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1 **Challenges in assessing Best Available Techniques (BATs)**
2 **compliance in the absence of industrial sectoral reference**

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Acronyms and abbreviations: AHP: Analytic Hierarchy Process, BAT: Best Available Techniques, BATc: BAT conclusions, BAT-AELs: Best Available Technique Associated Emission Levels, BREF: Best Available Techniques Reference Document, ELV: Emission Limit Value, EU: European Union, IED: Industrial Emissions Directive, Ineris: French National Institute for Industrial Environment and Risks, IPPC: Integrated Pollution Prevention and Control, IRPP: Intensive Rearing of Poultry and Pigs, KEI: Key Environmental Issue, LCA: Life Cycle Assessment, MCA: Multi-Criteria Analysis, MEFA: Material and Energy Flow Analysis, SME: Small and Medium-sized Enterprise, SWG: Sector Working Group, TWG: Technical Working Group

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1 **1. Introduction and legal context**

2 The Industrial Emissions Directive was adopted on 24 November 2010 to efficiently prevent, reduce
3 and, as far as possible, eliminate pollution arising from industrial activities by giving priority at the
4 source and prudent management of resources within the European Union (EU) (European
5 Commission, 2010). It aims to regulate the environmental impact of a wide range of industrial and
6 agricultural activities listed in its Annex I (~ 51000 installations in EU) through an integrated approach
7 in order to achieve a high level of protection of the environment as a whole and of human health. The
8 control of these impacts must be ensured by the implementation of techniques with an overall
9 performance equivalent to that of the “Best Available Techniques” (BATs), which are described in
10 Best Available Technical Reference documents (BREFs) (Table 1).

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Table 1: Example of BAT from the BREF for the production of Pulp, Paper and Board (European Commission, 2015)

BAT 19. In order to reduce emissions of pollutants into receiving waters from the whole mill, BAT is to use TCF or modern ECF bleaching (see description in Section 8.7.2.1), and a suitable combination of the techniques specified in BAT 13, BAT 14, BAT 15 and BAT 16 and of the techniques given below.

	Technique	Description	Applicability
a	Modified cooking before bleaching	See Section 8.7.2.1	Generally applicable
b	Oxygen delignification before bleaching		
c	Closed brown stock screening and efficient brown stock washing		
d	Partial process water recycling in the bleach plant		Water recycling may be limited due to incrustation in bleaching
e	Effective spill monitoring and containment with a suitable recovery system		Generally applicable
f	Maintaining sufficient black liquor evaporation and recovery boiler capacity to cope with peak loads		Generally applicable
g	Stripping the contaminated (foul) condensates and reusing the condensates in the process		

Table 2: BAT-associated emission levels for the direct waste water discharge to receiving waters from a bleached kraft pulp mill (European Commission, 2015)

Parameter	Yearly average kg/ADt ⁽¹⁾
Chemical oxygen demand (COD)	7 – 20
Total suspended solids (TSS)	0.3 – 1.5
Total nitrogen	0.05 – 0.25 ⁽²⁾
Total phosphorus	0.01 – 0.03 ⁽²⁾ Eucalyptus: 0.02 – 0.11 kg/ADt ⁽³⁾
Adsorbable organically bound halogens (AOX) ⁽⁴⁾ ⁽⁵⁾	0 – 0.2

⁽¹⁾ The BAT-AEL ranges refer to market pulp production and the pulp production part of integrated mills (emissions from papermaking are not included).
⁽²⁾ A compact biological waste water treatment plant can result in slightly higher emission levels.
⁽³⁾ The upper end of the range refers to mills using eucalyptus from regions with higher levels of phosphorus (e.g. Iberian eucalyptus).
⁽⁴⁾ Applicable for mills using chlorine containing bleaching chemicals.
⁽⁵⁾ For mills producing pulp with high strength, stiffness and high purity properties (e.g. for liquid packaging board and LWC), emissions level of AOX up to 0.25 kg/ADt may occur.

13 These technical documents give a partial picture of the least polluting industrially proven techniques
 14 for a given sector, *i.e.* the most eco-efficient ones at an economically acceptable cost, at the time of
 15 writing. They map commonly used techniques, their performance in terms of emissions, associated
 16 reference conditions, consumption and nature of raw materials, water consumption, use of energy,
 17 generation of waste, associated monitoring, cross-media effects¹, economic and technical viability.
 18 The chapter called “BAT conclusions” (BATc) presents which technique(s) are considered as BATs
 19 (Table 1), as well as a range of values corresponding to the Associated Emission Levels (BAT-AELs)
 20 that can be achieved through their use (Table 2), based upon real data from field experience. Indeed,

¹ Relevant negative effects on the environment due to implementing the technique, allowing a comparison between techniques in order to assess the impact on the environment as a whole (European Commission, 2012a)

21 the IED sets an obligation of results and not means (European Commission, 2010, art. 12). Industrial
22 operators are therefore free to implement the technique they want, as long as it achieves performance
23 levels equivalent to those of techniques officially considered as BATs. BATc are the only legally
24 binding part of the BREF as they are independently published as Commission Implementing Decisions
25 in the Official Journal of European Union (European Commission, 2012b), while the rest of the BREF
26 is more likely to be a guide for industry and authorities. This chapter must ultimately serve as a basis
27 for defining the authorization conditions that will be included in the environmental permit. In
28 particular, the emission limit values (ELVs) for a given installation shall “*be based on the best*
29 *available techniques, without prescribing the use of any technique or specific technology*” and “*not*
30 *exceed the emission levels associated with the best available techniques as laid down in the decisions*
31 *on BATc*” (European Commission, 2010). The IED provides that these conditions are periodically re-
32 evaluated, given the constant evolution of science and technology, and therefore the dynamic nature of
33 BATs. For a given installation, this review takes place at the end of the revision of the BREF
34 corresponding to the main activity. On this occasion, the comparison with BATs must enable the
35 operator to determine the presence or absence of discrepancies with BATc and, consequently, the
36 possible need for compliance with BATs. From the publication of the “main” BATc, local authorities
37 and operators are given 4 years to ensure that the environmental permits of all the installations
38 concerned are updated in accordance with these new BATc and that the new authorization conditions
39 are applied. Thus, the consideration of BATs is made at several stages of the life of an installation:
40 during the environmental impact assessment carried out by the operator to obtain the authorization to
41 operate, when ELVs are set by the local authority in the environmental permit and, finally, during the
42 periodic review of the operation of the installations.

43 In order to identify sectoral BATs and to develop high-quality reference documents on the basis of
44 consensus between stakeholders, a 3-year exchange of information is organized and coordinated by the
45 European Integrated Pollution Prevention and Control Bureau (EIPPCB) (European Commission,
46 2012b). It takes place at the Joint Research Centre in Sevilla (Spain), hence its name “Sevilla Process”
47 (Figure 1).

