SECTORAL LIFE CYCLE ANALYSIS OF CERAMIC TILE

[1] G. Benveniste, [1] C. Gazulla, [1] P. Fullana, [2] I. Celades, [2] T. Ros, [2] R. Moliner, [3] V. Zaera, [3] B. Godes

[1] Environmental Management Research Group (GiGa),
Escola Superior de Comerç Internacional (ESCI),
Universitat Pompeu Fabra (UPF), Barcelona, Spain.
[2] Instituto de Tecnología Cerámica (ITC),
Asociación de Investigación de las Industrias Cerámicas (AICE),
Universitat Jaume I, Castellón, Spain.
[3] Spanish Ceramic Tile Manufacturers' Association (ASCER),
Castellón, Spain.

ABSTRACT

Like any product of industrial origin, ceramic tiles have environmental impacts throughout the whole of their life cycle, in other words, from the extraction of raw materials to the evaluation or final elimination of the product, passing through the intermediate stages of distribution, use and maintenance. An understanding of the magnitude and nature of these impacts is essential so that we can concentrate our efforts on reducing them and improving product sustainability in comparison with other emerging products and competing materials.

To do this, a ceramic tile Life Cycle Analysis (LCA) on a sectoral level has been undertaken, in order to obtain scientifically valid and objective reference values for the different environmental loads of ceramic tiles. The working methodology used for performing LCA is based on the following reference standards: UNE EN ISO 14040:2006 and UNE EN ISO 14044:2006.

Over 50 Spanish companies from the ceramic sector (manufacturers of finished products, spray-dried powder, glazes, etc.) participated in the process of collecting the inventory data required to perform the LCA. Bibliographical data and the PE International GaBi software program database were used to complete the data related to other stages in the life cycle of the tile[1].

In the same study, Product Category Rules (PCRs) for ceramic tiles are also being drawn up, so that they can be used in the preparation of Environmental Product Declarations (EPDs). The UNE EN ISO 14025 and ISO 21930 standards are being followed in the preparation of the PCRs. These PCRs will be developed within the framework of the EPDc system (promoted by the Government of Catalonia and CAATEB[2]) and, once they have been approved, companies in the ceramic sector will be able to apply them in order to obtain a type III ecolabel which has been verified by a third party.

The companies that participated in this study were the Environmental Management Research Group (GiGa, ESCI-UPF) and the Instituto de Tecnología Cerámica (ITC-AICE), working in collaboration with members of the Spanish Ceramic Tile Manufacturers' Association (ASCER).

1. INTRODUCTION

As with any product of industrial origin, the manufacture of ceramic tiles generates a series of environmental impacts throughout their entire life cycle. Life Cycle Analysis (LCA) is a methodology that enables these impacts to be analyzed and evaluated so that we can concentrate our efforts on their reduction and, at the same time, improve product sustainability.

It should be emphasized that the information obtained in this type of research enables us to improve the competitiveness of a product in comparison with other alternative or emerging products. Moreover, life cycle analysis is the most suitable approach for this purpose, as it permits environmental aspects beyond the scope of the local limits of the systems which are analyzed to be evaluated, avoiding the problem of possible displacements throughout production line processes or within different impact categories.

Thus, to cite an example, certain building solutions are often presented as 'ecological' because they improve very specific environmental aspects during certain stages of the life cycle of buildings – such as when they are being built. However, when they are analyzed more holistically and other life cycle stages are considered – for example, their use, maintenance and final layout – these solutions lose their advantages compared to others. Consequently, the life cycle approach

1. *http://www.gabi-software.com/gabi/gabi-4/*

2. *Col.legi d'Aparelladors i Arquitectes Tècnics i Enginyers de Barcelona*

helps us to make decisions with scientific rigour when we are faced with choosing the best available techniques and minimizing the environmental impact of products starting from the design stage.

Before we can perform LCA, there is a critical phase, which is the compilation of inventory data on the ceramic tile manufacturing process. Over 50 Spanish companies from the ceramic tile sector (manufacturers of finished products, spray-dried powder, glazes, etc.) took part in the process of collecting all this information. The companies which participated account for about 40% of tile production and about 50% of the sector's total spray-dried granulate production. Bibliographical data and the PE International GaBi software program database[3] were used to complete the data related to other stages in the life cycle of the ceramic tile (use and waste management) and generic processes (electricity production, fuel, transport, etc.).

