ENVIRONMENTAL ASSESSMENT OF BEST AVAILABLE TECHNIQUES (BATs) APPLIED TO THE CERAMIC INDUSTRY

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Abstract

Prompted by the IPPC Directive, The European Commission is developing BREF documents (Reference Documents on Best Available Techniques (BATs)) for the industrial sectors affected by the IPPC Directive. The Emission Limit Values (ELVs) are defined on the basis of the BATs applicable to each industrial sector. The aim of BAT and ELVs is to provide a high level of environmental protection at a reasonable cost.

This paper examines the effectiveness of the proposed BATs on their environmental and economic performance for the ceramic sector. The environmental impacts have been assessed using Life Cycle Assessment (LCA). Four environmental indicators are considered: global warming, acidification, particulates and fluorine compounds. The economic costs comprise capital and operating costs.

The results show that, in addition to the environmental benefit, the energy-related BATs are economically feasible. In this context, it can be concluded that the best environmental performance does not have to be delivered by the most expensive BAT.

Keywords*: Life cycle assessment; LCA; eco-efficiency; ceramic tiles; Best Available Technique; BAT*

Resumen

Bajo el marco de la directiva IPPC, la Comisión Europea está elaborando documentos BREF (Documentos de Referencia sobre las Mejores Técnicas Disponibles (MTDs)) para los diferentes sectores industriales. Las Mejores Técnicas Disponibles (MTDs) aplicables a cada sector, sirven de base para la definición de los Valores Límites de Emisión (VLE) que permiten alcanzar un alto nivel de protección integral del medio ambiente.

Esta comunicación examina la efectividad de las MTDs propuestas para el sector cerámico desde un punto de vista ambiental y económico. La evaluación ambiental se realiza mediante la aplicación de la metodología de Análisis del Ciclo de Vida (ACV) mediante la que se analizan cuatro indicadores ambientales: calentamiento global, acidificación, partículas y compuestos del flúor. Los costes económicos incluyen la inversión y el coste de operación.

Los resultados muestran que las MTDs relacionadas con la eficiencia energética son económicamente viables. Por tanto, se confirma que el comportamiento ambiental de una MTD no es mejor cuanto mayor sea su coste.

Palabras clave: *Análisis del Ciclo de Vida; ACV; eco-eficiencia; baldosa cerámica; Mejor Técnica Disponible; MTD*

1. Introduction

On 6 January 2011, Directive 2010/75/EU on Industrial Emissions (DIE), which amends Directive 1/EC (2008) on Integrated Pollution Prevention Control (IPPC), came into force. Among the main modifications aimed at reducing the environmental burdens caused by industrial activities, this new directive incorporates the strengthening of the application of the Best Available Techniques (BATs) in the EU. In particular, Member States are required to ensure that installations are applying the BATs by restricting the divergence of BATs between enterprises and by establishing Emission Limit Values (ELV) associated with the BATs.

According to Mavrotas et al. (2007) and Georgopoulou et al. (2008), the relationship between the economic costs and the environmental & economic benefits is essential when comparing and selecting which BATs an industry should invest in. Other authors remark the importance of studying the "cost-environmental benefit ratio" in order to determine the economic feasibility of a BAT (Dijkmans et al., 2000). Even the IPPC directive states, within the definition of 'available', that to establish a BAT, both costs and advantages of each candidate technique should be taken into account.

This paper focuses on the proposed BATs for the ceramic sector. The aim is two-fold: a) to analyse the environmental and economic performance of six BATs listed in the Reference Document on Best Available Techniques in the Ceramic Manufacturing Industry (Bref, 2007), and b) to offer practical guidance for the improvement of the sustainability of the production process of ceramic tiles, taking into account the environmental and economic aspects. The attention is focused on improving the firing and drying lines because these are the steps with the highest environmental impacts in the manufacturing process (Bovea et al., 2010).

For these purposes, one baseline and six alternative scenarios are considered. The former is related to a standard process of manufacturing ceramic tiles (single-fired glazed stoneware) and the later are based on those proposed in the BREFs (2007).

The baseline scenario was established by combining the information given by Bref (2007) with our own Life Cycle Inventory (LCI), which was performed according to the standard ISO/TS 14048 (2002) and reported in Ibañez-Forés et al. (2011). All the flows of inputs and outputs produced throughout the different production stages of ceramic tiles were considered.