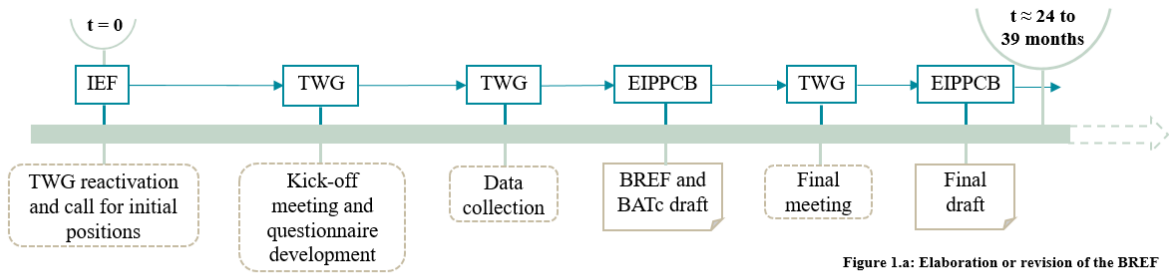


Figure 1.a: Elaboration or revision of the BREF

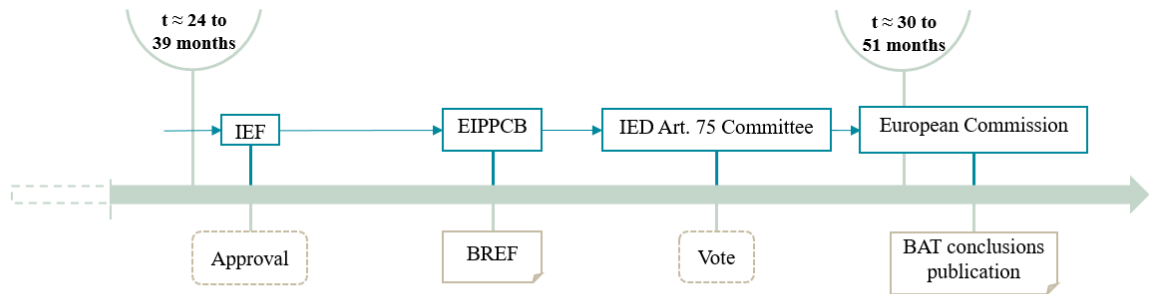


Figure 1.b: BAT conclusions publication

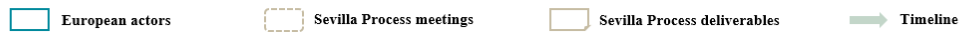


Figure 1: Sevilla process steps for a given industrial sector

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50 To address the need for continuous improvement, BREFs are revised through this process
 51 approximately every ten years by a Technical Working Group (TWG) made up of experts representing
 52 Member States, European Industry Federations, Non-Governmental Organisations promoting
 53 environmental protection and the European Commission. In addition, the Information Exchange
 54 Forum (IEF) is responsible for overseeing the Sevilla Process by ensuring that the exchange of
 55 information is efficient, objective and transparent, and that stakeholders provide sufficient quantitative
 56 and qualitative data on the basis of established guidelines for determining BATs or emerging
 57 techniques to achieve a particular environmental objective (European Commission, 2012b). This data
 58 collection is a key step in the exchange process, but also the most critical phase as it faces problems of
 59 comprehensiveness, quality and representativeness of an industrial sector and its facilities at European
 60 level (Evrard et al., 2015; Geldermann and Rentz, 2004; Laforest and Gaucher, 2015; Polders et al.,
 61 2012). This is one of the reasons for which BATs and BAT-AELs cannot be defined for all Key
 62 Environmental Issues (KEI). Other reasons may lead to shortcomings in BREFs, such as split views
 63 among the various types of actors or between Member States.

64 Consequently, when drawing up or revising a BREF at European level, it is not possible to precisely
 65 cover each industrial sector or sub-sector for all or some of the related environmental issues (Barros et
 66 al., 2007; Carretero et al., 2016). For many sectors, different types of situations for which the BAT
 67 reference is incomplete or non-existent can be observed (Lewandowski, 2018). Furthermore, the
 68 implementation of BATs is not limited to the 33 categories of activities listed in Annex I of the IED,
 69 but also applies to other sectors through their own regulation, e.g. nuclear facilities (OSPAR, n.d.),
 70 which do not have their own BREF but whose permit conditions have also to be periodically reviewed.
 71 Industrial plants involved in these activities without reference are not exempt from demonstrating
 72 BAT implementation. Indeed, the IED states that “where an activity or a type of production process
 73 carried out within an installation is not covered by any of the BATc or where those conclusions do not
 74 address all the potential environmental effects of the activity or process, the competent authority shall,
 75 after prior consultations with the operator, set the permit conditions on the basis of the BAT that it has

76 *determined for the activities or processes concerned, by giving special consideration to the criteria*
77 *listed in Annex III*". But the use of these criteria for BAT evaluation is not easy (Cikankowitz and
78 Laforest, 2008). Indeed, they are more in the form of a list of topics to be addressed as part of the
79 evaluation, without giving more details on how to do it (Laforest, 2014; Laforest and Berthéas, 2005).
80 The lack of reference technologies "officially" considered as BATs and the difficulty of using these 12
81 criteria without further processing may, consequently, lead operators to skip their installations
82 concerned in their BAT analysis and / or the competent authority not to fully check BAT compliance,
83 as they do not know how to proceed. As a result, the objectives of the IED may not be fully fulfilled,
84 and the protection of the environment and of human health not guaranteed. Methodological work is
85 therefore necessary to help operators position their facilities against BATc in the frame of regulatory
86 procedures in all situations where industrial activities are not fully covered by BREFs (Laforest and
87 Gaucher, 2015).

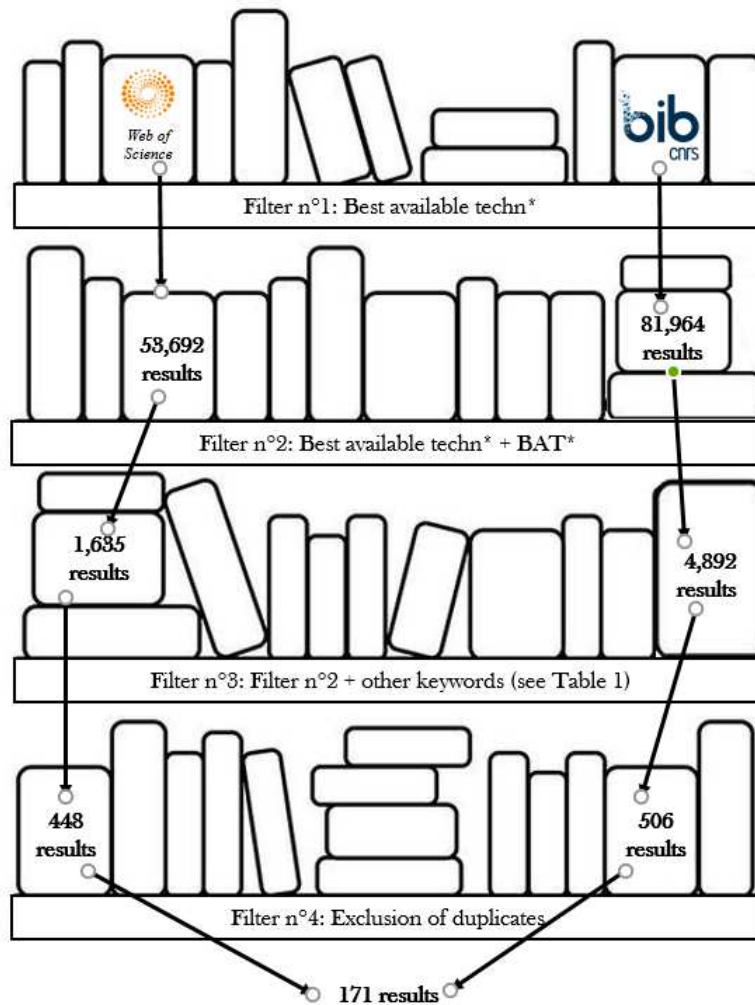
88 Since the inception of the Integrated Pollution Prevention and Control (IPPC) Directive in the 90s,
89 which was subsequently repealed by the IED, various work has been carried out at European level in
90 the field of BAT evaluation to address two major issues: (1) the determination of BATs and / or BAT-
91 AELs at industrial sector level and (2) the implementation of BATs at facility level. This article is
92 aimed at studying the possibility of using these methodologies to compare the performance of an
93 installation to BATs in the absence of an official and complete BAT reference.

