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Comparative Life Cycle Assessment of flooring materials: ceramic versus marble tiles[☆]

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Abstract

Flooring materials, particularly ceramic and marble tiles, play a relevant role in the Italian economy since this country covers respectively 23% and 18% of the world output in this sector. In this paper a comparative Life Cycle Assessment between these two flooring materials has been carried out in order to identify the one with the best environmental profile and the hot spots of the two systems. The analysis has shown a better environmental profile for the marble tile, a particular relevance of the energy consumption in both the system and, in the ceramic system, the critical point has been found in the raw material used for the glaze manufacturing which are responsible, during the firing process, for the relevant arsenic emissions.

Keywords: LCA; Flooring tile; Ceramic; Marble; Glaze

1. Introduction

Building materials represent an important research field in the environmentally responsible architecture [1]. Different floor coverings have been already studied with the Life Cycle Assessment (LCA) methodology in order to identify the so-called environmental hot-spots of the systems [2–4].

In this paper a comparative LCA between two flooring materials, not previously analysed, for buildings has been carried out: marble and ceramic. The choice of this typology of good is due to their relevance in the Italian economy and to the growing interest in environmental concerns in the building sector.

Italy is the most important producer of ceramic and marble tiles for buildings, with a production respectively about 18% and 23% of the world output in this sector [5,6].

There are three kinds of flooring ceramic tiles: unglazed (fired ware, red stoneware, porcelain stoneware, clinker); double-fired glazed; single-fired glazed. Consequently there are three productive processes which differ in the use of glaze and in the number of firing cycles (Table 1).

The 1998 Italian production of tiles for flooring and coating exceeded 600 million m^2, of which 57% was single-fired, 15% double-fired, 22% porcelain stoneware, and the remaining shared among other products as plain-fired and complements. In this study the single-fired flooring tiles are assessed.

Table 1
Typologies of tiles and technological requirements

	Glaze		Firing cycles	
	Yes	No	Before enamelling	After enamelling
Unglazed		X	1	
Double-fired	X		1	1
Single fired	X			1

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The world-wide production of marble is concentrated in a limited number of countries, particularly the European Union which supplies 46% of the globally extracted marble. Even in this sector Italy plays a primary role, since it is the main producer of raw and decorated marble with 58% of the world exportations of marble products [6].

2. Goal and scope definition

2.1. Goal of the study

The goal of the study is to compare the environmental profiles of the ceramic and marble tile in order to identify the one with the best environmental profile and the hot spots of the two systems.

2.2. Scope of the study

2.2.1. Systems, function of the systems and functional unit

The systems of the analysis are the single-fired ceramic and the marble tile. The function of the system is to ensure a proper cover of a building floor. The functional unit chosen is 1 m^2 of flooring tile over a period of 40 years.

2.2.2. System boundaries

The study covers the entire life cycle of the two systems; only few operations, for which no good data were available, have been excluded. In particular, for both the systems we have excluded the materials used to fix the tiles, because of lack of good quality data and of the equivalency of the two systems (mortar and adhesives), and all the products used for cleaning and hygiene.

Moreover, for the ceramic tile we have excluded:

- The emissions coming from the neutralisation of the exhausted lime from the abatement of the combustion fumes (Soliroc™ process) [7] and the sludge coming from the treatment of the waste water.

For the marble tile we have excluded:

- The production and the consumption of floor wax used during the tile life, and the production, use and disposal of the diamond wire.

2.2.3. Assumptions

For both the systems the following assumptions have been made:

1. the emissions of the electric energy production are those relative to the Italian energy system;
2. the distance of the transport of the materials used for the packaging of the functional unit from the collection point to the municipal solid waste incinerator is 10 km;
3. the distance of the transport of the tilling demolition to the landfill is 20 km.

Ceramic tile:

1. Average weight 18 kg/m^2[8].
2. The foreground of the manufacturing operations is the district of Sassuolo, Emilia-Romagna (North Italy).
3. The main countries from which the raw materials are imported have been identified using the Italian Trade Statistics.
4. The composition of the flue gas are measured downstream of the exhaust scrubber and of the abatements plants. These values represent an average of different plants operating in the district.
5. The manufacturing waste is recycled in the system.
6. The average life of the tiles has been assumed to be twenty years [9] on the basis of consumer preferences and of their technical characteristics. Consequently, the ceramic tiles have to be replaced once in order to fit in with the functional unit.

Marble tile:

1. The thickness is 1.8 cm and the average weight 48.6 kg/m^2 [10].
2. The foreground of the manufacturing operations are: the towns of Massa and Carrara, Tuscany (centre of Italy), which are 50 km from the extraction quarry.
3. The manufacturing waste is recycled out of the system after the required treatments.
4. The distance of the transport of the sludge from the sedimentation tank to the landfill is 10 km.
5. Disposal in landfill of the filter-press solid waste (called "marmettola"), since the reuse in cement, paper, varnish and plastic mills is still experimental.
6. The distance of the transport of the marmettola from the filter-press to the landfill is 10 km.
7. The average life is 40 years [9], during which two extraordinary maintenance operations of electric polishing and buffing and 400 ordinary waxing operations (length of each operation: 20 s/m^2) with electric machine by 0.4 kW power have been carried out.

2.2.4. Allocation

No allocation procedure has been done.

2.2.4.1. Ceramic system. The quantities and the prices of the materials which go out of the system are very small compared to those of the main materials: therefore allocation procedures on mass or economic basis are meaningless.

2.2.4.2. Marble system. Although the quantities of materials which go out of the system are relevant, they represent a waste of the production process; therefore there is no need to make an allocation on mass basis. Similarly, an economic-basis allocation is meaningless because of the extreme difference in the waste prices compared to those of the main products of the system.

2.2.5. Impact assessment methodology

The impact assessment methodology used is the "problem-oriented" [11] in which, as stated by the ISO series 14040 [12–15], the inventory data are associated with specific environmental impact categories in order to understand those impacts.

The impact categories which have been considered are: depletion of abiotic resources; global warming; ozone layer depletion; human toxicity; aquatic toxicity; acidification; nutrification; photochemical oxidant creation. The characterisation factors used are those stated in [11] with the exception of those cases in which factors have been updated (i.e. new global warming potential factors suggested by the IPCC) [16].

