

Accepted Manuscript

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PII: S0048-9697(18)35369-5
DOI: <https://doi.org/10.1016/j.scitotenv.2018.12.473>
Reference: STOTEN 30307

To appear in: *Science of the Total Environment*

Received date: 26 October 2018
Revised date: 20 December 2018
Accepted date: 31 December 2018

Please cite this article as: Germán Giner-Santonja, Víctor Vázquez Calvo, Gloria Rodríguez Lepe , Application of AHP and corrective factors for the determination of best available techniques and emission limit values at installation level: A case study in four cement installations. *Stoten* (2019), <https://doi.org/10.1016/j.scitotenv.2018.12.473>

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Application of AHP and corrective factors for the determination of best available techniques and emission limit values at installation level: a case study in four cement installations

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Abstract

After the adoption of the Industrial Emissions Directive in the European Union, requirements regarding emission limit values were made legally binding, and the competent authorities shall ensure that they do not exceed the emission levels associated with the best available techniques. This paper describes a two-stage method for the determination of best available techniques (BAT) and emission limit values (ELV) at installation level, applicable to all industrial sectors covered by the IED and to all pollutants to air and to water. This new method may support competent authorities to implement BAT conclusions into the IED permits. The determination of BAT is based on the use of analytical hierarchy process, while the ELV is determined by using corrective factors based on consumption and emission indicators from the installation. The method is applied in a case study on four existing cement installations in the region of Andalusia (Spain).

Keywords

Emission levels associated with the best available techniques (BAT-AEL)

Best available techniques (BAT)

Analytic hierarchy process (AHP)

Emission limit value (ELV)

1. Introduction.

Industrial Emissions Directive (IED) (European Parliament, 2010) regulates pollutant emissions to air, water and soil, and aims to prevent the generation of waste from about 50 000 industrial installations across the European Union (EU). Those industrial

installations generate almost one quarter of the total EU emissions to air and water (European Commission, 2014). Best available techniques (BAT) conclusions are the technical basis for national competent authorities in EU countries to set permit conditions for industrial installations in the relevant field, as stipulated by the IED (European Parliament, 2010). BAT conclusions aim at achieving a high level of protection of the environment as a whole under economically and technically viable conditions. BAT conclusions cover environmental issues such as emissions to air and to water, waste generation, energy efficiency or water consumption.

The IED aims to achieve significant benefits to the environment and human health, in particular through the mandatory application of BAT (European Commission, 2017). Article 3 of the IED defines BAT as the *"most effective and advanced stage in the development of activities and their methods of operation which indicates the practical suitability of particular techniques providing the basis for emission limit values and other permit conditions designed to prevent and, where that is not practicable, to reduce emissions as a whole"* (European Parliament, 2010).

To determine BAT conclusions, the European Commission (EC) organises an exchange of information between experts from the EU Member States, industry and non-governmental organisations promoting environmental protection. This work is coordinated by the European IPPC Bureau, located at the EU Joint Research Centre in Seville (Spain). This exchange process results in the adoption and publication of BAT conclusions, along with the BAT Reference Documents (the so-called BREFs). So far, fourteen BAT conclusions have been adopted as a Commission Implementing Decision under the IED (European Commission, 2018). BAT conclusions for each sector are foreseen to be reviewed no later than 8 years after the previous version (European Parliament, 2010).

Article 15.2 of the IED requires that *"the emission limit values and the equivalent parameters and technical measures referred to in Article 14(1) and (2) shall be based on the best available techniques, without prescribing the use of any technique or*

specific technology". Article 15.3 of the IED stipulates that "*the competent authority shall set emission limit values that ensure that, under normal operating conditions, emissions do not exceed the emission levels associated with the best available techniques as laid down in the decisions on BAT conclusions*". Moreover, article 15.4 of the IED addresses a way of derogation of article 15.3, stating that "such a derogation may apply only where an assessment shows that the achievement of emission levels associated with the best available techniques as described in BAT conclusions would lead to disproportionately higher costs compared to the environmental benefits due to: (a) the geographical location or the local environmental conditions of the installation concerned; or (b) the technical characteristics of the installation concerned." (European Parliament, 2010).