94 After having described the research methodology that enabled to conduct this literature review, this
95 article will first focus on whether and how these methods make it possible to answer the problem of
96 lack of BAT reference at local level. It will then wonder if they can be used by a single industrial
97 operator to position the performance of his installation against that of BATs in the absence of a
98 complete and official BAT reference (*i.e.* including BATs and BAT-AELs). Finally, key specifications
99 for an adequate methodology to answer this problem will be proposed.

100 **2. Search method for the literature review**

101 *2.1. Inventory of articles*

102 Bibliographic reference retrieval was carried out by searching methods related to BATs in
103 international journals indexed in recognized databases and accessible from Mines Saint-Etienne.
104 Searches were made in English and French on the Web of Science and BibCNRS, including in this
105 latter researches on Google Scholar. As the word "technologies" is frequently used rather than
106 "techniques" to designate BATs, an initial search using the terms "Best Available Techn*" was first
107 made to cover as wide a field of research as possible. The number of results obtained being
108 respectively 53,692 and 81,964 for the Web of Science and BibCNRS, revealing that the field of
109 research was too broad, a second filter was added to the first one (Figure 2).



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Figure 2: Methodology of research on scientific databases

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The same entries were associated with keywords either related to the decision-making process or to BAT characteristics in order to narrow the scope of research (Figure 2 – Filter n°2 and 3) (Table 3). As the number of rows needed to make a complex research using the “[or]” function would have been too high compared to the maximum of rows that the database can handle, the research corresponding to each cell of the table was made separately. For instance, the search carried out to obtain the result “39 (3)” for the shaded cell in Table 3 is given in Figure 3. Thus, duplication of results could not be avoided. To remedy this, all the articles were downloaded and sorted. If the full paper could not be found on one of the two databases, it was searched on Google Scholar or Research Gate. If it was still not available, a request was sent by Research Gate to the main author to get the full-text version. In Table 3, the numbers in brackets refer to the number of articles from which the full-text version could not be found, either by searching on other databases or by requesting it to the author. On the Web of Science, 5% of articles could not be found in full text, against 8% for BibCNRS. After deleting the duplicates, 171 articles in full-text version remained.

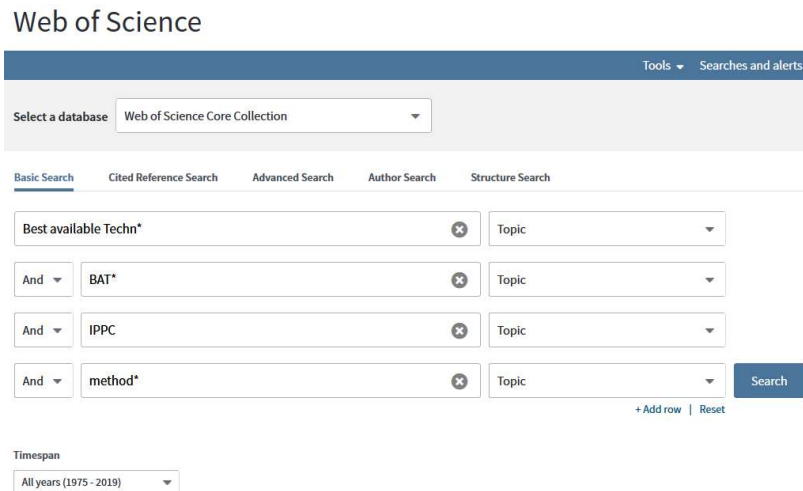
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Table 3: Number of search results with the different combinations of keywords used in the Web of Science and BibCNRS in July 2019

Database	Web of Science				BibCNRS			
	IPPC	IED	BREF	Total	IPPC	IED	BREF	Total
Keywords associated with “Best Available Techn*” and “BAT*”								
method*	39 (3)	26 (2)	18 (1)	83	55 (1)	15 (1)	16 (3)	86
analysis	31 (2)	17 (0)	13 (0)	61	38 (1)	13 (1)	17 (0)	68
selection	9 (0)	10 (1)	3 (0)	22	9 (1)	3 (0)	5 (0)	17
determination	11 (0)	6 (0)	4 (0)	21	11 (0)	4 (0)	4 (0)	19
assess*	30 (3)	11 (0)	8 (0)	49	39 (1)	12 (0)	17 (0)	68
environment*	76 (17)	33 (3)	19 (3)	128	100 (7)	22 (1)	45 (5)	167
eco-efficien*	7 (0)	2 (0)	0	9	5 (0)	0	0	5
decision-mak*	7 (0)	5 (0)	4 (0)	16	4 (0)	1 (0)	3 (0)	8
perform*	32 (1)	15 (0)	12 (0)	59	34 (1)	11 (0)	23 (2)	68
Total	242	125	81	448	295	81	130	506

448 : total number of references found in the database ; * : truncation applied to cover several words with the same radical (ex : assess* → assess, assessment, assessing) ; (7) : number of articles that could not be found in full version on the database, Google Scholar or Researchgate.

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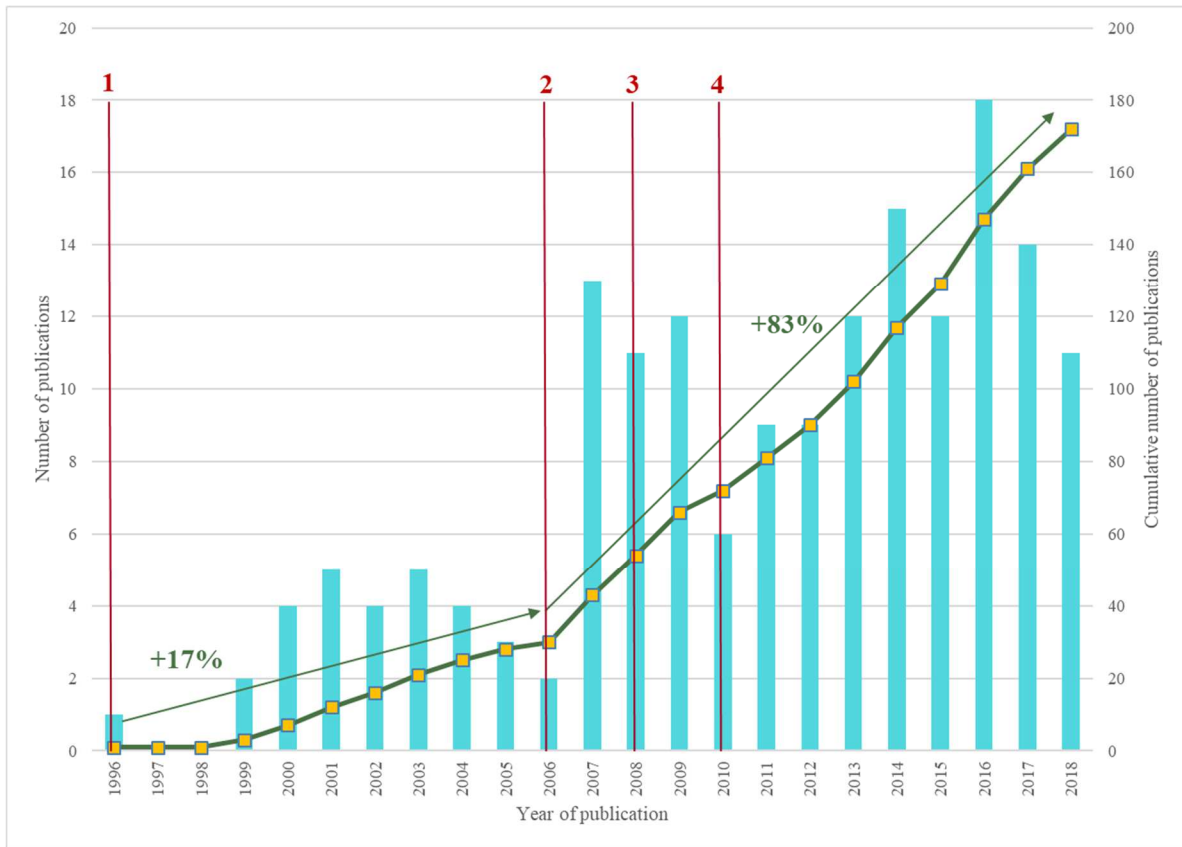
Figure 3: Example of a search done with the filter n°3 on the Web of Science