The environmental performance of all the scenarios was studied by applying the Life Cycle Assessment (LCA) methodology (ISO14040/44, 2006). In the view of the Technical Working Group (TWG) created within the EU framework to exchange the relevant information on BATs according to the IPPC Directive, LCA is particularly appropriate to identify which BAT is best among the available alternatives (Rinaldi et al, 2002).

In addition to the environmental impacts, the economic aspects of each BAT have also been considered. The economic data, comprising capital and net operating costs, are based on the Reference Document on Economics and Cross-Media Effects (Bref, 2005).

Finally, the relationship between the costs and environmental benefits has been studied for each scenario to identify the most sustainable BATs.

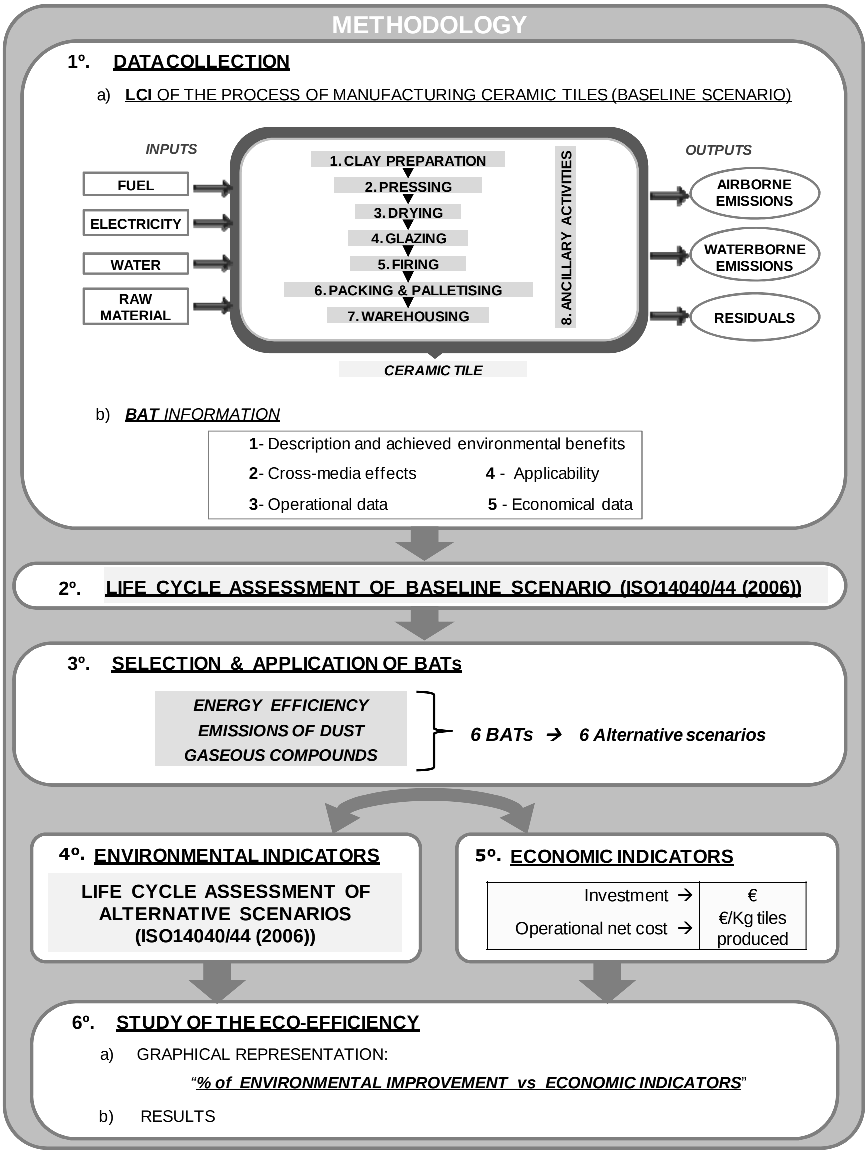
2. Methodology

As illustrated in Figure 1, the methodology used in the study consists of six stages.

The initial stage was data collection which was divided into two main parts. The first part included construction of the Life Cycle Inventory (LCI) for the production of ceramic tiles, the scope of which is shown at the top of Figure. This resulted in a baseline scenario which contains all the flows of inputs and outputs produced throughout the eight stages of tile manufacturing. The functional unit was the manufacture of 1 kg of ceramic tiles. The second part included collection of the main information for each BAT (see Figure 1 (1ºb)).

For these purposes, we combined both data from our own inventory (Ibañez-Forés et al., 2011) and data published on different reference documents: Reference Document on Best Available Techniques in the Ceramic Manufacturing Industry (Bref, 2007), Reference Document on Best Available Techniques on Emissions from Storage (Bref, 2006) and Reference Document on Economics and Cross-Media Effects (Bref, 2005).