The idea is to use all this information to obtain scientifically valid and objective reference values for the environmental loads of ceramic tiles during their entire life cycle. LCA ISO standards (UNE EN ISO 14040:2006 and UNE EN ISO 14044:2006) are being applied during the study.

One LCA application is the preparation of Environmental Product Declarations (EPDs) or type III ecolabels, which are based on LCA studies and permit the publication and circulation of quantified environmental data about the life cycle of a product.

For the EPDs produced by different manufacturers to be coherent with one another, it is essential for them to follow the same guidelines with respect to how to apply LCA methodology. These guidelines are called Product Category Rules and, amongst other things, they determine what the functional unit should be like, and impact categories, life cycle stages and data quality. Once the PCRs have been developed, companies will be able to design LCA studies and Environmental Product Declarations for their individual products independently.

The preparation of PCRs, in accordance with the UNE EN ISO 14025 and ISO 21930 standards, is another of the tasks in this study. The PCRs will be developed within the framework of the EPDc (promoted by the Government of Catalonia and CAATEB[4]), the first ecolabelling system for building products in Spain. Once they have been approved, companies in the sector will be able to apply them to obtain a type III ecolabel verified by a third party.

---

3. *http://www.gabi-software.com/gabi/gabi-4/*

4. *Col.legi d'Aparelladors i Arquitectes Tècnics i Enginyers de Barcelona*

2. OBJECTIVES OF THE STUDY

The objectives of the present study are as follows:

- To obtain scientifically valid and objective reference values for the environmental loads of ceramic tiles by performing a Life Cycle Analysis.
- To draw up Product Category Rules (PCRs) which are applicable to ceramic tiles, so that they can be used in the preparation of Environmental Product Declarations (EPDs).

3. LIFE CYCLE ANALYSIS METHODOLOGY

Life Cycle Analysis (LCA) is a valid tool for determining the environmental impacts of a product or activity. LCA enables us to identify, classify and quantify the effects that any product has on the environment, starting from the extraction of the raw materials of which it is composed and ending with its transformation into waste (this is why it is also known as analysis 'from the cradle to the tomb'). To do this we need to prepare a material and energy balance for the system to be analyzed and the environmental inputs and outputs must be identified so that the different environmental impacts they may cause can subsequently be identified.

The UNE EN ISO 14040 standard defines LCA as a technique for determining the environmental aspects and potential impacts associated with a product: by compiling an inventory of the relevant inputs and outputs of the system; evaluating the potential impacts associated with these inputs and outputs, and interpreting the results of the various inventory phases and their impact in relation to the study objectives (figure 1). LCA is structured so that it consists of four major phases (Fullana, P. et al., 2009; Fullana, P. et al., 1997):

- **Definition of objectives and scope of the study** In this phase what will be studied, and why and how, is described. The reasons why the study is being conducted and how the results will be used must be defined. Details of the scope of the study must also be provided, defining, amongst other aspects, the functional unit (quantification of product function), the system which is to be analyzed, its limits, the hypotheses it makes, the impact categories which will be considered and the limitations which exist.
- **Inventory analysis** This is a technical data collection process for quantifying the system's inputs and outputs, in other words, the energy and materials consumed, the emissions into the environment and the co-products which are produced throughout the entire life cycle of the product. The analysis must break the results down to the level of elemental flows, in other words the direct environmental inputs and outputs.
- **Evaluation of impacts** Identification and characterization of the effects

of the study system on the environment. First of all, the inventory inputs and outputs must be classified, depending on the impact category they may affect. Then the substances are characterized, in other words, converted to a common measurement unit, depending on the degree to which they contribute to the corresponding impact category. An additional option is for the results to be standardized in relation to the impacts produced in a larger system (a specific geographical zone) and weighted (depending on the relative importance of each impact category until the results are combined to give a single value).

- **Interpretation** Evaluation of the results of the inventory and/or the assessment of impacts in relation to the defined objectives and scope of the study with the aim of reaching a series of conclusions and recommendations.