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Three additional references not included in the two previous investigated databases were provided by the financiers of the thesis in the frame of which this article is written : (1) a methodology designed by the French National Institute for Industrial Environment and Risks (Ineris) to decide on the equivalence of techniques to BATs listed in the Intensive Rearing of Poultry and Pigs (IRPP) BREF (Zanatta et al., 2017), (2) a methodology designed by the United Nations Environment Program to determine BATs, cleaner technologies and Best Environmental Practices (PNUE, 2004) and (3) a methodology designed by VITO to help industrial operators within Flanders (Smets et al., 2017). The latter was only available in Flemish and had to be translated into French. The number of gathered references was then of 174.

140 Considering these 174 articles, Figure 4 presents the number of articles published on BATs over the
 141 years 1996 - 2018 in the light of regulatory developments. The interest for the theme increased slightly
 142 from 1996 (milestone 1 on Figure 4) until 2006 (milestone 2 on Figure 4), the deadline for bringing
 143 installations into compliance with the IPPC Directive with, in particular, the obligation to transmit the
 144 operating balance sheet to the inspection. This interest has intensified with the successive revisions of
 145 the regulation (2008 - milestone 3 on Figure 4 - for the recasting of the IPPC Directive and 2010 –
 146 milestone 4 on Figure 4 – with the adoption of the IED), which were accompanied by the introduction
 147 of new and more stringent measures.

148 This continuous evolution can demonstrate that several bottlenecks and scientific stakes have been
 149 identified / highlighted during the transposition and application of these two directives.



Key milestones:

- 1: Adoption of the IPPC Directive
- 2: Deadline for bringing existing installations into compliance with the IPPC Directive
- 3: Recasting of the IPPC Directive
- 4: Adoption of the IED

Figure 4: Evolution of the number of articles on BATs over time

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157 *2.2. Selection of articles to be analyzed in depth*

158 The titles, keywords, abstracts and conclusions of the 174 remaining articles were read, allowing to
 159 exclude 135 articles that did not really concern BAT assessment. Table 4 summarizes the general
 160 topics of exclusion, a brief description of the exclusion reasons and the number of articles related to
 161 each of them.

162 Along the remaining 39 articles, 11 articles could be excluded, either because the methodologies in
 163 question were presented in other more recent articles, or because the article was an application of a
 164 methodology presented in another article. Finally, 28 articles were kept to be analyzed in depth within
 165 this literature review.

166 *Table 4: Number of articles judged out of scope classified by theme*

Topic	Brief description of the topic	Number of articles found within the topic
About policy and legal study	<ul style="list-style-type: none"> - Regulatory concepts of the IED or other environmental policies - Review of policy challenges and needs arising from them for a given sector or territory - Potential of political instruments to integrate industrial ecology or environmental management aspects, to improve operational efficiency and financial performance, or to change managerial ways - Comparing the effectiveness of different environmental policies - Description and / or feedback of the transposition of the IED in a Member State - Transferring IPPC / IED principles to non-EU countries 	58
Other kinds of assessment than BAT assessment	<ul style="list-style-type: none"> - Cleaner production assessment which is not aimed at reaching BAT performance levels - Site Environmental Impact Assessment - Environmental Management Systems planification - Technical, societal or economic assessment only - Environmental or economic incomes following the implementation of BAT (before / after studies) 	44
Specific case studies	<ul style="list-style-type: none"> - Study of a single technique / introduction of a new technique / pilot tests - Analysis of monitoring results or characterization of measurement and monitoring methods - Sectoral survey (current use of a technique within a sector, future prospects of a sector in the context of environmental regulation, guidelines for a specific sector) - Waste management 	31
Reviews	<ul style="list-style-type: none"> - Literature reviews on methods of evaluation or selection of ecotechnologies 	2
Total number of excluded articles		135

167 **3. Results of the literature review**

168 *3.1. General aspects*

169 The analysis of the 28 articles shows that the two first important characteristics are the study scale
 170 (industrial or geographical scale) and the intended objective *i.e.* to determine sectoral BATs or BAT-
 171 AELs, assess and compare performances to BATs or find the most appropriate technique to
 172 implement.

173 The assessment may be purely environmental ("best") or include techno-economic criteria
 174 ("available"), as provided by the IED. Three methods also incorporate criteria classified as "social",
 175 which mainly concern the working conditions of employees and noise pollution.

176 Table 5 presents the main characteristics of the methods found in the literature.

177 *Table 5: Main characteristics of the methodologies identified*

Objectives	Assessment of BATs	Criteria	End user	References
Sector / European, national or regional				
Determination of sectoral BATs and / or BAT-AELs	Quantitative	Environmental	Policy-makers, business federations	Evrard et al. (2018) Laso et al. (2017) Carretero et al. (2016)
		Environmental and economic	Policy-makers	Mavrotas et al. (2009)
	Qualitative	Technical, environmental, economic	Policy-makers	Dijkmans (2000) and Polders et al. (2012)
		Environmental	Policy-makers, business federations	Barros et al. (2007, 2008)
		Technical support to the French Ministry of Environment	Zanatta et al. (2017)	
Installation / Local Scale				
Assessment of the performance of the facility with respect to BATs	Quantitative	Environmental	Industrial operators	Krajnc et al. (2007)
	Qualitative			Cikankowitz and Laforest (2013)
	Quantitative and qualitative			Panepinto et al. (2016)
				Di Marco and Manuzzi (2018) Cakir et al. (2016)
Selection of a BAT to implement	Quantitative	Environmental, economic, social	Industrial operators	Ibáñez-Forés et al. (2013)
		Environmental and economic		Georgopoulou et al. (2008) Yilmaz et al. (2015)
		Environmental		Nicholas et al. (2000) Cristóbal Andrade et al. (2014)
	Quantitative and qualitative	Environmental		Rodríguez et al. (2011) Barros et al. (2009)
		Technical, environmental, economic	Industrial operators, decision-makers	Geldermann et al. (2003)
	Qualitative	Technical, environmental, economic, social	Industrial operators	Midžić Kurtagić et al. (2016)
		Technical, environmental, economic	Industrial operators, technology suppliers	Laforest (2014)
		Environmental, economic, social	Industrial operators, decision-makers	Giner-Santonja et al. (2012, 2019)
		Guidelines	Technical, environmental, economic	Industrial operators