The normalisation factors are those on the European scale published by the Directoraat-Generaal Rijkswaterstaat [17].

The weighting factors are those published by the NOGEPA (Netherland Oil and Gas Exploration and Production Association) panel [18].

3. Inventory analysis

3.1. Ceramic tile inventory analysis

The life cycle of the ceramic tile and the relative material balance are shown in Fig. 1.

3.1.1. Productive cycle

The ceramic tile productive cycle is made up by two different stages: the first relative to the body manufacturing; (raw materials acquisition, mix preparation, forming, drying); and to the glaze manufacturing (raw materials acquisition, frit preparation and grinding); the second to the laying of the glaze on the body and the subsequent firing of the glazed body.

3.1.2. Body preparation

The process starts with the wet grinding of the raw materials in order to obtain a semi-manufactured that, after forming, is dried in kilns. 1.15–1.2 t raw materials are required to obtain 1 t of finished product.

3.1.2.1. Raw materials. The mix for the body production is constituted from different raw materials, particularly:

- Argillaceous materials (45%): they supply the wet mix with the plasticity required to obtain tiles which, in the raw state, already have proper mechanical characteristics.
- Degreasing materials (15%): siliceous sand or bauxite whose function is to rectify the plasticity and shape the ceramic core. They supply the necessary function to limit and control the dimensional variations taking place during the drying and firing operations.
- Soldering materials (40%: feldspars, 25% and limestone 15%); they have the function to produce, during the firing, a melt phase of proper viscosity which determines the compact and vitreous structure of the finished product.
- Recovered materials: they are waste from the operations of body preparation, enamelling, firing, exhausted lime from the cleaning of the firing furnace gases. The material balance for the production of 1 m^2 of ceramic tile body is shown in Table 2.

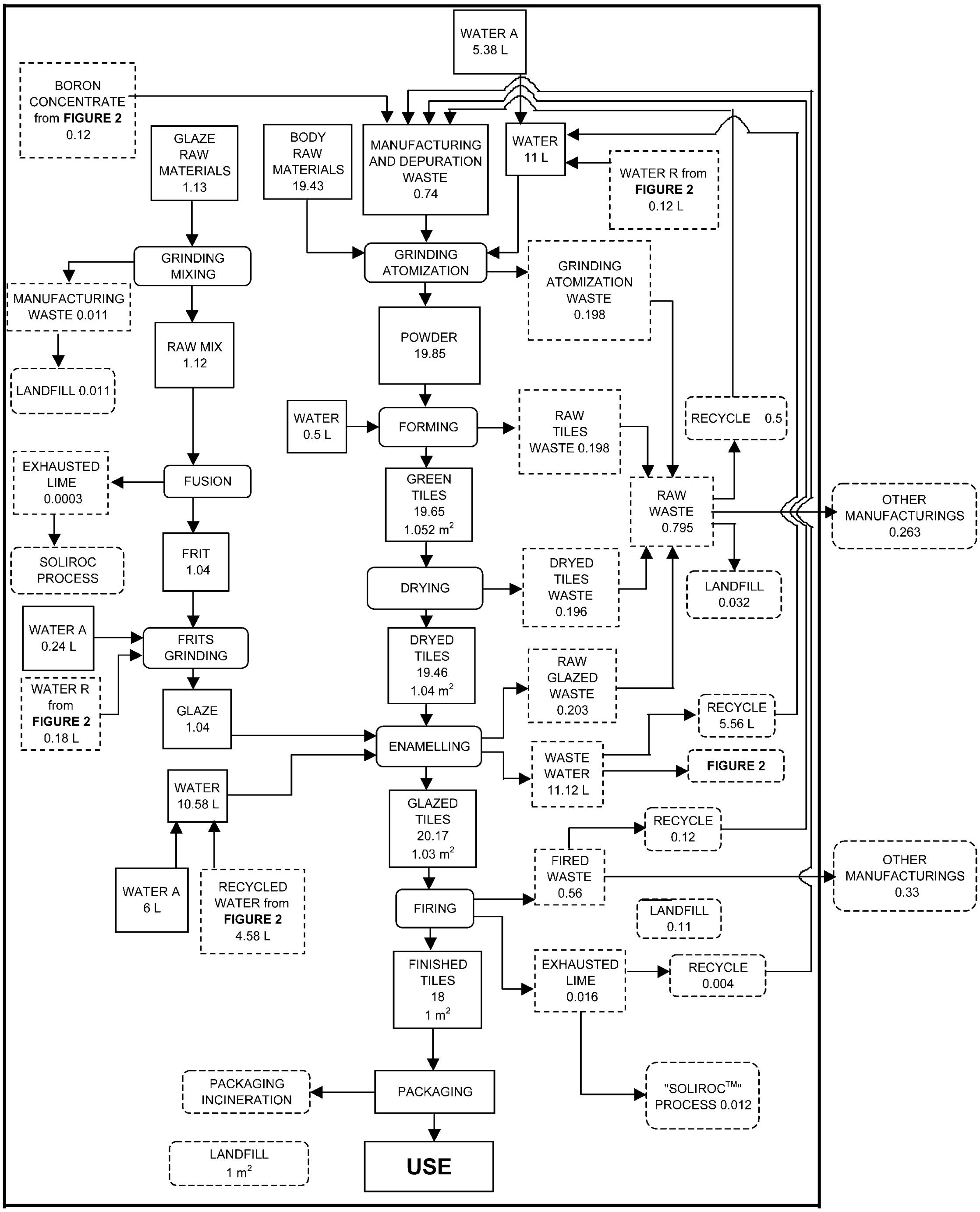
3.1.2.2. Mix preparation, forming, drying. Mix preparation: this consists of obtaining a material which has an homogeneous composition and a proper granulometric distribution. There are three main operations which make up this productive phase: grinding; mixing-soaking; and regulation of the water content. The first two phases can be carried out in different ways: dry (grinding of the raw materials and subsequent humidity regulation); wet (wet grinding of the raw materials and subsequent spray drying). The wet process is assumed in this study.

The main emissions in the atmosphere are relative to the movement and grinding of the raw materials, with relevant dust emissions, and to the combustion of natural gas.

