and cooling; *Selection and packaging process*: Tiles are selected according to quality and colour and are then packaged by machines that automatically put the tiles in boxes.

Table 5. Balance table of the Italian tile company considered in the case example.

		Production processes					
		A	B	C	D	E	
P. processes and products	Units per year	Intermediate consumption of main products z_{ij}					Finaldemand $\mathbf{f}_i$
A – Clay mixture	t	0	27950	0	0	0	0
B – Dried tiles	t	0	0	28000	0	0	0
C – Glazed tiles	t	0	0	0	27200	0	0
D – Cooked tiles	t	0	0	0	0	27230	0
E – Packaged tiles	t	0	0	0	0	0	26700
Types of purchased inputs	Units	Primary inputs					Total
1 - Crude wastes reused *	t	86	0	0	0	0	86
2-Clay	t	28 170	0	0	0	0	28 170
3- Washing mud reused *	t	350	0	0	0	0	350
4 – Glaze	t	0	0	160	0	0	160
5 – Water	m^3	16912	460	2 613	0	0	19985
6 – Recycled water *	m^3	0	0	390	0	0	390
Types of energy inputs	Units per year	Energy inputs					Total
Electric power	MWh	1530	1154	160	750	140	3734
Thermal power (natural gas)	kcal	$70 \cdot 10^8$	$30.8 \cdot 10^8$	0	$190 \cdot 10^8$	$20 \cdot 10^8$	$310.8 \cdot 10^8$
by-products & waste outputs	Units	Output of by-products and waste					Total
1- Crude wastes *	t	0	436	0	0	0	436
2-Washing mud *	t	401	0	0	0	0	401
3- Mud	t	0	0	303	0	0	303
4- Cooked wastes	t	0	0	0	627	604	1231
5- Glazed crude wastes	t	0	0	675	0	0	675
6- Flowing water	m^3	2913	0	2278	0	0	5191
7 – CO_2	kg 10^4	158	69.58	0	429.18	45.18	701.94
Gross output of main products x_j		27 950	28000	27200	27230	26700	

In terms of outputs, each process is characterized by a single main product (a specific intermediate or final product), and by waste, pollution and by-products. Based on the local supply chain indicated in Fig. 4, a materials/energy balance table can be completed (Table 5), which represents the actual material/energy accounting of the company supply chain. The data in the table refer to the year 2002.

Each column provides information on inputs and outputs for each production process. For example, to produce 28,000 t of dried tiles in process B it is necessary to consume 27, 950 t of clay mixture produced in process A and to purchase 460 m^3 of water. At the same time, 436 t of crude wastes are produced. It can be noted that some inputs are recycled waste - these products (e.g., water) are indicated in the table with a star. The company is rather careful in terms of rational use of the resources and has recently developed a system to monitor water flows and energy consumption. In the whole, the company consumes 0.14 MWh of electric energy and 0.73m^3 of water per ton of packaged tiles per year.

6.3. Comparison and preliminary results

The comparison is straightforward if one takes into account the balance tables of the two companies (see Tables 3 and 5) and all the input-output coefficients tables calculated as indicated in section 5, which have been omitted here for brevity.

So, for example, portions of Tables 3 and 5 can be considered (they indicate the elements of *by-products and waste*) to calculate the input-output byproduct/waste coefficients. The result gives that the total w_{CO2} coefficient per unit of total output is 300 kg of CO_2 per unit ton of final product in the Chinese company.

The same coefficient for the Italian company is 262 kg of CO_2 per unit ton of final product. Therefore in this respect the Italian firm is slightly more efficient. In fact, it uses only electric energy and natural gas as energy inputs (see Table 5), whereas the Chinese company uses also diesel oil and heavy oil (Table 3). However, the fact is that this is only a small difference.

It can also be noted that in the Chinese company water consumption is not measured. In fact, they do not have any gauges to measure water usage, nor do they reuse any of the wastes or by-products or water, that instead are reused in the Italian company. This can be an important improvement to make in the Chinese company considering how important water shortage is going to be in the future. The Italian company needs 0.73m^3 of water per ton of packaged tiles per year.

Additionally, the input-output energy coefficients can be calculated (Table 6), from the portions of Tables 3 and 5 which indicate the *energy* consumption flows.

Table 6. Total energy input coefficients e_k per unit of total output produced.

	Electric energy coefficient	Thermal energy coefficient
China	e_{el} = 0.259 MWh/ton	e_{th} = $105 \cdot 10^4$ kcal /ton
Italy	e_{el} = 0.139 MWh/ton	e_{th} = $116 \cdot 10^4$ kcal /ton

The result is that the Italian company consumes in total 0.139 MWh of electric energy per unit of total output produced. The Chinese company consumes in total 0.259 MWh of electric energy per unit of total output produced.

The Italian company consumes in total $116 \cdot 10^4$ kcal of thermal energy produced with natural gas. In comparison, the Chinese company consumes in total $105 \cdot 10^4$ kcal /ton (derived from

natural gas, diesel oil and heavy oil). The fact that similar values are being shown for the thermal energy coefficients indicates that this Chinese company uses up to date technologies (e.g. machines and appliances). In fact, as already mentioned, it was founded quite recently, in 1998, and is reasonable to think that it has new plants.
But, what is surprising is that to produce a ton of packaged tiles the Chinese company consumes almost twice as much than the Italian company in terms of electric energy. It is surprising that the data we have, show in this case a waste of the noblest, more valuable kind of energy: the electric energy. This interesting observation deserves more in depth investigation.

7. Conclusions

In Italy, industrial districts represent even today an important socio-economic pivot for local development, where in China similar industrial clusters[2] are developing. This paper is based on an enterprise input-output model applied to supply chains of companies located in industrial districts. In particular, two tile companies have been investigated: one in Italy and one in China.
China and Italy are amongst the biggest tile production countries in the world. The Chinese production of tile**s** is destined substantially for the domestic market and is concentrated in five areas: Foshan, accounting for nearly half of China's output, Shanghai, Shandong, Fujian and Chongqing. The Chinese company for this case example is located in Foshan, where there are more than 500 tile productive enterprises, 298 of which are big scale enterprises, like the one that represents the Chinese case example.
Almost 80 percent of the Italian tile production is produced by 190 firms in the ceramic tile industrial district of Sassuolo formed by ten municipalities in the provinces of Modena and Reggio Emilia in the North of Italy. The Italian company for this case example is one of the biggest tile companies in the district of Sassuolo.
The model used as an accounting tool shows immediately through the balance tables the attention both the firms pay to environmental issues. In fact, in the case study presented, the Italian firm considered uses the most up to date technologies available, so its coefficients may be used as a benchmark for other similar firms (in the same district or other areas). Moreover, comparing the values and technical IO coefficients with those that represent the Chinese company, the evidence shows that the latter are not so different. The only macroscopic differences are the fact that the Chinese company does not gauge the water consumption and the reuse of water, energy, and materials.
The tables are a tool handy to use also for managers and public administrators to monitor their firm performance. The proposed approach seems particularly suitable to support the planning of local sustainable development actions. In this paper, big companies with innovative and updated plants and environmental regulations have been recognized. Nevertheless we have found that in the Chinese company there is a waste of the noblest type of energy, electric energy, these results deserve in depth investigations so to understand why this happens.
In the near future, we intend also to extend the analysis to the whole district of Sassuolo and the Foshan area and in particular to the small enterprises that compose the two areas.

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[2] Similar in terms of final products produced.

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