Figure 1: Methodology Applied



In the second stage, the environmental impacts of the baseline scenario were then estimated following the CML 2000 method (Guinee, 2002) and using SimaPro7.1 (2008) LCA software. The LCA study followed the guidelines in the ISO14040/44 standard (2006).

As can be seen from Figure 1.3º, the alternative scenarios for the production of ceramic tiles were configured in the third stage of the methodology. For this purpose, we selected six

BATs and combined their environmental benefits, operational data and cross-media effects with the baseline scenario to obtain the data relative to inputs and outputs which characterise each proposal. In the selection of BATs, attention was focused on the measures related to the reduction of energy consumption, abatement of dust emissions and purification of gaseous compounds.

Following this, we applied the LCA methodology to each proposed scenario and we compared the environmental indicators obtained with the environmental indicators from the baseline scenario. The following two impacts were studied: acidification (kg SO_2 eq.) and global warming (kg CO_2 eq.). Additionally, two environmental burdens were also considered: suspended particulate matter (kg SPM eq.) and fluorine compounds (kg HF eq.).The changes in the impacts associated with implementing the BATs were then calculated.

To assess the economic feasibility, two parameters were studied: investment (€) and net operational cost (€/kg). Bearing in mind that monetary information for BATs depends on the size of the installations, the achieved effectiveness of the technique and the circumstances of the individual application (BREF, 2007), the economic data were analysed qualitatively rather than quantitatively.

Finally, we compared the environmental impacts and burdens with the economic indicators associated with each BAT to examine the trade-offs. The results are presented in section 4; prior to that, the selected BATs are described in the next section.

3. Description of the selected BATs

As mentioned above, six BATs have been chosen for study here, of which two are related to improved energy efficiency, two to the abatement of particulates and two to the removal of fluorine (HF).

Table 1 details some of the main characteristics of the selected BATs: short definition of the technique, efficiencies and the stages in the process of manufacturing tiles where the BATs are applied.

Table 1: Definition and Efficiencies for the Selected BATs

Measure	BAT	Stage applied in the manufacture of tiles	Efficiency
ENERGY EFFICIENCY	BAT 1	- *FIRING*: Recovery of excess heat from kilns employing heat exchangers. - *DRYING*: Chimney flow optimization.	< 12 % energy
	BAT 2	- *FIRING & DRYING*: Adjustment of water according to the required material plasticity and usage of water vapour for mixing.	< 3 % water < 90 kWh/t thermal energy < 1,5 kWh/t electricity
DUST EMISSIONS	BAT 3	- *PRESSING, DRYING & FIRING*: Bag filters with pressure pulse regeneration for dust removal from off-gases.	SPM: > 98 %
	BAT 4	- *PRESSING, DRYING & FIRING*: Electrostatic precipitator (ESP) with channelling of the smoke of chimneys	SPM: > 99 %
GASEOUS COMPOUNDS	BAT 5	- *DRYING & FIRING*: Dry flue-gas cleaning: cascade-type packed bed absorber using modified $CaCO_3$*	SPM: 100 % SO_2: 30 – 85 % HF: > 99 % HCl: > 50 %
	BAT 6	- *DRYING & FIRING*: Wet flue-gas cleaning using water/$Ca(OH)_2$ or $CaCO_3$	SPM: 100 % SO_2: 98 % HF: 99 % HCl: 95 %