LCA is usually used to identify the main elements of a system which need to be improved in order to reduce their global environmental impact, thereby enabling efforts to achieve this to be optimized. It is also common to use this tool to compare alternatives or to estimate the potential effects a change in the design of a product or system can have. Finally, another of the most common applications of LCA is the calculation of the Carbon Footprint of products or services. It is determined from the *Global Warming Potential (GWP)*, which quantifies the total amount of greenhouse gas emissions associated with the analyzed system in kg equivalent carbon dioxide (CO_2-eq.).

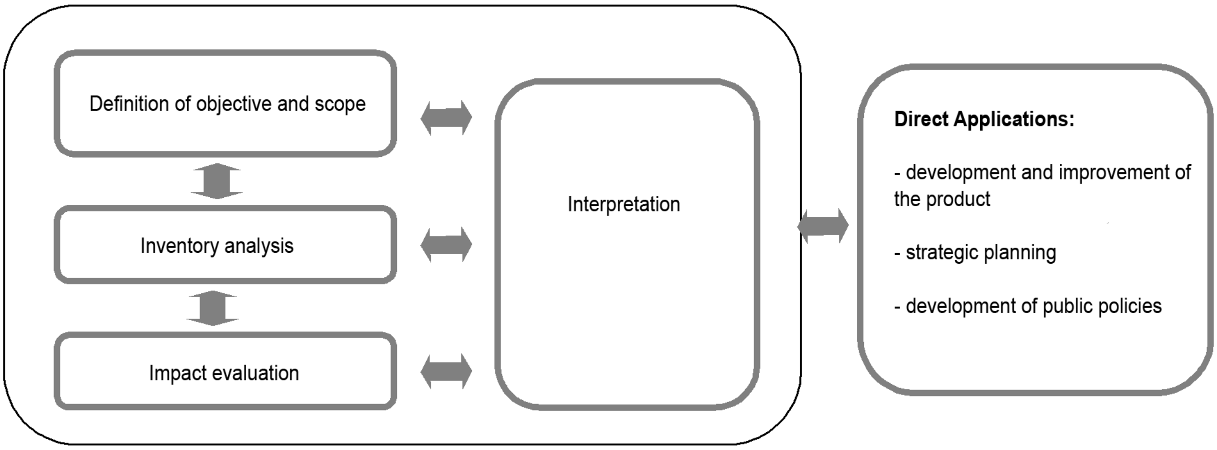

Figure 1. Stages in a Life Cycle Analysis [Source: UNE EN ISO 14040, 2006].

4. THE LIFE CYCLE OF CERAMIC FILES

Given that the aim of the LCA study is "to establish the magnitude and nature of the environmental impacts generated by ceramic tiles throughout their lif cycle", the main types of tiles manufactured in Spain and the main production techniques which exist will be evaluated.

In this study, the most extensively produced types of ceramic tiles in Spain will be analyzed in order to obtain an average profile which is characteristic of the sector. These tiles are:

- Red- or white-body earthenware (wall) tiles (hereafter AR or AB)
- Glazed white- or red-body stoneware tiles (hereafter GEB or GER)
- Porcelain tile (hereafter GP)

In this study the functional unit will be physical in nature and will consist of '1m^2 ceramic tile'.

The system limits determine what is included in the system being studied and what is left out. Normally, stages which are not expected to be significant are excluded from the analysis [Puig, R. et al., 2002]. (figure 2).

In this study, the entire life cycle of all the ceramic tiles which are studied, including the extraction of raw materials, their transportation, the manufacture of the product, its distribution to its point of consumption and waste management, will be analyzed.

The elements which **are excluded from the analyzed system** are:

- The **production of industrial machinery and equipment**, owing to the difficulty of performing an inventory of all the items involved and also because the LCA community regards the environmental impact per product unit to be low compared to the rest of the processes which are included.
- Consumption of energy or emissions produced by tiles during their **useful stage**, in other words, once they have been installed, given that the environmental impacts associated with this stage are insignificant, both in terms of mass and energy, and environmental importance. However, parameters such as impacts caused by materials when tiles are being installed on the floor will be taken into account.
- **The recycling process for different types of waste** produced throughout the life cycle of ceramic tiles, owing to the method for assigning loads which is applied.