In this phase there are no releases into water: it partly evaporates during drying, partly remains in the dusts. If the forming is carried out with the pressing process the humidity of the dusts will be between 4% and 7%, while with the extrusion process it will be between 15 and 20%. In this study the forming with the pressing process has been assumed.

Forming: the aim of the forming is to mould the tile in the specific "green" format. The result is a compact product with the mechanical characteristics required for the following manufacturing operations.

Drying: this operation enables the removal of the water required for the forming operation. The operative conditions must be rigorously monitored in order to prevent writhing, breakthroughs or other damage. The dried tile has a water content of $<1\%$. The dryers can be different, but usually those with pressed hot air are used.



Water A: water coming from the aqueduct
Water R: recycled water

Fig. 1. Ceramic tile life cycle (mass flow in kg).

3.1.2.3. Glaze manufacturing. The glazes are the vitreous coating of the tile working surface. They are applied to the surface of the body in order to make it impermeable, harder and more resistant, easily cleaned and more attractive.

Part of the raw materials must go through a thermal treatment, called fritting, which provides insolubility in water.

3.1.2.4. Raw materials. The glaze raw materials are shown in Table 3. The glaze is made up by one or more frits and other materials. It can be transparent, opaque, coloured. The opacifers and the colourings are generally metal oxide compounds.

3.1.2.5. Frit preparation. The frit is prepared after the wet grinding of the raw materials and the subsequent

Table 2
Materials used for the production of 1 m^2 ceramic tile body[a]

Raw materials	Quantity (kg)
Clay	8.80
Feldspars	4.89
Soldering	2.93
Silicious and feldspars sands	2.81
Ground fired waste	0.12
Ground raw waste	0.50
Exhausted lime	0.004
Boron concentrate	0.12
Total	20.17

[a] Source: our elaboration of the ASSOPIASTRELLE data.

Table 3
Average composition of the raw materials used in the manufacturing of the frit quantity used in the production of the functional unit

Raw materials	Amount (kg)
Zinc oxide	0.076
Zirconium powders	0.033
Colemanite	0.130
Dolomite	0.163
Penta-hydrate borax	0.110
Quartz and feldspar sands	0.251
Feldspar	0.221
Aluminium oxide	0.007
Lead oxide	0.129
Barium oxide	0.010
Tin oxide	0.001
Titanium oxide	0.002
Total	1.13

fusion of the mixture. The vitreous material obtained is added to the other raw materials, and then further wet ground. Its average composition is shown in Table 4.

Table 4
Average oxides composition of a frit[a]

Oxides	Composition (%)
Na_2O	3.9
K_2O	1.3
MgO	0.6
CaO	9.1
ZnO	8.1
Al_2O_3	6.0
ZrO_2	2.3
SiO_2	42.0
B_2O_3	11.4
PbO	13.8
BaO	1.1
SnO_2	0.2
TiO_2	0.2

[a] Source: our elaboration of the ASSOPIASTRELLE data.

3.1.2.6. Enamelling and firing of the glazed body. The conventional technique of enamelling is the wet one.

Enamelling: the average quantity of glaze necessary to cover the surface unit is 1 kg/m^2. This operation requires a relevant quantity of water with consequent generation of waste water.

Firing: this enables the tile to obtain the mechanical characteristics required for the different uses and the properties of chemical inertia. The firing can be conducted in different types of kilns. The operative temperature is about 1150–1200° and the fuel used is methane.

3.1.2.7. Waste water purification. The average water requirements in the production process taken in consideration is 0.024 m^3/m^2 of ceramic tile [19]. The operations which require water are the wet grinding of the raw materials and the preparation and application of the glazes. During these operations about 50% of the water is lost as steam. The waste water obtained during the glaze purification, about 0.012 m^3/m^2 of a glazed ceramic, can be recycled in the grinding of the raw materials. Therefore the water requirement of the process is about 0.012 m^3/m^2 of a glazed tile. In this study it has been supposed that $>$90% of the waste water is recycled [20] in the system, as shown in Fig. 2.

3.1.3. Packaging, use and disposal

The life cycle of the ceramic tile includes the operations of packaging, use and disposal. The distribution of tiles is carried out after packaging in cardboard boxes with polythene sheets.

During the use phase there are no emissions (the use of detergents used for the cleaning of the floor has been excluded from the system).

At the end of the life cycle the disposal consists of

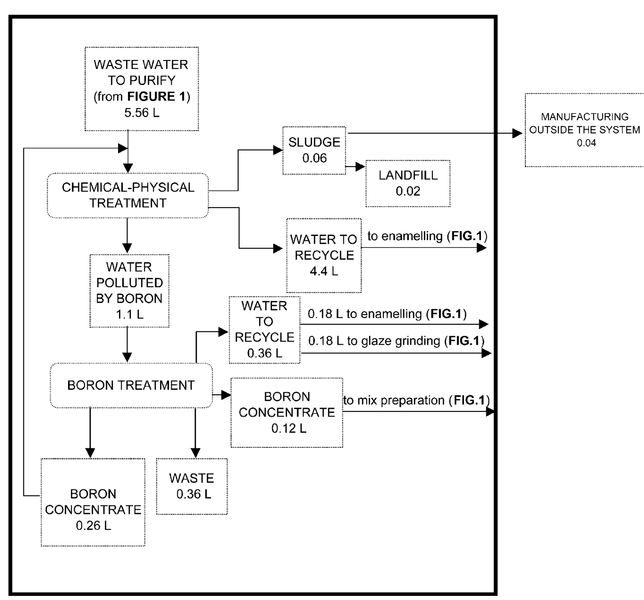


Fig. 2. Ceramic system waste water.

demolishing the tiles and transporting these inert materials [21] to the landfill.

In Table 5 the energy consumption relative to the main operations of the ceramic tile productive cycle are shown.

3.2. Marble tile inventory analysis

The life cycle of the marble tile and the relative material balance are shown in Fig. 3.

3.2.1. Productive cycle

The productive cycle of the marble tile is constituted by the following phases:

- quarry operations;
- raw blocks cutting;
- cutting of the standard size blocks (“refilatura”);
- polishing, buffing.