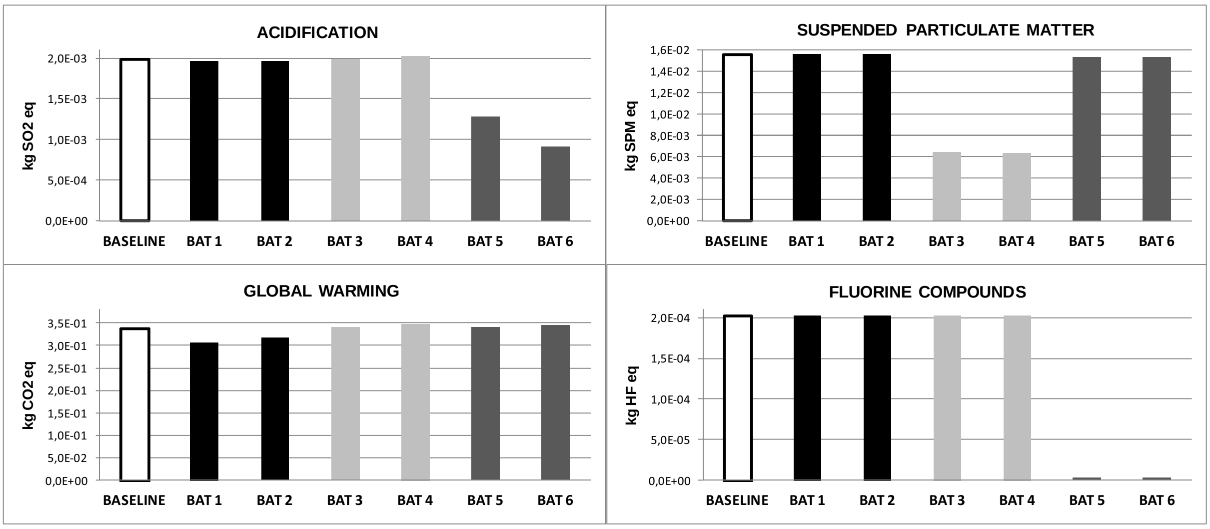
* Note: Modified CaCO3 absorber uses a mixture of CaCO3 and $Ca(OH)_2$. This increases the porosity and increases the content of calcium hydroxide, thereby increasing the affinity for acid gases (i.e. greater adsorption of HF).

4. Results

4.1 Environmental indicators

Figure 2 compares the LCA results of the baseline and the six alternative BAT scenarios, while Table 2 shows the relative reduction potential of the BATs scenarios compared to the baseline.

Figure 2: Comparison of environmental impacts of the baseline and different BAT scenarios



As can be seen, BATs 1 and 2, related to the energy efficiency, offer the highest reduction potential for global warming (up to 10%). Further reduction of global warming could be achieved if the energy-related BATs are used not only for the drying line but also in other manufacturing stages, particularly in the pressing line where the energy consumption is quite significant.

As also shown in Table 2, BATs 3 and 4 reduce the suspended particulate matter by up to 60% while BATs 5 and 6 achieve up to 54% reduction of acidification and almost completely eliminate fluorine compounds.

Table 2: Percentages of Impact Reductions in Relation to the Baseline Scenario

	BAT 1	BAT 2	BAT 3	BAT 4	BAT 5	BAT 6
GLOBAL WARMING	**9,97 %**	**6,94 %**	-0,03 %	-2,24 %	-0,44 %	-1,40 %
ACIDIFICATION	1,21 %	1,02 %	-0,05 %	-2,19 %	**35,60 %**	**53,91 %**
SPM	0,00 %	0,00 %	**58,68 %**	**59,56 %**	1,93 %	1,93 %
FLUORINE COMPOUNDS	0,00 %	0,01 %	0,00 %	-0,07 %	**98,51 %**	**98,48 %**

One point to note is that some techniques, such as filters or sorption plants, reduce pollutant emissions at the expense of increased energy consumption, larger amounts of raw materials (absorbers) and more waste. This is why some BATs achieved negative “reduction potentials” in some categories, as can be seen from the Table 2.

4.2 Economic indicators

In order to study economic data of each BAT, investments and net operational costs were scored in accordance with the criteria shown in Table 3.

It should be noted that if a BAT produces a bigger benefit than the cost of implementing it, the net operational cost will be negative. As a result, we introduced the negative score (-1) for net operational cost, which accounted for the net economic benefit.

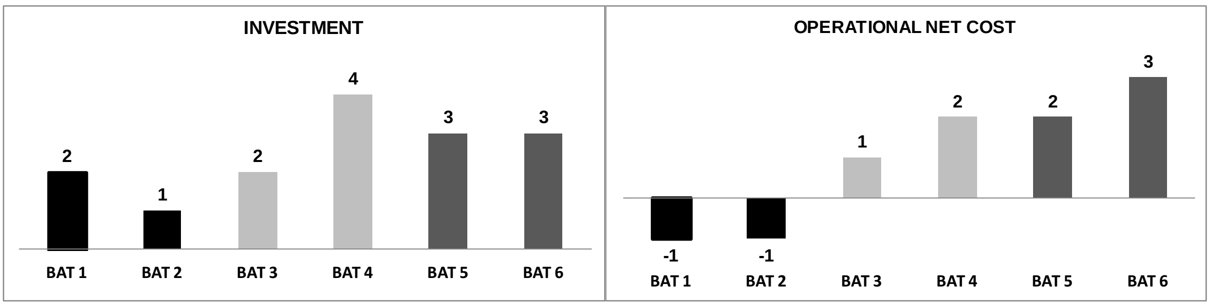
Table 3: Percentages of Impact Reductions in Relation to the Baseline Scenario