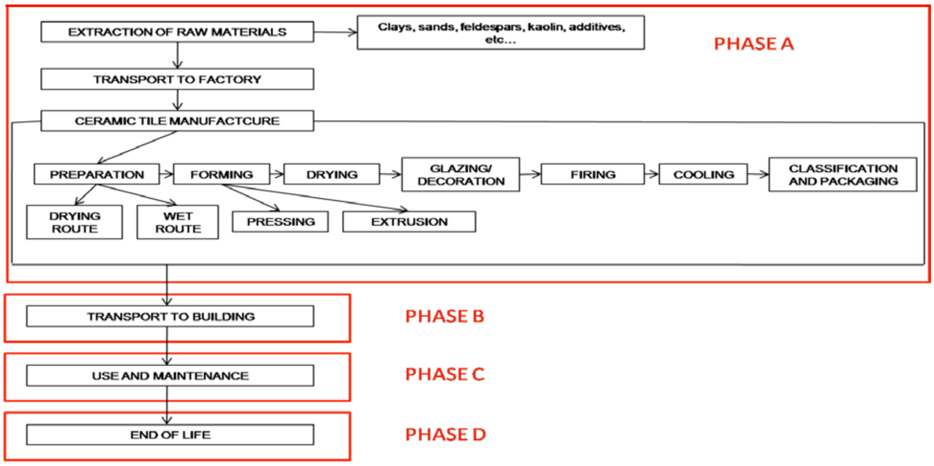

Figure 2. Life Cycle of ceramic tiles (Source: prepared by the research team).

4.1. Inventory analysis.

Data on the inputs and outputs for materials, energy consumption, emissions and the waste which is produced have been collected for each phase of the life cycle of the ceramic tiles. The collected data correspond to the information available from forms that the companies in the study have compiled and inventory data contained in PE International GaBi 4 calculus software.

Table 1 summarizes the characteristics of the products which were analyzed.

	GP	AB	AR	GEB	GER
Final tile weight (kg/ m^2)	23	17	17	20	20

Table 1. Weights of each Type of Tile (kg/m^2).

4.1.1. Phase A-Manufacture.

Table 2 summarizes the average composition values of the main materials for a generic ceramic tile.

Raw materials	Percentage of final Weight
Clays	60%
Sands	7%
Carbonates	2%
Feldspars	17%
Kaolins	1,7%
Additives	0,7%
Glazes	4%
Recycled material	7%

Table 2. Average composition of a generic tile.

Raw materials have different origins: provincial, national, European and other origins. In order to evaluate the environmental impact of the phase corresponding to the transport of raw materials, the model which has been created enables the transport type and distance to be selected, depending on the origin of each raw material.

Another point to consider in the manufacturing phase is energy consumption (electrical and thermal energy). In the ceramic sector, the fuel which is used most widely to produce thermal energy is natural gas in the spray-drying, drying and firing phases. Some of the companies in the survey have cogeneration plants in which, in addition to heat, electrical energy is produced and sold to the local electricity board. This production is treated as an avoided impact in the system, since part of the electricity which is consumed is put back.

During the manufacturing cycle of ceramic tiles the emissions which are produced directly need to be inventoried. In this way, using experimental measurements, representative values for the emissions into the atmosphere as a result of different stages of the process, including emissions produced by the combustion of natural gas and during transport, have been determined for the sector as a whole. The model also enables indirect emissions, in other words emissions that cannot be identified by the producer and which may have their origin in the manufacture of specific raw materials or in the production of primary energy, to be calculated.

Water emissions (discharges) have been omitted from the inventory since, in the case of the ceramic tile manufacturing industry, direct recycling of the tiles, either internally and/or externally, during the stage corresponding to the preparation of raw materials, is common practice, as occurs with waste generated during the manufacture of unfired products. In the case of fired waste products (scrap), they must be crushed prior to recycling during the stage of raw material preparation.

The last stages of the manufacturing process are classification and packaging, the latter using cardboard, polyethylene film and europallets. The model allows for the quantification of packaging for each type of tile, and its production and delivery to the production plant.

4.1.2. Phase B Transport.

The ceramic sector produces tiles which are commercialized all over the world; it is estimated that the total production of tiles is destined for delivery to the following regions (table 3).

Destination	Means of transport and distance	Percentage of tiles [%]
Spain	27 t lorry, 500 km	47
Europe	27 t lorry, 2000 km	28
Resto of the world	Ocean-going cargo vessel, 5000 km	25

Table 3. Destination for tiles (Source: ASCER, 2007).