The document of BAT conclusions for a specific industrial sector contain several individual conclusions, each of them addressing an environmental objective related to the prevention or reduction of one or more pollutants. The IED permits should make reference to one or a combination of the techniques listed in the corresponding BAT conclusion(s). The techniques listed and described in the BAT conclusions are neither prescriptive nor exhaustive. Other techniques may be used that ensure at least an equivalent level of environmental protection. The selection of (a) technique(s) to prevent or reduce a specific pollutant at installation level is a relevant decision depending on complex information, such as the technical configuration of the installation, the raw materials used, economics, sector legislation or safety issues. All this information is relevant to assess the applicability of a technique, and may be mentioned in BAT conclusions (European Commission, 2012). A proper selection of a technique support increase in environmental investments at the facility level and, as a consequence, improvements in environmental performance (Testa et al., 2014).

In order to determine emission limit values (ELV), the competent authorities have to take into account the environmental performance of a specific installation and the emission levels associated with the best available techniques (BAT-AEL). Hence, some

flexibility is allowed to competent authorities when determining BAT and ELV at installation level.

For these reasons, multi-criteria decision analysis (MCDA) is a suitable approach to determine BAT and ELV for a specific pollutant at installation level. MCDA has been applied in many cases to determine BAT at sector level (Dijkmans, 2000; Halog et al., 2001; Derden et al., 2002; Geldermann et al., 2004; Krajnc et al., 2007; Mavrotas et al., 2007; Georgopoulou et al., 2008; Karavanas et al., 2009; Chung et al., 2013), and several studies apply MCDA for the determination of BAT at installation level (Barros et al., 2009; Bréchet and Tulkens, 2009; Giner-Santonja et al., 2012, Ibáñez-Forés et al., 2013, Ozturc et al., 2015).

Other studies have developed methods to determine BAT-AEL at sector level (Polders et al., 2012; Derden and Huybrechts, 2013; López Carretero et al., 2016; Huybrechts et al., 2016; Mahjouri et al., 2017; Evrard et al., 2018). However, no methods have been found in the scientific literature to determine ELV at installation level, which may represent a gap in the implementation of the BAT conclusions into the IED permits. According to the latest IED implementation report (Amec Foster Wheeler, 2016), EU Member States have reported very little information on the procedure followed in order to decide which value within the BAT-AEL range to include as ELV in the permit. In general, EU Member States quoted the relevant national legislation, requiring the ELVs to be set according to the BAT-AELs included in the BAT conclusions. The upper end of the BAT-AEL range is sometimes used in the permits (IEEG, 2017). A competent authority frequently determines the same ELV for a specific pollutant for different installations belonging to the same sector (Daddi et al., 2014). Considering these current practices, it seems that the flexibility principle when determining ELV at installation level is not properly implemented in the IED permits.

This paper presents a method to determine the BAT and the ELV for a specific pollutant at installation level, taking into account the BAT conclusions and the particular techno-economic characteristics of an installation. The method can be applied by

operators and competent authorities involved in the issuing of the IED permits, and it is generally applicable to all industrial sectors under the scope of the IED and for all pollutants to water and to air.

The first stage is based on the use of analytic hierarchy process (AHP) and is oriented to determine BAT(s) for a specific pollutant at installation level, taking into consideration the list of techniques published in BAT conclusions and the scores given on economic, environmental and social criteria (Giner-Santonja et al., 2012). The second stage of the method is based on the application of a corrective factors and is oriented to determine the ELV, for the same specific pollutant and considering the results from the first stage.

The two-stage method presented in this paper is also validated in a case study, in order to determine the BAT and the ELV for dust emissions to air from a kiln firing process in four existing cement and clinker installations located in the Region of Andalucía (Spain).

2. Method.

2.1. Overview of the two-stage method.

The starting point for the first stage is the list of techniques published in BAT conclusions, which are prioritised by applying AHP. AHP is a MCDA proposed by Saaty (1980, 1994), validated by hundreds of studies, is able to manage both qualitative and quantitative criteria, allows integrating opinion from a multidisciplinary team and requires simple calculations.

The first stage was already validated in a previous study (Giner-Santonja et al., 2012). That study used seven determination criteria to select a BAT, grouped into three clusters: economic criteria, implementation costs and environmental criteria. Following AHP, once the hierarchy is established, the first stage follows three steps: i) criteria weighting, ii) determination of BAT for each criterion, and iii) priority matrix. AHP is a

multi-criteria decision tool validated by hundreds of scientific studies. The numerical results of AHP help to find a clear answer about the technique(s) to be prioritised, based on several and rather simple mathematical operations. The prioritised BAT will be used as an input to determine the ELV in the second stage of the method, for which three steps are proposed:

Stage 2.1: corrective factors are obtained to assess the environmental performance of the technique, the resource efficiency of the installation and its environmental effects on the local environment. These factors are the BAT factor, the consumption factor and the environmental quality factor.