Economic Parameters	Ranges	Score
INVESTMENT (€)	< 100.000	1
	100.000 – 400.000	2
	400.000 – 700.000	3
	> 700.000	4
OPERATIONAL NET COST (€/Kg of tile)	< 0	-1
	0 – 0,007	1
	0,007 – 0,014	2
	> 0,014	3

The scores assigned to each BAT can be compared in Figure 3. As can be seen, BAT 4 has the highest investment while BAT 6 has the highest operational costs.

BATs 1 and 2 are the most economical because they have the cheapest investment and negative operational costs. In other words, the energy savings attained by these techniques are enough to pay for the rest of the costs and to obtain some benefit.

Figure 3: Scores Given to the Investment and the Net Operational Cost



5. Discussion and conclusions

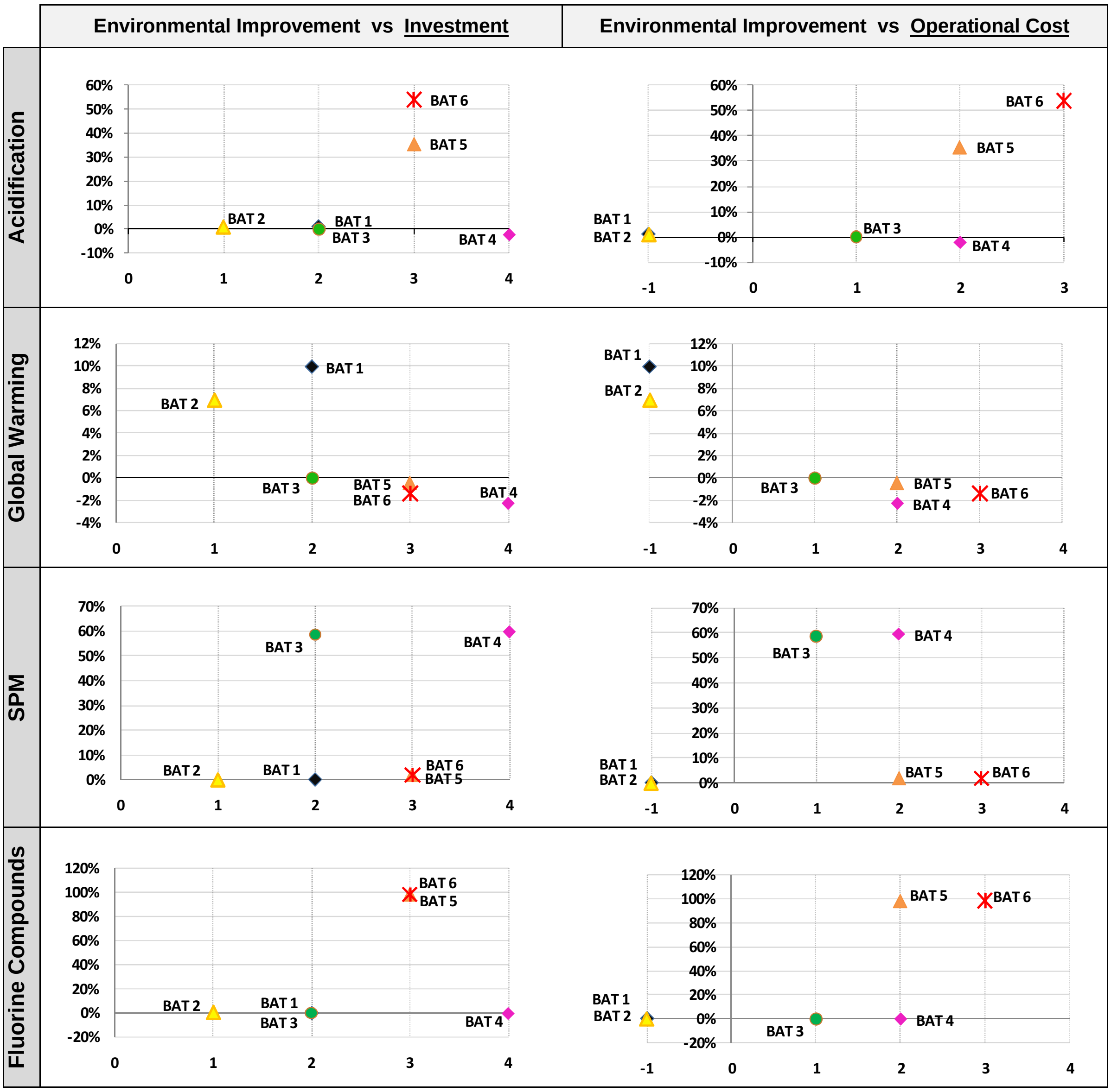
The eco-efficiency of several BATs for the ceramic sector was evaluated by comparing the environmental and economic aspects.