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182 At sector (European, national or regional) level, the potential users of the methodologies identified are
183 the policy-makers, their technical support, or possibly business federations. These are therefore active
184 stakeholders in the Sevilla Process and / or shadow groups who gather and analyze information
185 collected from representative sites and establish national positions at Member State level. These actors
186 not only have sectoral data that allow them to use quantitative methods (Carretero et al., 2016; Evrard
187 et al., 2018; Laso et al., 2017; Mavrotas et al., 2009), but also benefit from an extensive feedback
188 (Barros et al., 2007, 2008). As they participate in the drafting of the BREFs and also in the
189 implementation of BATc after their revision, they are therefore entitled to provide expert judgment in
190 the frame of working groups to determine the sectoral BATs at the scale of a country (Zanatta et al.,
191 2017) or a region (Dijkmans, 2000; Polders et al., 2012).

192 The IED does not provide any methodology for industrial operators to assess the environmental
193 performance of a given facility in relation to sector-specific BATs. Most of the methods proposed in
194 the scientific literature for this purpose are both quantitative and qualitative, making it possible to
195 compare the characteristics of the installation with those of BATs and the environmental performance
196 levels of the installation to BREF values (Cakir et al., 2016; Cikankowitz and Laforest, 2013; Di
197 Marco and Manuzzi, 2018; Panepinto et al., 2016). Only an exclusively quantitative method has been
198 found (Krajnc et al., 2007). In the case of non-compliance, 11 methods aim to provide tools and / or
199 guidelines to select the most appropriate BAT for their facility (Barros et al., 2009; Cakir et al., 2016;
200 Cristóbal Andrade et al., 2014; Geldermann et al., 2003; Georgopoulou et al., 2008; Giner-Santonja et
201 al., 2012, 2019; Laforest, 2014; Midžić Kurtagić et al., 2016; PNUE, 2004; Rodríguez et al., 2011;
202 Smets et al., 2017) while 3 methods prioritize the selection of the most sustainable BAT (Ibáñez-Forés
203 et al., 2013; Nicholas et al., 2000; Yilmaz et al., 2015). Following the selection of this “best” BAT,
204 only Giner-Santonja et al. (2012, 2019) propose a method to establish suitable ELVs.

205 In the following paragraphs, the potential of these different methods to be used by an operator to
206 position his installation against BATs in the particular context of absence of reference will be
207 analyzed. In a first time, methods to be used at local level are assessed.

208 *3.2. BAT-related methods at installation level*

209 18 methods for assessing and selecting BATs at local level were catalogued. These methods have 2
210 distinct objectives: (1) verify BAT compliance and (2) select one or a combination of BAT(s) to be
211 implemented in case of non-compliance. In the following paragraphs, they will be grouped by
212 objective to be analyzed.

213 *3.2.1. Assessment of the performance of the facility with respect to BATs (review procedure)*

214 Five methods have been found on the issue of comparing an existing installation with BAT
215 performance. They focus exclusively on the environmental dimension of BATs (Table 5).

216 As stated by Cakir et al. (2016), “*BAT implementation in an industrial facility is basically a*
217 *comparison between the facility’s already existing performance and that which could be achieved with*
218 *the implementation of BAT recommended in the BREFs*”. To evaluate BAT implementation, they
219 therefore carry out a comprehensive Material and Energy Flow Analysis (MEFA) to compare on-site
220 measured emissions and consumptions with the values of the applicable BREFs and identify non-
221 compliances. Candidate techniques are then proposed to reach compliance. In addition to verifying
222 compliance with BAT-AELs, Di Marco and Manuzzi (2018) compare qualitatively on-site applied

223 techniques with the BATs of the BREF. No indication is nonetheless given on the extent to which a
224 site would not be in compliance with BATs, especially in cases where other techniques than the ones
225 cited as BATs in BATc are applied on-site and no associated performance level is provided.
226 Flexibility, which is a central principle of the IED, does not seem to have any place in such an
227 approach where the techniques implemented and the techniques of the BREF are put face to face
228 without further analyzing their equivalence, which is however the most common way of proceeding in
229 permit applications.

230 Krajnc et al. (2007) are particularly interested in this principle of flexibility. They propose the use of
231 fuzzy logic to position the environmental performance of beet sugar plants with regard to BAT
232 performance levels. To do this, five qualitative environmental performance levels are established in
233 the form of fuzzy sets and are assigned a membership function. A system of indicators deemed
234 relevant for beet sugar manufacturing is defined on the basis of expert judgment regarding the Food,
235 Drink and Milk BREF and feedback on the sector. Once the different performance levels have been
236 established, two fictitious sites are built, one having a very high overall performance and the other a
237 very low one. By comparing the performance levels of the installation concerned with these two
238 extremes, it is possible to visualize the aspects on which the installation must improve in priority. The
239 indicators used and the performance levels established for each of them are sector-dependent, or even
240 sub-sector-dependent. This fuzzy logic model is thus not generic as it stands and must therefore be
241 completely recreated for each industrial activity by experts who not only have a good knowledge of
242 the sector, but also master fuzzy logic concepts. In addition, the authors do not provide all the keys to
243 adapt the model to other sectors, such as fuzzy rules for assigning values to performance sub-indices.
244 In the absence of reference values in BREFs, this methodology cannot be used to determine if the
245 facility has performance levels equivalent to those of BATs. To overcome this problem, it is proposed
246 to use other reference performance levels based on scientific literature or sectoral feedback. This
247 practice however raises the question of the legitimacy and validity of these values to be used as a BAT
248 reference.

249 Through another approach, Cikankowitz and Laforest (2013) propose a methodology, called L-BAT
250 (for “Local-BAT”), for evaluating the compliance of the installation with the requirements of the
251 Surface Treatment of Metals and Plastics (STM) BREF. It consists of an evaluation of the
252 implementation of BATs at three levels (technique, installation, site), taking into account the main
253 themes covered by the STM BREF and the 12 considerations of the IPPC directive. The analysis of the
254 installation through these aspects not only makes it possible to integrate the comparison of its
255 performance levels with the thresholds set by the regulation as one of the evaluation elements among
256 others, but also to qualitatively assess the equivalence between existing techniques and BATs.
257 Although very comprehensive and in line with the expectations of the IPPC Directive, 2 of the 3 tools
258 created are sector-dependent and must therefore be completely redone for each BREF, which limits the
259 genericity of this method. The third tool is a questionnaire designed to rapidly assess the vulnerability
260 of the local environment, whose responses can be superimposed on the spider graph illustrating the
261 level of compliance of the facility. This representation allows the decision-maker to better visualize
262 where improvements are needed and to efficiently plan for compliance by indicating which
263 environmental compartments require priority action.