3.2.1.1. Quarry operations. The marble is extracted from the quarries using different techniques depending on the characteristics of the rocks and deposits. The main technique utilises the diamond wire that, running on the rocks, makes a linear cut. In the hollow a water and sand suspension is thrown. The water has the function to cool the diamond wire, while the sand is used to improve the abrasive function. After the rocks have been cut the quarry operations end with sectioning and cutting of the blocks. The maximum dimension of the blocks are 24 t (about 8 m^3), transportable on truck.

The main impact in this phase is essentially the production of unformed blocks called “ravaneti”, scabbing and stony fragments coming from the extractions which can be used to fill land or for other economic activities. Other impacts are those related to the use of electric energy and fuels for the functioning of the equipment.

3.2.1.2. Raw blocks cutting. In the factories the blocks are classified, sorted and cut. The cutting technology of the flooring marble tile features the cutting of the larger blocks in smaller sizes; (the length and the width of these blocks are already those of the final format, the thickness is five to six times that of the final product). In this phase the solid waste are constituted by sawing sludge and stony fragments called “cocciame”.

3.2.1.3. Standard blocks cutting, polishing and buffing. The last sawmill operation is the cutting of the standard size blocks, in order to obtain products of the required thickness. Usually from a reduced size block one can obtain four raw marble tiles.

The polishing and buffing operations can be carried out in factories but, more often, they take place after the laying. In this study it has been assumed that the first polishing and buffing belong to the marble tile production phase.

Table 5
Primary energy consumption for the manufacturing of a 1 m^2 ceramic tile[a]

Life cycle phase [*a*] phase	Electric energy (kWh) [*b*] energy	Thermal energy (MJ) [*c*]	Electric energy+thermal energy (MJ)[b] [*d*=(*b*×9.2)+*c*]lectric
Pre-production	2.92	2.24	29.09
Body raw materials	0.57	0.36	5.60
Transport body raw materials	0.47	1.54	5.86
Glaze raw materials	1.87	0.09	17.29
Transport of the glaze raw materials	0.01	0.25	0.34
Body production	1.81	49.33	65.97
Mix preparation	1.07	40.52	50.36
Forming	0.45		4.14
Drying	0.29	8.81	11.47
Glaze production	0.16	2.64	4.09
Grinding of glaze raw materials	0.03		0.27
Frit fusion	0.04	2.64	3.00
Frit grinding	0.09		0.82
Production	0.74	52.92	59.72
Enamelling	0.18		1.65
Firing	0.56	52.92	58.07
Use	0	0	0
Disposal	0	2.77	2.77
TOTAL	5.63	109.90	161.67

[a] Source: our elaboration of ASSOPIASTRELLE data.
[b] 1 kWh=9.2 MJ.

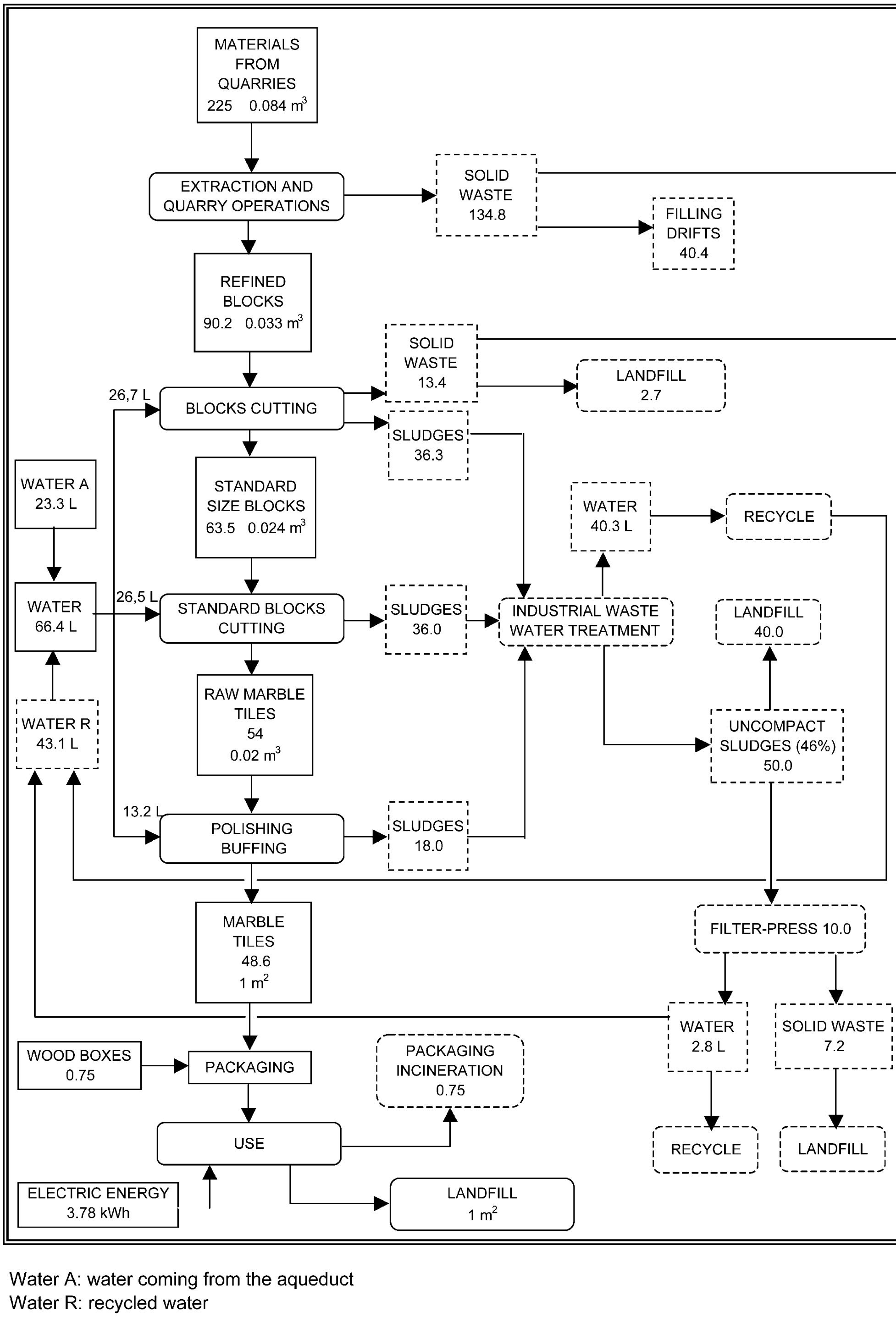


Fig. 3. Marble tile life cycle (mass flow in kg).