Stage 2.2: determination of the representative values of the emission levels.

Stage 2.3: the ELV is obtained from the BAT-AEL by applying the corrective factors.

2.2. Stage 1 – Determination of BAT at installation level

The objective of this stage is to apply AHP to select one or a combination of BAT at installation level from the list of techniques published in BAT conclusions. This determination should be done for each pollutant environmentally relevant for the installation. Based on the criteria from Annex III of the IED, this stage uses seven determination criteria, grouped into three clusters (Giner-Santonja et al., 2012):

- Cluster 1. It contains three economic criteria: C_{11} (implementation costs), C_{12} (resource consumption), and C_{13} (energy efficiency).
- Cluster 2. It contains three environmental criteria: C_{21} (waste water management), C_{22} (air emissions management), and C_{23} (waste management). These three criteria correspond to the three environmental medium (water, air, soil) where emissions can be released from the installation. The criteria included in the other two clusters may also have subsequent effects on these three medium.
- Cluster 3. It contains one social criteria: C_{31} (workers' health).

The hierarchy model containing the determination criteria is shown in Figure 1.

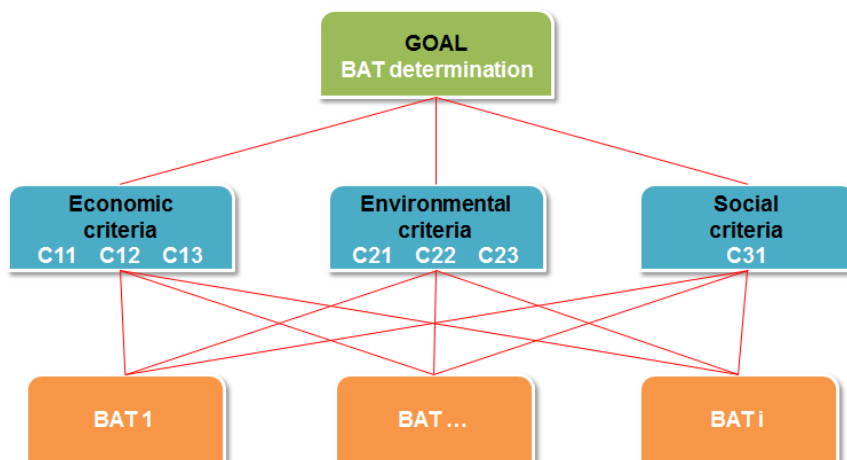


Figure 1.- AHP model for BAT determination at installation level (Giner-Santonja et al., 2012)

AHP can be applied by one or more decision makers. The individual judgments emitted can be aggregated using the geometric mean (Saaty and Peniwaty, 2008). Following AHP, the seven criteria are weighted, thus obtaining the local and global weights. This weighting is based on individual pairwise comparison matrices for the different clusters and for different criteria within a cluster (Giner-Santonja, 2012). Subsequently, the candidates techniques are assessed for each criterion (also using pairwise comparisons) to finally obtaining the prioritisation. The pairwise comparisons between BAT are done using questions such as: Given a certain criterion and two BAT to compare, which BAT better satisfies the criterion and to what extent according to Saaty's 1-9 scale? The applicability restrictions included in BAT conclusions can be linked to one or more of the seven determination criteria and should also be taken into consideration when applying AHP. The technique to be chosen is the one with the highest priority value (Giner-Santonja et al., 2012). In case of BAT conclusions allowing for a combination of techniques, the techniques to be chosen are those with the highest

priority values. This selection will be also used to determine the BAT factor in the second stage of the method presented in this paper.

2.3. Stage 2 – Determination of ELV at installation level

The integrated approach is one of the pillar on which the IED is based. The integrated approach means that the IED permits should take into account the whole environmental performance of the installation: not only the prevention and control of pollution (emissions to air, water and land, and generation of waste), but also the resource efficiency. Moreover, the IED permits should take into account the BAT conclusions and the BAT-AELs.

Therefore, a proper determination of ELV should integrate information and data such as consumption level of the resources used by installation, ambient pollution levels, the emission levels from the installation, the lower and the upper end of the BAT-AELs, or the emission levels for each of the techniques included in BAT conclusions. The purpose of the method to determine ELV proposed in this paper is to find an emission level between the lower and the upper end of a BAT-AEL. The specific position of the ELV is determined by three corrective factors addressing the aforementioned information and data (see formula (6)).