Packaging waste management

The main forms of waste generated during the manufacture of ceramic tiles corresponds to waste water, fired and unfired product waste, and packaging waste. The former are almost entirely reused during the production phase. However, the management of packaging material waste is the responsibility of the client who receives the merchandise and therefore the regulations and statistics for the stages which correspond to the receiver must be applied. Therefore, in order to perform the analysis of this phase, the following models have been used with three different options: waste management in Spain, Europe and the Rest of the World. The average selective collection data for different types of waste were used to prepare the models. (National Integrated Waste Plan Data, Eurostat) (table 4).

Type of waste management	Spain	Europe	Resto of the world
Percentage cardboard incinerated	20%	2%	20%
Percentage cardboard distributed to dumps	10%	24%	10%
Percentage cardboard recycled	70%	74%	20%
Percentage PE film incinerated	14%	26%	10%
Percentage PE film distributed to dumps	66%	47%	70%
Percentage PE film recycled	20%	27%	70%
Percentage pallets incinerated	47%	20%	20%
Percentage pallets distributed to dumps	9%	42%	50%
Percentage pallets recycled	44%	38%	30%

Table 4. Waste management classified according to geographical area.

4.1.3. Phase C - Tile installation and maintenance.

It is assumed that adhesive mortar is used for manual tile installation. In this model, cleaning activities during the phase of tile use has not been taken into account. This is due to the fact that cleaning tends to be an activity which largely depends on the final consumer and on the type of use the tile is designed for (residential, commercial or healthcare installations). Consequently, an analysis of the cleaning phase deserves to be addressed as part of a more exhaustive sensitivity analysis.

Generally speaking, average useful life has been estimated as 50 years, according to UNE EN 14411: 2007 for Ceramic tiles. Definitions, classification, characteristics and branding.

4.1.4. Phase D - Demolition and end of life cycle.

This phase is classified as belonging to demolition activity and the subsequent management of the solid waste which is produced. It is regarded as the end of the useful life of the ceramic tile. Bearing in mind the fact that tiles represent 0.32% of the total weight of a building, the energy consumption associated with their removal can, as such, be disregarded. However, once a building has been demolished, it is assumed that the tiles are deposited as inert building material at dumps, as indicated in the National Integrated Waste Plan (2006), *Appendix 6. Building Waste*. The environmental impacts of this type of waste management and impacts associated with the transport of demolition material to dumps (50 km) has been taken into account.

4.2. Impact evaluation.

The environmental impact categories have been selected from the categories recommended by the operation manual for the application of LCA ISO standards [Guinée, J. et al., 2001] (table 5).

Impact category	**Depletion of Abiotic Resources (ADP)**
Inventory result:	extraction of minerals and fossil fuels (in kg)
Characterization model:	technique which evaluates the concentration of reserves and the rhythm of extraction
Category indicator:	depletion of maximum reserves in relation to the annual use of the resource
Characterization factor:	depletion potential for each extraction of minerals and fossil fuels (kg of equivalent Sb/kg extracted)
Indicator result:	kg of equivalent Sb
Impact category	**Acidification (AP)**
Inventory result:	emissions of acidifying substances (in kg)
Characterization model:	RAINS10 model, developed in IIASA[5], describing the destination and deposition of acidifying substances and adapted to LCA
Category indicator:	critical deposition/acidification load
Characterization factor:	acidification potential of each acid emission (kg of equivalent SO_2/kg of acid emission)
Indicator result:	kg of equivalent SO_2
Impact category	**Global Warming (GWP)**
Inventory result:	atmospheric emissions of greenhouse gases (in kg)