In Table 6 the energy consumption, subdivided in the different phases of the marble tile life cycle, is shown.

3.2.2. *Packaging, use and disposal*

The finished marble tiles are distributed after packaging in wood boxes, about 0.75 kg wood/m^2 of the marble tile. The disposal phase consists of the tilling demolition and their transfer to the landfill.

4. Impact assessment

In Table 7 the contributions of the impact categories to the eco-indicator[1]. of both the systems are shown. The

[1] This term does not refer to the methodologies "Eco-indicator 95" and "Eco-indicator 99", but to the environmental final score of the systems. For those methodologies see Goedkoop and Spriensma [23,24].

Table 6
Primary energy consumption for the production of a 1 m^2 marble tile

Life cycle phase [*a*]	Electric energy (kWh) [*b*]	Thermal energy (MJ) [*c*]	Electric energy+thermal energy (MJ)[a] [*d*=(*b*×9.2)+*c*]
Pre-production	5.94	9.1	63.75
Marble extraction	5.94	1.67	56.32
Transport	0	7.43	7.43
Production	6.48	0	59.61
Raw blocks cutting	1.67	0	15.36
Standard blocks cutting	1.94	0	17.85
Polishing-buffing	2.87	0	26.40
Use	3.78	0	34.77
Disposal	0	3.73	3.73
TOTAL	16.2	12.83	161.83

[a] 1 kWh=9.2 MJ.

Table 7
Contributions of the impact categories to the eco-indicator (in percentages)

Impact categories	Ceramic		Marble	
	Eco-indicator	%	Eco-indicator	%
ADP	2.53E-16	0	4.09E-16	0
GWP	1.93E-12	46	7.10E-13	37
ODP	8.33E-15	0	1.43E-14	1
HT	1.24E-12	29	4.47E-13	24
ECA	1.36E-13	3	1.36E-13	7
AP	6.70E-13	16	4.23E-13	22
POCP	1.46E-13	4	5.49E-14	3
NP	8.14E-14	2	1.18E-13	6
TOTAL	4.21E-12	100	1.90E-12	100

most important categories are global warming, human toxicity and acidification due, basically, to the energy consumption.

In Fig. 4 the two systems have been compared. One can see that the ceramic scores worse for most of the impact categories.

4.1. Contributions of the life cycle phases to the eco-indicators

In Fig. 5 the eco-indicators of the two systems are compared: the marble tile eco-indicator scores about two times better than the ceramic one. This result can be better understood going through a closer examination of the contributions of the life cycle phases to the eco-indicators.

From Figs. 6 and 7 one can see the relations between the phases of the two systems with the impact categories. In the ceramic system the phase with the highest burden is production, while in marble it is pre-production, strictly followed by production.

In Fig. 8 the environmental performance of the life cycle phases are compared. It can be easily noted that the production phase is the most responsible for the gap

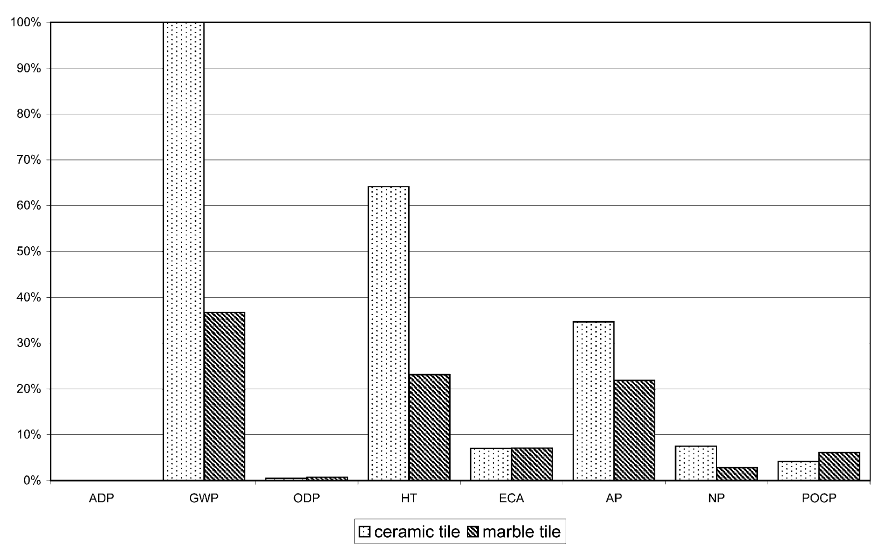


Fig. 4. A comparison between the two systems.

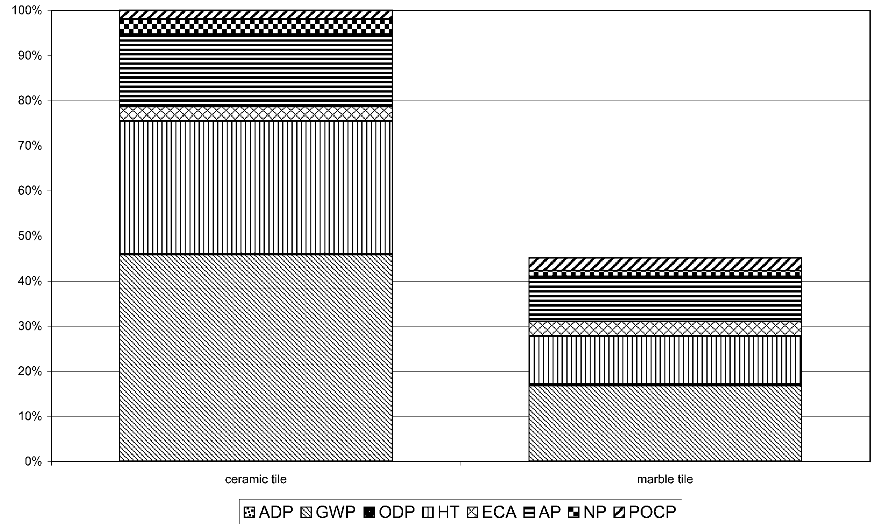


Fig. 5. Eco-indicators.