2.3.1. Corrective factors

Three types of corrective factors are proposed to determine the ELV: the BAT factor, the consumption factor and the environmental quality factor.

The BAT factor (BAT_F) is reflecting the general performance of the technique (or a combination of techniques) selected during the first stage of the method (see Section 2.2). When the emission levels of technique(s) are generally associated to the lower end of the BAT-AEL, BAT_F can be equal to 0; conversely, when the technique(s) is

generally associated to the upper end of the BAT-AEL or a higher emission level, BAT_F can be equal to 1. BAT_F can also be between 0 and 1, depending on the emission levels associated to the use of the technique(s) selected with AHP, and its position in the corresponding BAT-AEL range. Information on emission levels associated to each of the techniques included in BAT conclusions can be found generally found in the BREFs. When the BREF does not contain information on emission levels for a specific technique, other emission levels scientifically established (e.g. scientific publications, European, national or international guidelines) can be used.

The consumption factor (C_F) is calculated using the formula (1):

$$C_F = \sum_{i=1}^n \varepsilon_i \cdot CR[CL_i] \quad \sum_{i=1}^n \varepsilon_i = 1 \quad \varepsilon_i = \frac{1}{n} \quad (1)$$

where i is the raw material which is consumed; ε_i is the weight of the consumption ratio of the resource i ; $CR[CL_i]$ is the consumption ratio of the resource i , calculated using the formula (2):

$$CR[CL_i] = \frac{BAT - AEPL \text{ of } [i]}{CL_i} \quad (2)$$

where BAT-AEPL is the environmental performance level associated to the BAT, related to the raw material i ; CL_i is the specific consumption level of the raw material i . In case there is not a BAT-AEPL published in the BAT conclusions, other reference consumption indicators scientifically established (e.g. scientific publications, European, national or international guidelines) can be used. If $CR_i \geq 1$, this means the consumption is efficient, and $CR_i = 1$ should be taken.

CL_i and BAT-AEPL are usually related to specific consumption, i.e. the amount of the raw material i consumed by an installation or process for each unit of product. Thus, a

higher specific consumption of raw materials in an installation is linked to higher emission levels. For the proposed method, a higher specific consumption is linked to a lower C_F , and subsequently to a lower ELV. Less resource-efficient installations are penalised in this way. Attention should be paid to the calculation of CR for water consumption, because a higher consumption is linked to waste water dilution and to lower emissions to water expressed in concentration. For water consumption, the formula to be used is:

$$CR[CL_{water}] = \frac{CL_{water}}{BAT - AEPL \text{ of } [i]} \quad (3)$$

The environmental quality factor (E_F) is calculated using the formula (4):

$$E_F = \sum_{j=1}^n \varepsilon_j \cdot EQ_j \quad \sum_{j=1}^n \varepsilon_j = 1 \quad \varepsilon_j = \frac{1}{n} \quad (4)$$

where j is the pollutant emitted (to air or to water); ε_j is the weight of the environmental quality indicator of the pollutant j ; EQ_j is the environmental quality indicator of the pollutant j . EQ_j is calculated using the formula (5):

$$EQ_j = \frac{\text{environmental quality standard of } [j] \text{ around the installation}}{\text{ambient pollution level of } [j] \text{ around the installation}} \quad (5)$$

If $EQ_j \geq 1$, this means the pollution level around the installation is of a good quality, and $EQ_j = 1$ should be taken. For the proposed method, a higher ambient pollution level is linked to a lower E_F , and subsequently to a lower ELV. Installations located in an area with bad air quality are penalised in this way.

2.3.2. Emission levels

The emission levels (to air or to water) monitored at a specific emission point can be represented by a normal distribution. The characteristics of the normal distribution depends on the monitoring method, the frequency of monitoring, sampling time, etc.

The monitoring of industrial emission points can be continuous or periodical, depending on a risk-based approach. Statistics are used to deal with the variability of the emission levels. The confidence level can be calculated including 95 % of values of the distribution of the emission levels; thus, outliers, also called other than normal operating conditions in the IED, can be excluded, in particular when the difference between the 95th percetile and the maxime emission value is significant (Brinkmann et al., 2018). For the purpose of this paper, the maximum value of the emission levels is noted as EL_M .

2.3.3. Emission limit value

For all existing installations, the environmental objective is that they progressively reduce their emission values for every pollutant, from the EL_M to the BAT-AEL_{LE}. This progressive reduction can be legally achieved by setting an ELV in the permit for a specific pollutant.