5. International Institute for Applied Systems Analysis.

Characterization model:	model developed by the IPCC (Intergovernmental Panel on Climate Change) which defines the global warming potential of different greenhouse gases
Category indicator:	density of infrared radiant energy flow (W/m^2)
Characterization factor:	global warming potential of each greenhouse gas in a time span of 100 years (kg of equivalent CO_2/kg of greenhouse gas)
Indicator result:	kg of equivalent CO_2
Impact category	**Formation of Photo-oxidants (POPC)**
Inventory result:	emissions of substances (VOCs, CO) into the air (in kg)
Characterization model:	UNECE model[6]
Category indicator:	formation of tropospheric ozone
Characterization factor:	photochemical ozone creation potential of each VOC or CO emission into the air (kg of equivalent ethylene/kg of photo-oxidant emission)
Indicator result:	kg of equivalent ethylene (C_2H_4)
Impact category	**Stratospheric Ozone Depletion Potential (ODP)**
Inventory result:	Emissions of substances into the air (in kg)
Characterization model:	Solomon & Albritton, 1992 model for the 'Nordic Guidelines on Life-Cycle Assessment, Nord 1995:20
Category indicator:	Depletion of stratospheric ozone
Characterization factor:	Depletion potential of each emission into the air (kg of equivalent R11/kg of emission)
Indicator result:	kg of equivalent trichlorofluoromethane (R11)
Impact category	**Eutrophization (EP)**
Inventory result:	emissions of nutrients into the air, water or soil (in kg)
Characterization model:	stoichiometric process for identifying the equivalence between nitrogen and phosphorus in both terrestrial and aquatic systems
Category indicator:	deposition of nitrogen/phosphorus in the biomass
Characterization factor:	eutrophization potential of each eutrophizing emission into the air, water or soil (kg of equivalent PO_4/kg of eutrophizing emission)
Indicator result:	kg of equivalent PO_4

Table 5. Impact Indicators Used.

6. United Nations Economic Commission for Europe.

The following indicators are also included in the analysis:

- consumption of Primary Energy (MJ).[7]
- consumption of water (kg).

In the evaluation individual data have been treated confidentially and average values which are representative of the sector and its most relevant products have been used in calculations (earthenware (wall) tile, glazed stoneware tile, and porcelain tile). Data from the literature and the PE International GaBi software program database were used to complete the data related to other stages in the life cycle of the ceramic tile (use and waste management) and generic processes (electricity production, fuel, transport, etc.).[8] The contributions of each phase to the total values for the indicators described above are indicated in figure 3. These results correspond to a generic tile, which is the average of the 5 types of tile analyzed in the study.

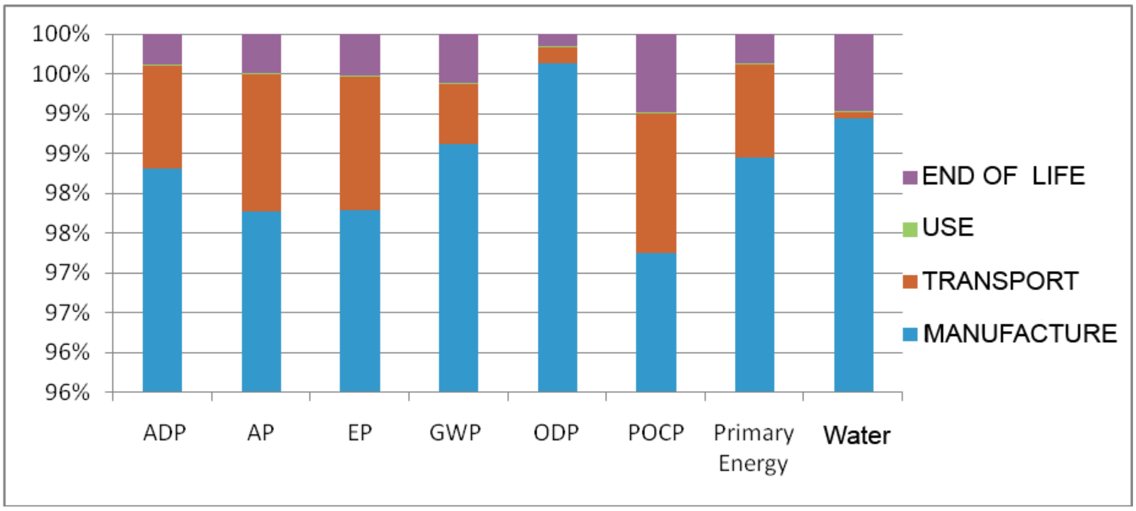

Figure 3. Contributions to the impact categories for the different life cycle phases.

In this model cleaning activities have been disregarded during the phase of use as indicated above. Therefore the analysis of the cleaning phase can cause impacts which will affect the values indicated in figure 3 significantly, so its inclusion should be addressed in a more exhaustive sensitivity study.