264 In the same vein, Panepinto et al. (2016) proposed a method called Enterprise IPPC Compatibility
265 Study based on the development of three indexes thanks to a qualitative scoring and weighting system

266 to assess compliance of a given plant with the BREF. This "site" approach makes it possible to weight
 267 each activity according to the importance of the associated pollutant flow and to score it based on user
 268 appreciation of the closeness of the current situation to the BATs listed in the BREF. In case of non-
 269 compliance, it is possible to prioritize the improvements to make. This means, however, that the
 270 operator is the sole judge of the importance of this discrepancy, and even if a notation on a 1-4 scale is
 271 recommended, no indication is given as to how to assign marks. The risk of this method lies thus
 272 mainly in the subjectivity of the allocation of scores by the user, *e.g.* the operator.

273 The characteristics of the different methods analyzed in this section are shown in Table 6. It can be
 274 observed that the existence of reference BATs and associated performance levels is a prerequisite to
 275 the use of the current methods to evaluate the conformity of the installation to BATs. Indeed, none of
 276 these methods integrates the possibility of creating a BAT reference when this is missing. Only one of
 277 them proposes the use of scientific literature to find other benchmarks (Krajnc et al., 2007), but it is
 278 not reproducible for other sectors than beet sugar manufacturing. Moreover, how to be certain that this
 279 reference is good, and that it corresponds to BATs? This must have been demonstrated prior to
 280 comparing the performance of the installation to it. In the absence of BAT reference, these evaluation
 281 methods could therefore be used downstream of the determination of BATs and / or BAT associated
 282 performance levels. Some authors propose methodologies for selecting the most suitable BAT to be
 283 implemented at local level. Unlike the methods presented in this section, which are methods to
 284 evaluate performance against a specific reference system, these methods are meant to be decision-
 285 support tools in the context of the design or compliance procedure of an installation.

286 *Table 6: Characteristics of the methods for assessing the compliance of the installation with BATs*

		Cakir et al. (2016)	Di Marco and Manuzzi (2018)	Krajnc et al. (2007)	Cikankowitz and Laforest (2013)	Panepinto et al. (2016)
Comparison with BATs						
	Of the BREFs	✓	✓	✓	✓	✓
	Found in other sources	-	-	-	-	-
Use of the definition and 12 criteria of IED annex III		-	-	-	✓	-
Integration of the principle of flexibility		-	-	✓	✓	✓
Consideration of the sensitivity of the local environment		-	-	-	✓	-
Compliance analysis scale						
	Technique	-	✓	-	✓	-
	Installation / site	✓	✓	✓	✓	✓
Non-necessity of expert judgment		✓	✓	-	✓	-
Genericity of the method as it stands		✓	✓	-	-	✓
Planning elements for compliance		-	-	✓	✓	✓

✓ : presence of the characteristic - : absence of the characteristic

287

288 *3.2.2. Selection of a BAT to implement (conceptual phase or compliance procedure)*

289 In this section, methods are analyzed with a view to exploring the possibility of using them to build a
290 local BAT reference. The application of these methods is consecutive to the planning stage of the
291 actions to be implemented or KEIs to be treated. They are therefore used following the reconsideration
292 of the authorization conditions or, in the case of a first application, the environmental impact study, to
293 choose the appropriate technique to be implemented.

294 *3.2.2.1. Main steps to select a BAT to implement on site*

295 In their respective methodologies, PNUE (2004) and Smets et al. (2017) give guidelines on the four
296 main steps to select the most appropriate BAT at local level : (1) description of the problem, (2)
297 identification of candidate techniques, (3) assessment of the candidate techniques and (4) selection of
298 the most appropriate BAT. The assessment of candidate BATs must be based on technical,
299 environmental and economic criteria. These authors also provide examples of tools that can be used to
300 carry out these steps, such as the BREFs and the Flemish BAT studies for the identification of
301 candidate techniques or the Life Cycle Assessment (LCA) for the evaluation of cross-media effects
302 during step 3. The selection of BATs is placed at the end of the methodology, but if the technical,
303 environmental and economic dimensions are evaluated successively and not simultaneously, some
304 alternatives may already be eliminated at the end of each of these substeps if further analysis is
305 considered superfluous for these techniques (Smets et al., 2017). PNUE (2004) specifies that after
306 having evaluated the different alternatives with regard to these 3 criteria, the BAT to be implemented
307 could be selected rather than other candidate techniques with regard to three other criteria: intangible
308 benefits (improvement of working conditions, product quality, reduction of complaints and accidental
309 risks...), local environmental conditions and the geographical location.

310 *3.2.2.2. Identification of the main environmental aspects of the site*

311 To identify the environmental problems to be addressed by the implementation of BATs, Barros et al.
312 (2009), Geldermann et al. (2003) and Rodríguez et al. (2011) propose to identify the critical points of
313 the process by the realization of a MEFA. Unlike in the study by Cakir et al. (2016), it is not used for
314 performance comparison to BATs but only for the purpose of selecting the improvable flows. Indeed,
315 even if the current flows do not exceed the BAT associated performance levels, this does not mean
316 that the performance of the installation cannot be improved. Cristóbal Andrade et al. (2014) propose a
317 similar approach through the use of process simulation to compare the current situation to what can be
318 expected from the implementation of BATs. However, generic process steps are used as a baseline
319 scenario and, therefore, there is no consideration of local environmental conditions. In addition, no
320 details are given on how the investigated scenarios were constructed. In both cases, the tools used
321 (MEFA and process simulation) are time-consuming and not always accessible as they require specific
322 softwares.

323 *3.2.2.3. Inventory of candidate techniques*

324 Barros et al. (2009) and Rodríguez et al. (2011) propose the combination of MEFA and BAT analysis
325 to select BATs to target the identified improvable flows. BAT analysis consists mainly in the creation
326 of a data sheet for each technique, which includes the necessary information to make a decision. On
327 the basis of this information, the candidate techniques that can be used to answer the previously
328 identified environmental aspects are presented. In each of these publications, the advantages and

329 disadvantages of each technique are presented, but not the process of selecting the techniques in itself.
330 Yet, Barros et al. (2009) specify that “*at the time of determining specific BATs for this installation,*
331 *considerations according to annex IV of the IPPC Directive have been considered, in addition to the*
332 *local environmental conditions, geographical location and distinctive technical characteristics of the*
333 *facility*”. Only a distinction is made between the techniques implemented or not, those that could be
334 and those that are not applicable. The search for techniques is not limited to the BREF, but no BAT
335 evaluation is performed for techniques coming from other sources. For the same environmental issue,
336 no mention is made of possible mutual exclusions or combinations between the proposed alternatives
337 (Georgopoulou et al., 2008). Indeed, some could be implemented in combination for an even better
338 environmental performance, but this is not necessarily the case for all. The implementation of a single
339 technique may also be sufficient to achieve the desired environmental objective, but this is not always
340 the case either (Dijkmans, 2000; Zanatta et al., 2017). To determine this, it is necessary to know the
341 environmental performance of the proposed technologies and the investment and operating costs
342 associated with their implementation. These studies are thus more in keeping with an inventory of
343 environmental issues and the techniques to treat them than with a method to select BATs.