There are two likely situations according to the position of the EL_M . A first situation is when the ERV_M is above the upper end of the BAT-AEL; this situation corresponds to an installation with poor environmental performance. A second situation is when the EL_M is between the upper and the lower end of the BAT-AEL; this is the case for an installation with an acceptable environmental performance. For these two situations, the emission limit value (ELV) can be calculated using the formula (6):

$$ELV = BATAEL_{LE} + \frac{(BAT_F \cdot C_F \cdot E_F \cdot (BATAEL_{UE} - BATAEL_{LE}))}{n} \quad (6)$$

where $BATAEL_{LE}$ is the lower end of the range of the emission levels associated to the BAT; C_F is the consumption factor; E_F is the environmental quality factor; $BATAEL_{UE}$ is the upper end of the range of the emission levels associated to the BAT; n is the degree of the environmental reduction.

The objective of parameter n is to address the relative effort to be made by an installation to comply with a BAT-AEL. The value for the parameter n can be selected so that the ELV divide the range between the upper and lower ends of the BAT-AELs into three similar parts or sections (see Figure 2). When the EL_M is above the $BAT-AEL_{UE}$, a value of $2/3$ can be adopted for the parameter n . When the EL_M is in the range of the BAT-AEL, a value of $1/3$ can be adopted for the parameter n .

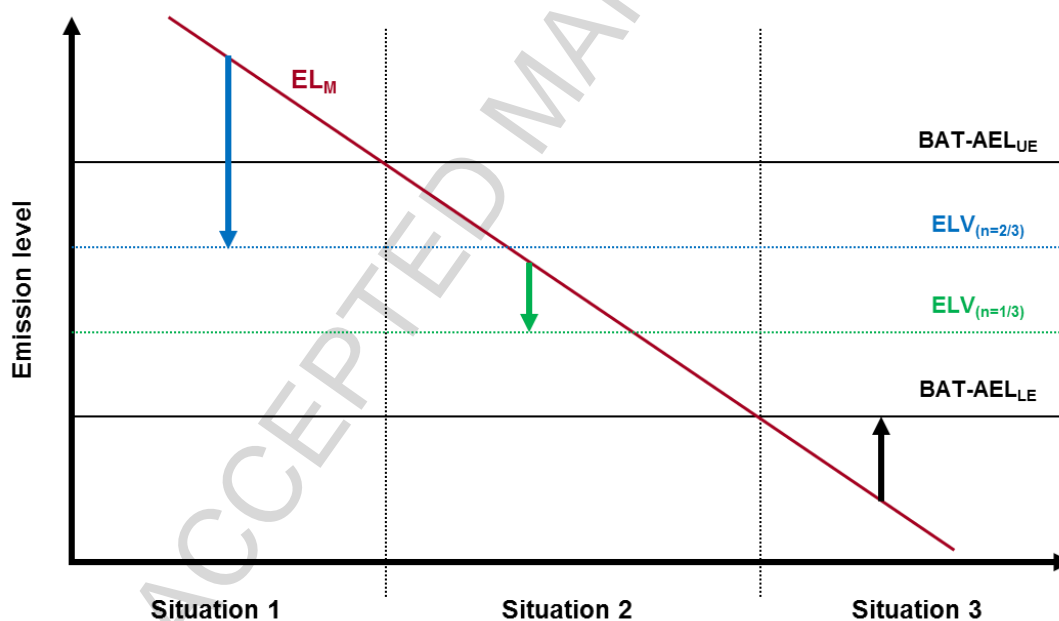


Figure 2.- Scheme of situations for EL_M

A less likely situation is when the EL_M is below the $BAT-AEL_{LE}$. This situation corresponds to an installation with an optimum environmental performance, and then formula (7) should be applied:

$$ELV = BAT_F \cdot C_F \cdot E_F \cdot BATAEL_{LE} \quad (7)$$

3. Case study.

The aim of the case study is the determination of BAT and ELV for dust emissions to air from a kiln firing process in four existing clinker and cement installations located in the Region of Andalucía (Spain). The four installations, which have been anonymised for confidentiality reasons, have a production capacity between 1 400 and 3 000 tonnes clinker/day. The ELV for dust emissions set in their IED permits (before being updated with the BAT conclusions for the production of cement, lime and magnesium oxide (European Commission, 2013)) range between 20 and 50 mg/Nm³.