As can be seen, the phase which has most influence on environmental indicators is the manufacturing phase and it is on this phase that our efforts should be focused when what we want is to reduce environmental impacts, since this stage is within the control of the producer. Furthermore, we need to point out that in the part of the life span which has been analyzed the impacts associated with tile replacement (phase of use) have not been taken into consideration and this implies a saving on potential impacts caused by the replacement of material.

7. Amount of renewable and non-renewable energy obtained directly from the environment without being subjected to any conversion process.
8. http://www.gabi-software.com/gabi/gabi-4/

5. EXPLOITATION OF THE LCA RESULTS: PREPARATION OF PRODUCT CATEGORY RULES FOR CERAMIC TILINGS

Environmental Product Declarations or type III ecolabels which comply with ISO classification standards facilitate the communication of objective, comparative and reliable information about the environmental behaviour of products. EPDs do not offer criteria about the environmental preference of a product or establish minimum requirements which have to be met. Nevertheless, analyzing a product in depth always leads to the detection of alternatives for improvement. Generally the information contained in an EPD has been verified by an independent third party and consists of relevant data about the environmental impacts caused by a product throughout its life cycle (impact categories and consumption of raw materials, and the production of relevant emissions and waste).

The information contained in an EPD is based on LCA studies and permits the publication and circulation of quantified environmental data about the life cycle of a product. For the EPDs produced by different manufacturers to be coherent with one another it is essential for them to follow the same guidelines on how to apply LCA methodology. These guidelines are known as Product Category Rules and, amongst other things, they determine what the functional unit should be like, impact categories, life cycle stages and data quality.

Another objective of this ongoing study is to draw up some Product Category Rules (PCRs) for ceramic tiles, which can be used in the preparation of Product Environmental Declarations (PEDs). For the preparation of PCRs the results of the LCA study for the sector are being used, and UNE EN ISO 14025 and ISO 21930 standards and the prEN 15804 draft are being followed. The opinion of the companies in the sector has also been taken into account. Finally, the PCR documents for similar products made in other countries will be taken into account as well.

Once the PCRs have been developed, companies will be able to design LCA studies and Environmental Product Declarations for their individual products independently.

ACKNOWLEDGEMENTS

The Spanish Ceramic Tile Manufacturers' Association (ASCER) has collaborated with this study through the participation of its members, as a result of the collaboration agreement with ITC and the GiGa, and by funding a project entitled **'Life Cycle Analysis of Ceramic Tiles'**, as part of the Sector Competitiveness Plans (period 2008-2009), funded by the Government of Valencia and approved by IMPIVA (grant No. IMPCNC/2008/124) and European Regional Development Fund (ERDF).

REFERENCES

[1] Fullana P.; Gazulla, C.; Bala, A.; Chiva, P.; Fabregó, L. Vidal, M. Guía de Aplicación Ecojoguina. Barcelona: Generalitat de Catalunya. 2009.

[2] Fullana, P. y Puig, R. Análisis del Ciclo de Vida. Barcelona: Ed. Rubes. 1997.

[3] ISO 21930:2007 Sustainability in building construction - Environmental declaration of building products.

[4] MINGUILLÓN BENGOCHEA, M.C. Composición y fuentes del material particulado atmosférico en la zona cerámica de Castellón [Tesis doctoral]: Impacto de la introducción de las mejores técnicas disponibles. Castellón: UJI, 2007.

[5] PLAN NACIONAL INTEGRADO DE RESIDUOS (PNIR) 2007-2015. Ministerio de Medioambiente, 2006.

[6] prEN 15804:2008 Sustanibility of construction Works – Environmental product declarations – Product category rules.

[7] UNE-EN ISO 14040:2006 Gestión ambiental. Análisis de ciclo de vida. Principios y marco de referencia.

[8] UNE-EN ISO 14044:2006 Gestión ambiental. Análisis de ciclo de vida. Requisitos y directrices.

[9] UNE-ISO 14025:2007 Etiquetas y declaraciones ambientales. Declaraciones ambientales tipo III. Principios y procedimientos.

[10] UNE EN 14411: 2004 baldosas cerámicas. Definiciones, clasificación, características y marcado.