From Figure 4 it can be seen that the most expensive BAT does not deliver the best environmental performance. For instance, for the particulate matter, there are no significant differences between the environmental performance of BATs 3 and 4, but the first one is much cheaper. The same is true for fluorine compounds where BAT 5 involves a slightly higher environmental improvement and lower operational cost than BAT 6.

Examining the values for global warming and acidification, it can be seen that improved environmental performance entails higher costs. However, the negative net operational costs indicate that in the specific case of energy-related BATs, these techniques are shown to be economically feasible.

Finally, it is worth mentioning that the favourable economic performance of BATs 1 and 2, mainly due to the benefits obtained from fuel savings, makes them beneficial for the industries and for the environment. Hence, their implementation is recommended.

Figure 4: Study of the Eco-Efficiency



Acknowledgements

This work was made possible thanks to funding from the Spanish Ministry of Science and Innovation (project DPI2008-04926/DPI) and the Generalitat Valenciana (project ACOMP/2011/036).

References

Bovea M.D., Díaz-Albo E., Gallardo A., Colomer F.J., Serrano J. (2010) Environmental performance of ceramic tiles: Improvement proposals. *Materials and Design, 31*, 35-41.

BREF (2005) *Reference document on economics and cross-media effects*. European Commission, DG JRC, Sevilla, Spain.

BREF (2006) *Reference document on Best Available Techniques (BAT) on emission from storage*. European Commission, DG JRC, Sevilla, Spain.

BREF (2007) *Reference document on Best Available Techniques (BAT) in the ceramic manufacturing industry*. European Commission, Institute for Prospective Technological Studies, Sevilla, Spain.

Dijkmans R. (2000) Methodology for selection of best available techniques (BAT) at the sector level. *Jounal of Cleaner Production, 8*, 11-21.

Directive 2010/75/EU of the European Parliament and the Council, of 15 January, concerning Industrial Emissions (DIE).

Directive 2008/1/EC of the European Parliament and the Council, of 15 January, concerning integrated pollution prevention and control (IPPC).

Directive 1996/61/EC of the European Parliament and the Council, of 24 September, concerning integrated pollution prevention and control.

Georgopoulou, E., Hontou, V., Gakis, N., Sarafidis, Y., Mirasgedis, S., Lalas, D:P:, Loukatos, A., GArgoulas, N., Mentzis, A., Economidis, D., Triantafilopoulos, T., Korizi, K. (2008) BEAsT: a decision-support tool for assessing the environmental benefits and the economic attractiveness of best available techniques in industry. *Journal of Cleaner Production, 16*, 359-373.

Guinée J.B. (2002) *Handbook on life cycle assessment: operational guide to the ISO standards*. Kluwer Academic Publisher, Dordrecht, The Netherlands.

Ibáñez-Forés, V., Bovea M.D., Simó A. (2011) Life cycle assessment of ceramic tile. *submitted 2011*

ISO 14040 (2006) *Environmental management – Life Cycle Assessment – Principles and framework*. European Committee for Standardization (CEN).

ISO 14044 (2006) *Environmental management – Life Cycle Assessment – Requirements and guidelines*. European Committee for Standardization (CEN).

ISO/TS 14048 (2002) *Environmental management – Life Cycle Assessment – Data documentation format*. European Committee for Standardization (CEN).

Mavrotas, G., Georgopoulou, E., Mirasgedis, S., Sarafidis, Y., Lalas, D., Hontou, V., Gakis, N. (2007) An integrated approach for the selection of Best Available Techniques (BAT) for the industries in the greater Athens area using multi-objective combinatorial optimization. *Energy Economics, 29*, 953-973.

Rinaldi C., Fregni A., Palmonari C., Timellini G. (2002) Methodology for Life Cycle Assessment of ceramic floor and wall tiles – Applications in BAT definition for ceramic tiles industry. *Key Engineering Materials, 206-213*, 829-834.

SIMAPRO 7.1. (2008) PRé Consultants B.V. Amersfoort, The Netherlands.

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