The information used in this case study was collected from 1) the best available techniques reference document for the Production of Cement, Lime and Magnesium Oxide (CLM BREF) (Schorcht et al., 2013); and 2) by a sector working group (SWG). After the adoption of the IED, different sector working groups (SWG) were set up in the Region of Andalucía for different sectors covered by Annex 1 of the IED. These SWG consisted of representatives from the industry, either from individual companies or industry organisations, environmental public agencies and independent experts from research and technology centres. The following information collected by the SWG was used in this case study:

- a. A description of the productive process used by the cement installations, as well as the main environmental aspects related to each stage of such processes.
- b. Information on the techniques used in the cement installations.
- c. Information related to the calculation of the consumption and environmental quality factors.
- d. Data on emissions to air from cement installations in the Region of Andalucía.

From the BAT conclusions for the production of cement, lime and magnesium oxide (European Commission, 2013), three candidate techniques were considered from BAT conclusion 17, which is the BAT intended to reduce dust emissions from kiln firing processes:

- BAT₁: Electrostatic precipitators (ESPs)
- BAT₂: Fabric filters
- BAT₃: Hybrid filters

According to BAT conclusion 17: 'The BAT-AEL for dust emissions from flue-gases of kiln firing processes is <10 – 20 mg/Nm³, as the daily average value'. In addition to the particular requirements of these BAT, their relevance to the technical and environmental characteristics of the cement installations was also taken into consideration.

4. Results.

4.1. Stage 1 Determination of BAT at installation level

The local and global (aggregated) weights of the criteria, according to the hierarchy approach to determine BAT, used in this case study corresponds to the ones already obtained by Giner-Santonja (2012), given that they are applicable to any BAT determination (Table 1). The highest-rated criteria are energy efficiency (C₁₃) and resource consumption (C₁₂).

Table 1.- Local and global weights of the criteria (Giner-Santonja et al., 2012)

Goal	Cluster	Criteria	Local	Global
BAT selection	Economic criteria 0.741	C ₁₁ . Implementation costs	0.193	0.143
		C ₁₂ . Resource consumption	0.268	0.199

		C ₁₃ . Energy efficiency	0.540	0.400
Environmental criteria 0.184		C ₂₁ . Wastewater management	0.319	0.059
		C ₂₂ . Air emissions management	0.391	0.072
		C ₂₃ . Waste management	0.291	0.054
Social criteria 0.074		C ₃₁ . Workers health	1	0.074

A specific questionnaire was designed to evaluate the three techniques of this case study for each cement installation, using questions such as: Given a certain criterion (e.g. C₁₁) and two techniques to compare (e.g. fabric filters and hybrid filters), which technique better satisfies the criterion and to what extent according to Saaty's 1-9 scale?

The questionnaire was filled in by the authors based on the information available, and in all individual judgment matrices it was verified that their consistency ratios were less than 0.1. Tables 2, 3, 4 and 5 show the scores obtained and the final priority for each cement installation, calculated according to AHP. The selected technique was the use of an ESP (BAT₁) for installations B and D, and a fabric filter (BAT₂) for installations A and C.

Table 2.- AHP priority matrix for dust emissions in installation A

Global weights	C ₁₁	C ₁₂	C ₁₃	C ₂₁	C ₂₂	C ₂₃	C ₃₁	Final priority
BAT ₁	0.43	0.45	0.29	0.49	0.21	0.35	0.10	0.34
BAT ₂	0.20	0.28	0.60	0.21	0.07	0.08	0.71	0.40
BAT ₃	0.36	0.27	0.10	0.31	0.72	0.57	0.19	0.26

Table 3.- AHP priority matrix for dust emissions in installation B

Global	C ₁₁	C ₁₂	C ₁₃	C ₂₁	C ₂₂	C ₂₃	C ₃₁	Final
weights	0.142	0.199	0.400	0.059	0.072	0.054	0.074	priority
BAT ₁	0.33	0.45	0.72	0.31	0.25	0.41	0.67	0.53
BAT ₂	0.07	0.20	0.19	0.07	0.07	0.07	0.20	0.15
BAT ₃	0.60	0.35	0.09	0.62	0.68	0.53	0.12	0.31

Table 4.- AHP priority matrix for dust emissions in installation C

Global	C ₁₁	C ₁₂	C ₁₃	C ₂₁	C ₂₂	C ₂₃	C ₃₁	Final
weights	0.142	0.199	0.400	0.059	0.072	0.054	0.074	priority
BAT ₁	0.29	0.08	0.45	0.29	0.05	0.34	0.49	0.31
BAT ₂	0.07	0.72	0.32	0.49	0.62	0.54	0.21	0.40
BAT ₃	0.65	0.20	0.24	0.22	0.33	0.13	0.31	0.29