344 3.2.2.4. Use of multicriteria analysis in the selection of BATs

345 Rather than successively (PNUE, 2004; Smets et al., 2017), the technical, environmental and
346 economic criteria can be evaluated simultaneously using a multicriteria analysis (MCA) method
347 (Geldermann et al., 2003; Giner-Santonja et al., 2012; Laforest, 2014; Midžić Kurtagić et al., 2016).
348 The MCA methods proposed by these authors are all qualitative, probably because of the lack of
349 available quantitative data, especially when techniques are emerging (Laforest, 2014). To define the
350 evaluation criteria, Giner-Santonja et al. (2012), Laforest (2014) and Midžić Kurtagić et al. (2016)
351 reworked the 12 criteria for defining BATs in Annex III of the IED. They propose additional
352 economic criteria, as the "available" BAT dimension is present only in the definition of a BAT, and
353 not in these 12 criteria. Indeed, as previously mentioned, the study conducted by Laforest and Berthéas
354 (2005) among some forty experts from various professions related to environmental issues has shown
355 that these criteria were difficult to use and that it was necessary to restructure them. Geldermann et al.
356 (2003) and Giner-Santonja et al. (2012) use MCA methods – respectively Analytical Hierarchy
357 Process (AHP) and PROMETHEE - that allow to aggregate the scores assigned to the techniques by a
358 consortium of experts, which makes them hardly reproducible at installation level. To overcome the
359 need for this expert judgment, Giner-Santonja et al. (2012) propose the use of the Analytic Network
360 Process as an alternative to AHP, but its use is arduous because of the difficulty in evaluating the
361 influences between the criteria, and uncertain because it is necessary to make assumptions on these
362 influences. There is therefore a significant risk of losing information and, consequently, of obtaining
363 an erroneous result. On the contrary, the methodologies developed by Laforest (2014) and Midžić
364 Kurtagić et al. (2016) are meant to be used by a single user, but they do not include elements to
365 moderate the judgment of the operator on the alternatives he compares. Thus, they may leave too
366 much room for his subjectivity. Indeed, the operator has both the hand on the notes and the weight of
367 the criteria (Midžić Kurtagić et al., 2016). In the study by Midžić Kurtagić et al. (2016), the
368 information used to establish the scores are, before any analysis, grouped in data sheets, recalling the
369 BAT analysis of Barros et al. (2009). Thus, the attributed scores can be supported by these data sheets
370 when examined by the competent authority. One of the perspectives proposed by Laforest (2014) to
371 objectify her method is the weighting of the criteria. For example, she proposes the panel weighting

372 method which allows to gather stakeholder opinion and expertise thanks to a questionnaire sent to
373 experts. Unlike the methods of Geldermann et al., (2003) and Giner-Santonja et al. (2012), the
374 judgment formalized by a group of experts would be used here only once to set the weights of the
375 criteria, and would not be necessary to mark the alternatives each time the method is used. The
376 subjectivity of the user may be of less importance if BATs have already been determined at sectoral
377 level, and if the local method is only intended to choose the most suitable BAT for the facility. This is
378 for example the case of the interface developed by Georgopoulou et al. (2008), called BAT Economic
379 Attractiveness Tool (BEAsT), which allows to use the data of representative installations to choose the
380 most-eco-efficient BAT. In the case study presented, the use of this tool is made possible thanks to an
381 important data collection on the industrial park of Attica (Greece) and the air pollution it generates
382 (Mavrotas et al., 2009). To make it generic to all geographical situations and all types of pollution, it
383 would be necessary to carry out huge data collection and analysis. In addition, given the dynamic
384 dimension of BAT, data need to be updated regularly.

385 *3.2.2.5. Consideration of the local conditions*

386 In all these methods, the local conditions of the installation are taken into account in different ways. In
387 the study by Laforest (2014), the indicators associated with each of the criteria are case-specific. They
388 must therefore be redefined for each new case study according to the objectives and the available data,
389 so that the evaluation is really customized. PNUE (2004) and Smets et al. (2017) recommend to take
390 into account local environmental conditions to make an appropriate choice of technology. In the
391 methodology by PNUE (2004), this is an element to be taken into account in the final choice of a BAT
392 to be implemented, regardless of the basic constraints that were used to evaluate the candidate
393 techniques firstly. For Smets et al. (2017), on the contrary, local environmental conditions are an
394 integral part of the evaluation process of candidate techniques. In particular, if a certain homogeneity
395 of sensitivity between the different environmental compartments is noted, the authors advise to
396 conduct a thorough environmental analysis, such as an LCA, to decide between the alternatives. In
397 contrast, if it is clear that an environmental compartment is largely overriding the others, the analysis
398 can be focused on this compartment. Without necessarily taking into account the surrounding
399 environment, the environmental performance of the site itself can be a local element of analysis. For
400 example, Barros et al. (2009), Georgopoulou et al. (2008) and Rodríguez et al. (2011) use these
401 performance levels as a basis for selecting candidate techniques to study only those that would
402 actually improve the performance of the site. Finally, the economic dimension of BATs can indirectly
403 illustrate local particularities. Indeed, the IED provides that if it is shown that obtaining BAT-AELs
404 would lead to a disproportionate increase in costs compared to the environmental benefits due to local
405 environmental conditions, geographic location or technical characteristics of the installation, it is
406 possible to derogate from these values. In the absence of reference in BATc, however, the economic
407 criterion remains determinant of what a BAT is because, by definition, a BAT must be "available" (see
408 Appendix A). While several authors include an economic component in their selection method
409 (Geldermann et al., 2003; Georgopoulou et al., 2008; Laforest, 2014; Midžić Kurtagić et al., 2016),
410 only the methods of PNUE (2004) and Smets et al. (2017) suggest a personalized economic analysis,
411 not only taking into account the investment and operating costs, the return on investment and the
412 payback period, but also the economic means of the company itself.

413

414 3.2.2.6. Usability of Life Cycle Assessment in the frame of BAT selection

415 The use of LCA in the BAT selection process was first recommended in the Economics and Cross-
416 Media effects Reference Document (Commission Européenne, 2006) for the assessment of cross-
417 media effects. Accordingly, Ibáñez-Forés et al. (2013), Nicholas et al. (2000) and Yilmaz et al. (2015)
418 propose the use of LCA to compare BATs between them and determine the most sustainable one
419 among several BAT taken from the BREFs. The fictitious baseline scenarios developed by these
420 authors are the result of (1) the aggregation of data obtained from several installations of the sector
421 (Ibáñez-Forés et al., 2013; Nicholas et al., 2000) or (2) performance levels found in the literature, for
422 example in the BREFs (Yilmaz et al., 2015). The sectoral or local scope of these methodologies is
423 therefore unclear, as it is not really specified in any of these studies. In view of the baseline scenario,
424 which is intended to be a "standard" process, one could deduce that they rather target the industrial
425 sector scale. Yilmaz et al. (2015) express a desire to guide the iron casting sector in prioritizing BATs
426 according to their respective eco-efficiency. Ibáñez-Forés et al. (2013) mention that their methodology
427 aims at "*identifying sustainable and most appropriate BAT for a given industrial installation and*
428 *sector*". Finally, Nicholas et al. (2000) caution that "*for both scenarios most of the data used are*
429 *industry averages for the purpose of demonstration of methodological issues only, but that the*
430 *conclusions must be verified by plant-specific data for any particular installation*". In any case,
431 whether these methodologies are applied at sector or installation level, the usefulness of such
432 approaches to assess BATs can be questioned. Indeed, all the techniques compared are already
433 considered as BATs at sector level and the choice of a BAT to be implemented at local level shall be
434 made based on local indicators (sensitivity of the local environment, economic and technical means of
435 the company), which cannot be handled by LCA. As demonstrated by Nicholas et al. (2000), LCA
436 should be coupled with local tools such as Impact Pathway Assessment to assess both global and local
437 environmental aspects. Without taking into account these local aspects, it is not possible to weight the
438 various environmental aspects on a case-by-case basis (Ibáñez-Forés et al., 2013), because the
439 planetary boundaries cannot be prioritized relative to each other. As mentioned by Laforest (2014),
440 LCA is a site-independent approach. It is also a poorly adapted tool for local application for practical
441 and economic reasons. Indeed, it is a complex, time consuming and expensive tool that requires a lot
442 of data which are often unavailable (Geldermann et al., 2003; Giner-Santonja et al., 2012; Laforest,
443 2014; Nicholas et al., 2000). Moreover, although it is a tool based on a consensual method of impact
444 assessment and on the concept of integrated approach, it includes a certain level of subjectivity in the
445 choice of system boundaries, functional units and methods for allocating and weighting environmental
446 loads. Geldermann et al. (2003) point out that most of the data available in the BREFs are "*data on*
447 *material and energy flows considered without further aggregation*". They demonstrate that "*LCA*
448 *impact assessment would not yield further information or useful data aggregation*".