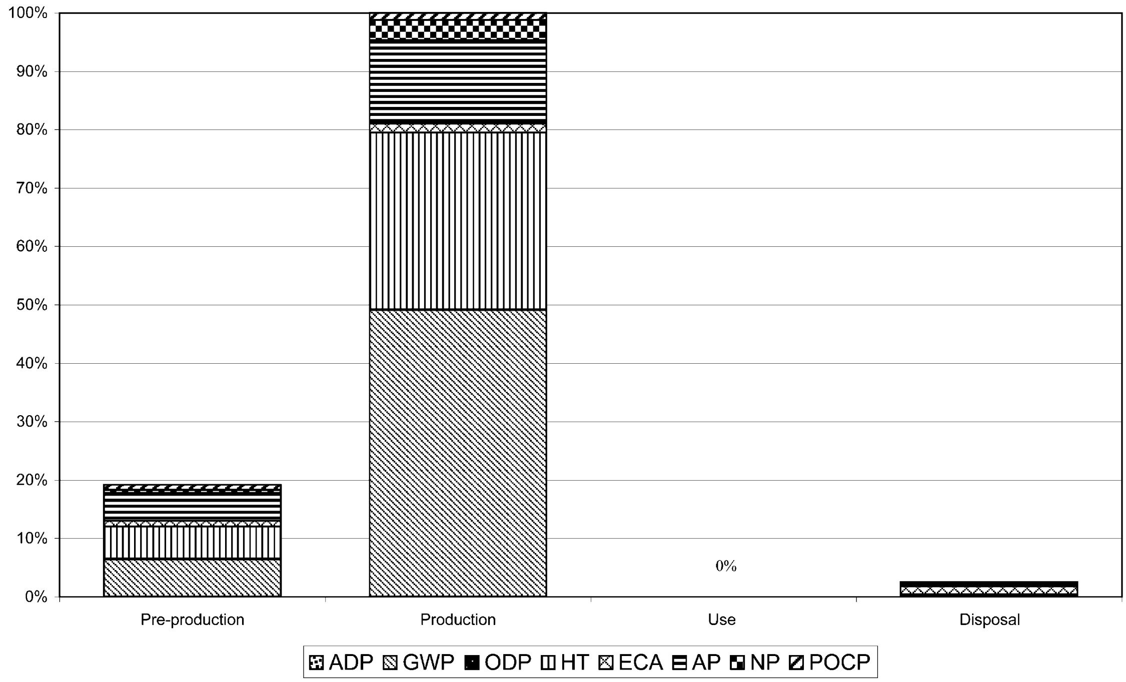


Fig. 6. Ceramic tile — contributions of the life cycle phases to the eco-indicator.

between the two systems. The use phase also has a relevant difference between the two systems.

The environmental impact of the pre-production phase in the ceramic system is shared between the following operations: 33% to the extraction and transport of the body raw materials and 67% to the extraction and transport of the glaze raw materials. The environmental relevance of the glaze raw material is much more evident if one considers that the per cent values are relative to the production of about 20 kg body raw materials and of just 1.13 kg for the glaze.

The production phase can be divided in three groups of operations:

- body preparation;
- glaze production;
- production of the glazed tile.

The contribution of the production phase to the eco-indicator is due for the 40% to the body forming, 17% to the glaze production and 43% to the production of the glazed tile. In Fig. 9 and Table 8 the relations between the unit operations of the production phase and the impact categories are shown. The operations of firing, preparation of the mix body and frit fusion appear as the most relevant. The impact categories which are more involved in these three operations are:

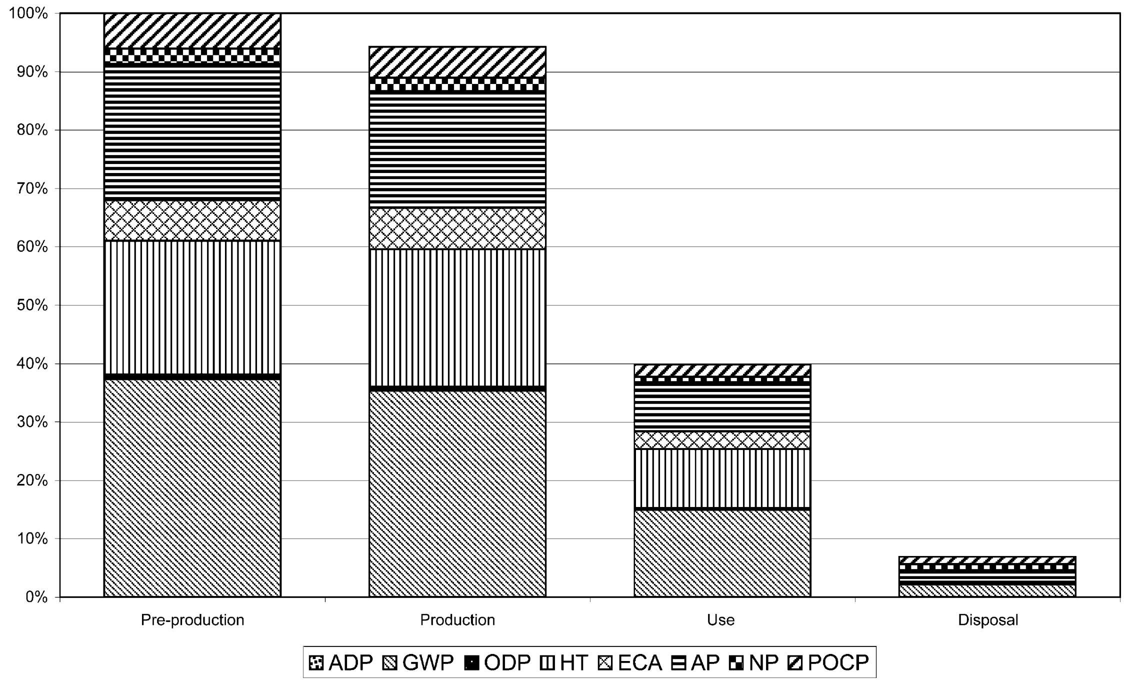


Fig. 7. Marble tile — contributions of the life cycle phases to the eco-indicator.