Table 5.- AHP priority matrix for dust emissions in installation D

Global	C ₁₁	C ₁₂	C ₁₃	C ₂₁	C ₂₂	C ₂₃	C ₃₁	Final
weights	0.142	0.199	0.400	0.059	0.072	0.054	0.074	priority
BAT ₁	0.09	0.27	0.73	0.21	0.44	0.38	0.71	0.48
BAT ₂	0.71	0.07	0.18	0.07	0.20	0.06	0.18	0.22
BAT ₃	0.20	0.66	0.09	0.72	0.36	0.56	0.11	0.30

4.2. Stage 2 Determination of ELV at installation level

4.2.1. Corrective factors

The following consumption indicators were calculated for the cement installation:

$$CL_1 = \frac{\text{raw materials}}{\text{kiln activity rate}} \quad (8)$$

where CL_1 is the specific consumption of raw materials for the production of clinker, expressed in tonnes/tonne of clinker; raw materials is the total amount of raw materials (chalk, clay, loam, etc.) consumed by the kiln firing process, expressed in tonnes/year; kiln activity rate is the total amount of clinker produced by the kiln firing process, expressed in tonnes clinker/year.

$$CL_2 = \frac{\text{energy consumption}}{\text{kiln activity rate}} \quad (9)$$

where CL_2 is the specific energy consumption for the production of clinker, expressed in MJ/tonne; final energy consumption is the total amount of energy consumed by the kiln firing process, expressed in MJ/year; kiln activity rate is the total amount of clinker produced by the kiln firing process, expressed in tonnes/year.

According to the BREF for the Production of Cement, Lime and Magnesium Oxide (Schorcht et al., 2013), a reference consumption level of raw materials is 1.57 tonnes/tonne of clinker. The BAT conclusions for the production of cement, lime and magnesium oxide (European Commission, 2013) contain a BAT-associated energy consumption level for kilns up to 3,300 MJ/tonne of clinker. The consumption factors for the case study were calculated according to the formulae indicated in Section 2.3.1 of this paper, and the results are indicated in Table 6.

Table 6.- Consumption factors obtained for the case study

Installation	CL_1	CL_2	$CR[CL_1]$	$CR[CL_2]$	C_F
A	1.36	3 516	1	0.94	0.97
B	1.34	3 500	1	0.94	0.97
C	1.65	3 643	0.95	0.91	0.93
D	1.46	3 506	1	0.94	0.97

Values of CR[CL_i] in table 6 are close to one for the case study, showing that the resource efficiency of the four installations is quite acceptable.

For the calculation of the environmental quality indicators (EQ_j) and the environmental quality factors (E_F), data collected from the stations for Air Quality Surveillance and Control Network in Andalucía were taken into account (Junta de Andalucía, 2018). The environmental quality standard around the installations for PM₁₀ is 50 µg/m³ as a daily average. The E_F for the case study were calculated according to the formulae indicated in Section 2.3.1 of this paper, and the results are indicated in Table 7.

Table 7.- Environmental quality factors obtained for the case study

Installation	Average		
	pollution level (µg/m ³)	EQ	E _F
A	34	1	1
B	25	1	1
C	38	1	1
D	29	1	1

Values of EQ in table 7 are equal to one for the case study, showing that the standard for air quality in terms of dust are respected in the surrounding of the installations.

The determination of BAT_F was based on the data available in the CLM BREF. The dust emission levels attained by rotary kiln systems equipped with an ESP are between less than 10 and 30 mg/Nm³. In the case of fabric filters, dust emissions levels are between less than 10 to 20mg/Nm³, as a daily average (Schorcht et al., 2013). The BAT-AEL for dust emissions from flue-gases of kiln firing processes is <10 – 20

mg/Nm³, as a daily average, so BAT_F is equal to 1 for the installations of the case study.

4.2.2. Emission levels

The emission levels (EL) for the dust emissions from the rotating kiln in the case study were obtained from the environmental reports of the different installations located in Andalucía. The maximum values of EL (EL_M) are included in Table 8 and expressed in mg/Nm³, at a temperature of 273.15 K and a pressure of 101.3 kPa, referred to 10 % of oxygen content in the waste gas.