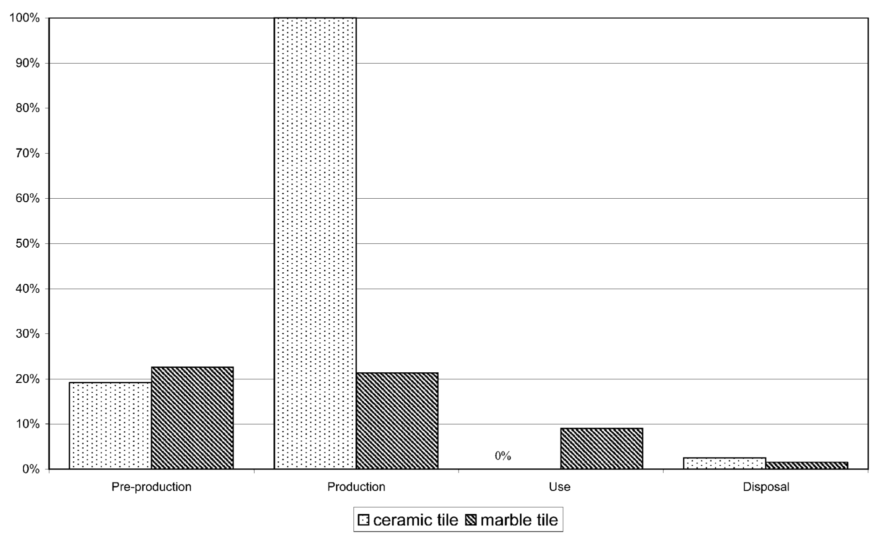


Fig. 8. Comparison of the life cycle of the two systems.

- Global warming in the operations of preparation of the body mix (35%) and of firing (36%), due to the relevant thermal energy consumption.
- Human toxicity in the operations of frit fusion (37%) and firing (30%), due to the emissions of arsenic and lead in the atmosphere.
- Acidification in the operations of firing (41%), preparation of the body mix (22%).

From Fig. 10 one can see that even in the marble system the impact categories mostly involved are global warming, human toxicity and acidification. In Table 9 the relations between the unit operations (marble extraction, blocks cutting, standard blocks cutting, polishing and buffing) and the impact categories are shown. The unit operation of “marble extraction” appears as the most relevant, and this is due to the higher energy consumption (see Table 6).

Other environmental effects could derive from the relevant quantity of sludge coming from the sawing, polishing and buffing but, while the sludge coming from the production phase does not imply relevant disposal

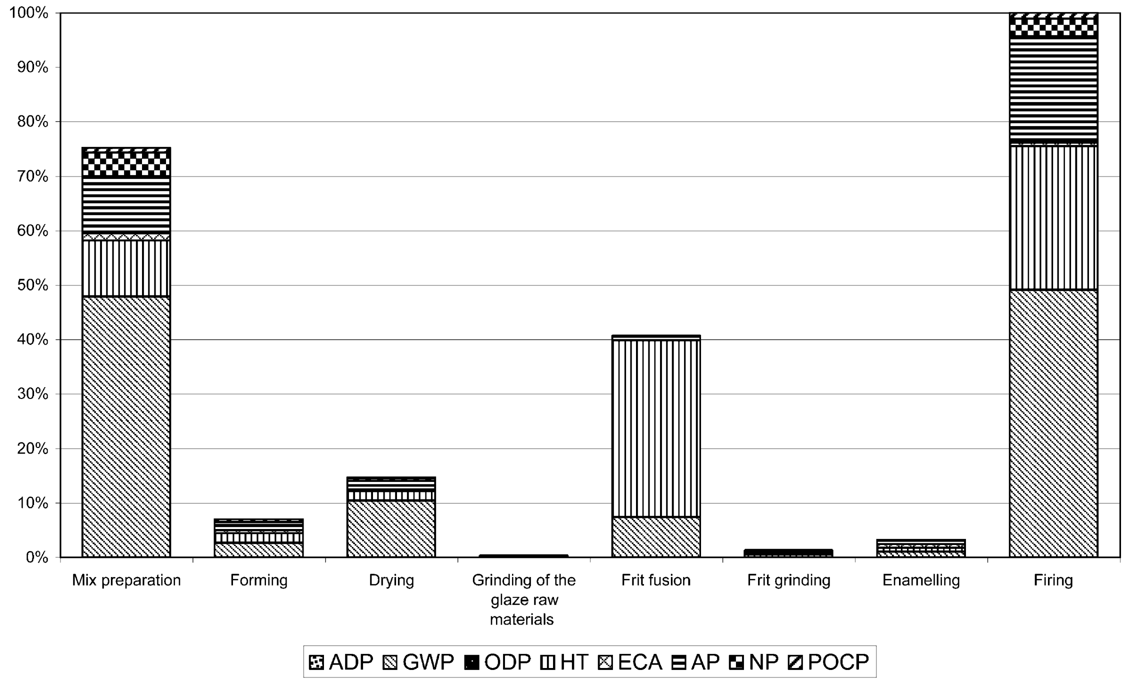


Fig. 9. Ceramic tile — environmental profile of the production operations.

Table 8
Contributions of the operations groups of the production phase at the impact categories in the ceramic system (in percentages)

	Body preparation			Glaze production			Glazed tile production	
	Mix preparation	Forming	Drying	Glaze raw materials grinding	Frit fusion	Frit grinding	Glazing	Firing
ADP	25	9	7	1	1	2	4	15
GWP	35	2	8	0	5	0	1	36
ODP	21	9	6	1	1	2	3	11
HT	12	2	2	0	37	0	1	30
ECA	13	6	4	0	0	1	7	7
AP	22	3	3	0	1	1	1	41
NP	42	2	4	0	3	0	1	31
POCP	16	7	4	0	1	1	3	20
TOTAL[a]	25	2	5	0	14	0	1	34

[a] This total refers to the contribution of each operation to the eco-indicator.

problems, the waste water coming from the quarry operations, if discharged directly in the surface water, could cause serious damage to the all aquatic life forms.

4.2. Interventions contributions in both the systems

Table 10 shows the contributions of the interventions to the eco-indicator.

It shows that almost the whole environmental impact of the two systems is due to the emission in the atmosphere. The incidence of the raw material used as inputs is almost zero, since the raw materials which are used in the two systems are not considered depletable in the next 100 years.