Table 8.- Maximum emission levels (EL_M) for dust emissions from the installations of the case study

Installation	Emission point	EL _M (mg/Nm ³)
A	Rotating kiln	10.3
B		28
C		19.1
D		24.8

4.2.3. Emission limit values

The value for the parameter n in installation A is 1/3, given that the EL_M is in the range of the BAT-AEL. The parameter n is equal to 2/3 for installations B, C and D, because the EL_M is above the BAT-AEL_{UE}. The results obtained by applying formula (6) are shown in Table 9.

Table 9.- Determination of ELV for the case study

Installation	BAT	EL_M	C_F	E_F	BAT_F	BAT- AEL_{LE}	BAT- AEL_{UE}	Parameter n	ELV
A	Fabric filter	10.3	0.97	1	1	10	20	1/3	13.2
B	ESP	28	0.97	1	1	10	20	2/3	16.5
C	Fabric filter	19.1	0.93	1	1	10	20	2/3	16.2
D	ESP	24.8	0.97	1	1	10	20	2/3	16.5

5. Conclusions.

This paper describes a two-stage method for combining the determination of BAT and ELV at installation level. No methods have been found in the scientific literature to determine ELV at installation level. This method consists of choosing one or more techniques compatible with the configuration of the installation and with the BAT conclusions of the corresponding sector, and subsequently obtaining an ELV based on the current environmental performance of the installation and its surrounding environment. The ELV is obtained from techniques, consumption and emission data collected at installation level, ensuring an integrated approach in the permitting procedure. The method can be applied by operators and competent authorities involved in the issuing of the IED permits, and it is generally applicable to all industrial sectors under the scope of the IED and to all pollutants to air and to water.

The application of this method can lead to several advantages. The method may improve the implementation of the BAT conclusions into the IED permits. The proposed determination of BAT at installation level by using AHP may help to prioritise the techniques from BAT conclusions, and to select one or a combination of them. The proposed determination of ELV supports the setting of ELV lower than the upper end of the BAT-AEL, in particular when the ELV should be updated due to the implementation

of recently adopted BAT conclusions. The proposed determination of ELV may also help to improve the current practices carried out by competent authorities when setting ELV in the IED permits.

The method presented in this paper has some limitations. The determination of BAT may entail the collection of a considerable amount of information when the list of best available techniques is long. The values of parameter n used for the determination of ELV need to be validated in more cases, to verify their suitability to the current practices of competent authorities when setting ELV in the IED permits.

The case study was applied to four installations belonging to the same sector in a specific Spanish region. As a consequence, more research is needed in order to verify its suitability to other IED sectors and EU regions.

Acknowledgements.

We would like to thank the Regional Government for Environment of the Andalusian Region for supporting the sector working groups.

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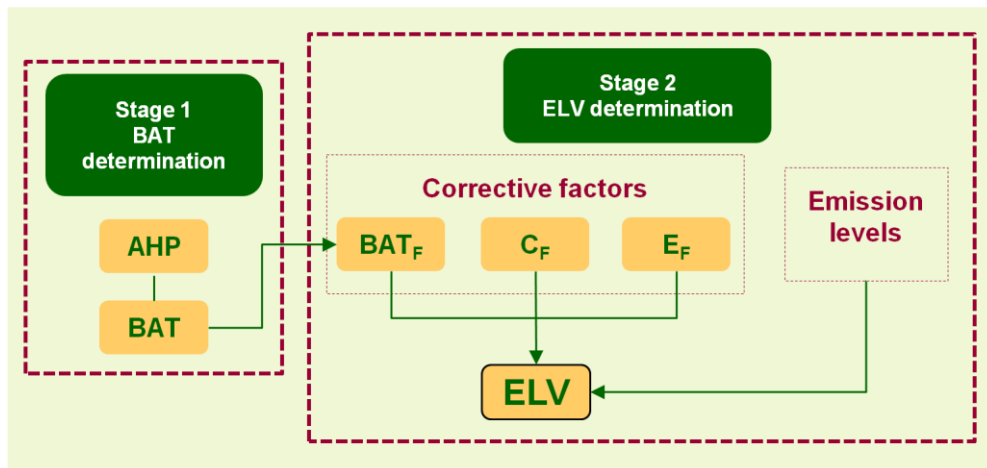
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ACCEPTED MANUSCRIPT



Graphical abstract

Highlights

- Method to determine BAT and ELV at installation level
- Determination of BAT using AHP
- Determination of ELV based on consumption and emission indicators
- Method applicable to all IED sectors and for all pollutants to air and to water

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