As could be expected the most contributing emissions in both the systems are connected to the electric and thermal energy use. In the case of the ceramic tile, one has to add the metals emissions due to the specific type of raw materials used in the glaze production. Particularly the operations which cause these emissions are the frit fusion and the tile firing (Table 11).

5. Interpretation

The results of the study show that the impacts of both the systems are due mostly to the energy consumption. In the case of the ceramics there is a significant contri-

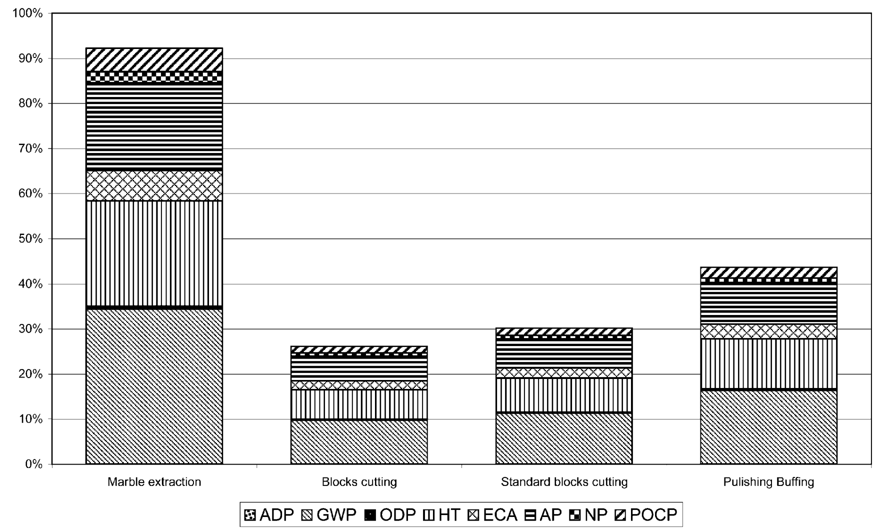


Fig. 10. Marble tile — environmental profile of the extraction and production operations.

Table 9
Contributions of the pre-production and production phases to the impact categories in the marble system (in percentages)

	Pre-production (transport excluded)	Production			
	Marble extraction	Blocks cutting	Standard blocks cutting	Polishing and buffing	Total
ADP	38	11	13	19	43
GWP	36	10	12	17	39
ODP	34	10	11	17	38
HT	38	11	12	18	41
ECA	37	11	12	18	41
AP	34	10	11	16	37
NP	33	9	10	14	33
POCP	33	9	11	15	35
TOTAL[a]	36	10	12	17	39

[a] This total refers to the contribution of each operation to the eco-indicator.

Table 10
Contribution of the interventions to the eco-indicator (in percentages)

	Ceramic tile	Marble tile
Raw materials	0	0
Emissions to air	97	93
Emissions to water	3	7
Solid waste	0	0

bution of a different nature (emissions due to the composition of the raw materials used for the production of the glaze). The arsenic compounds are contained in the raw materials used for the preparation of the frit mix, particularly in the boron minerals as colemanite and borite; they are released during the high temperature treatments. The environmental relevance of this pollutant in the ceramic sector is due to its toxicity and to its high concentration in the gaseous emissions coming from these oper-

Table 11
Contributions of the main atmosphere emission in the two systems (in percentages)

Atmosphere emissions	Ceramic tile	Marble tile
CO_2	46	36
As	10	
SO_2	9	29
NO_X	8	10
SO_X	8	2
NO_2	6	
NMVOC	1	6
Pb	5	
Ni		3
V		2
TOTAL	93	88

ations. Environmental improvement in the whole profile of the ceramic tile should be directed to a greater yield in the purification treatments of the flue gases.

Concerning lead, it represents an important element in the ceramic glazes, where it has a soldering flux function supplying brightness. In recent years the lead emissions of the ceramic sector have been reduced due to the growing diffusion of single-fired tiles that, being manufactured at an high temperature, have helped the use of lead-free or low-lead content glazes. However, the growing use of these typologies of glazes imply a greater use of raw material with boron with consequent arsenic emissions. The choice of one of the different typologies of glaze leads to a different impact (i.e lead emissions versus arsenic emissions) which could be quantified and compared in further LCA research. The trend is towards the use of boron glazes, which implies that growing arsenic emissions could be expected. Therefore, it is suggested that an environmental policy for this pollutant very similar to that already made for the fluorine will be carried out in the ceramic tile sector.

Fluorine is one of the typical pollutants of the ceramic industry. The presence of this compound in the atmosphere emissions is due to the fact that many raw materials, particularly clays, contain traces of fluorine [22]. The emissions of these compounds are those coming from the firing processes. The surprising result found with this study is that the fluorine has a much lower impact than could be expected (0.06% of the eco-indicator). The reason has to be found in the new abatement technology, forced by new environmental legislation, and in the selection of clays with a very low fluorine content. This is the path for the reduction of arsenic emissions on the basis of the effective example of fluorine.

6. Conclusions

The main results of this study are:

1. The life cycle score of the ceramic tile is over twice as bad as the marble tile (4.21E-12 versus 1.90E-12).
2. The most important impact categories of the life cycles of the two systems are global warming, human toxicity and acidification.
3. The phases of the life cycles with the highest burdens are the pre-production in the marble system, the preparation of the body, the fusion of the frit and the firing of the glazed body in the ceramic system.
4. The most crucial interventions are among the atmosphere emissions.
   Marble system: CO_2, SO_2, NO_x, NMVOC and metals.
   Ceramic system: CO_2, As, SO_2, NO_x, SO_x, NO_2 and Pb.
5. The source of these emissions has been determined: for the case of marble, during the conversion of fossil fuels in electric energy, which is used very much in this system. In the ceramic system it is to be found during the thermal processes and in the high quantity of potential volatile pollutants that are contained in the mix raw materials.
6. Better environmental performance can be reached in the marble system by improving the efficiency of the technology in its whole production system in order to save energy.
7. In the ceramic system the improvements are to be found in a further reduction of the thermal energy consumption, in the research of plant solutions, which could lead to the abatement of the arsenic emissions, and in the research of raw materials with the least arsenic and other potential pollutants.

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