449 3.2.2.7. Summary of the identified characteristics of local BAT selection methods

450 To summarize, the characteristics of the different methods analyzed in this section are shown in Table
451 7. Overall, we note that the majority of these methods do not offer complete autonomy to the user and
452 / or do not integrate the preliminary stage of definition of the study framework which, in the absence
453 of BAT reference, can be problematic. Indeed, without a reference document explicitly listing the
454 environmental issues to be taken into account and / or the most polluting process steps, it is difficult to
455 know which aspects of the installation to focus on. It would be far too tedious and irrelevant to
456 demonstrate the implementation of BATs across the whole site. The local conditions to be taken into

457 account are never all studied, contrary to what is recommended in the guides (PNUE, 2004; Smets et
458 al., 2017). Regarding the consideration of the sensitivity of the local environment, the results of the
459 case study conducted by Giner-Santonja et al. (2012) were taken up by Giner-Santonja et al. (2019) to
460 create a two-step methodology. Step 1, detailed in the article by Giner-Santonja et al. (2012), is the use
461 of AHP to determine BATs on the basis of 7 criteria inspired from annex III of the IED. Step 2,
462 published by Giner-Santonja et al. (2019), consists in determining the ELVs for a given installation by
463 applying three corrective factors to the BAT-AELs of the BREF: the BAT factor, the consumption
464 factor and the environmental quality factor. Considering that “*a competent authority frequently*
465 *determines the same ELV for a specific pollutant at installation level*”, these corrective factors make it
466 possible to place the ELV on the range of BAT-AELs according to the flow of the installation and the
467 sensitivity of the local environment. Thus, the determination of ELVs is proportionate to the
468 environmental issues and, as required by the IED, it is based on BAT performance levels. Finally, the
469 definition and the 12 criteria for determining BAT (see Appendix A and B) are rarely explicitly
470 mentioned, in spite of the fact that they are the only tools provided by the IED to determine BATs in
471 the case of absence of reference (European Commission, 2010).
472

Table 7: Characteristics of local BAT selection methods

	1	2	3	4	5	6	7	8	9	10	11	12	13
	Description of the problem												
Scope and objective definition in the study	-	✓	✓	✓	✓	-	✓	-	✓	✓	-	✓	-
	Identification of candidate techniques: sources of information used												
BREF	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Scientific literature	-	✓	✓	-	✓	✓	-	✓	✓	✓	-	-	-
Grey / technical literature	-	✓	✓	-	✓	✓	✓	✓	-	✓	-	-	-
Questionnaires / Reference installations	-	-	-	-	-	-	-	✓	-	-	-	-	-
	BAT evaluation criteria												
Technical	-	✓	✓	✓	-	✓	-	-	-	-	-	✓	-
Environmental	✓	✓	✓	✓	-	✓	✓	✓	✓	✓	✓	✓	✓
Economic	✓	✓	✓	✓	-	✓	✓	✓	-	-	-	✓	✓
Social	✓	-	-	✓	-	-	-	-	-	-	-	✓	-
Cross-media effects	✓	✓	✓	-	-	✓	✓	-	-	-	-	-	✓
Use of the definition and 12 criteria of IED annex III	✓	-	-	✓	-	✓	-	-	-	-	-	-	-
	Inclusion of local conditions												
Sensitivity of the local environment	✓	✓	✓	-	-	-	-	-	-	-	-	-	-
Geographical location	✓	✓	✓	-	-	✓	-	✓	-	-	-	-	-
Technical specificities of the installation	-	✓	✓	✓	✓	✓	-	-	-	-	-	-	-
Economic means of the company	-	✓	✓	-	-	-	-	-	-	-	-	-	-
	Autonomy of the user												
Non-necessity of expert judgment	-	-	✓	-	✓	✓	-	✓	✓	✓	-	-	✓
Genericity of the method as it stands	-	✓	✓	✓	✓	✓	-	-	✓	✓	✓	-	✓
Non-necessity of a specific software	✓	✓	✓	✓	✓	✓	✓	-	-	-	-	-	-
<i>✓ : presence of the characteristic - : absence of the characteristic</i>													
1 : Giner-Santonja et al. (2012, 2019)	6 : Laforest (2014)				11 : Nicholas et al. (2000)								
2 : Smets et al. (2017)	7 : Geldermann et al. (2003)				12 : Ibáñez-Forés et al. (2013)								
3 : PNUE (2004)	8 : Georgopoulou et al. (2008)				13 : Yilmaz et al. (2015)								
4 : Midžić Kurtagić et al. (2016)	9 : Rodríguez et al. (2011)												
5 : Barros et al. (2009)	10 : Cristóbal Andrade et al. (2014)												

474 3.2.3. Conclusion on the analysis of local methods

475 To conclude, none of the existing local methods seems to be fully adapted to help companies position
476 themselves against BATs in case of missing data or references. However, their analysis has
477 highlighted six essential steps in the determination of BATs at local level and the bottlenecks, at each
478 of these stages, that should be resolved to allow industrial operators to build a reference when it does
479 not already exist in the BREFs (Table 8).

480
481

Table 8: Main steps of the determination of BATs at local level and their associated bottlenecks in the absence of BAT reference

<i>Main steps of the determination of BATs at local level</i>		<i>Description of the step</i>	<i>Main bottlenecks in the absence of BAT reference</i>
1	Description of the problem	Identification of the technical perimeter and environmental issues to target for the application of BATs	The tools currently used are time-consuming or not always accessible.
2	Identification of candidate techniques	Completion of an inventory of pollution prevention or abatement techniques which are candidate to be BATs for the considered KEI	Apart from BREFs, few sources of information on existing technologies are used by operators and local authorities. Scientific literature is often used in research work, but not always available to operators.
3	Assessment of the performance of the candidate techniques, comparison of their performance and selection of BATs	Positioning of candidate techniques against each other and classification of these techniques	The evaluation of techniques often involves expert judgment or the processing of quantitative data, both of which are not widely available at local level. The sensitivity of the local environment is never taken into account when assessing the protection of the environment as a whole. LCA comes back quite often but is ill-adapted to BAT evaluation.
4	Comparison of plant performance with BAT performance	Positioning of the performance levels of the facility against those of BATs	The use of BREFs as a reference system is essential. If need be, the use of another reference is proposed, but its validity as BAT is not verified or proven.
5	Action planning	Identification of the issues to be addressed in priority	No bottleneck was identified for this step: tools already exist for this.
6	Selection of a BAT to implement	Choice of the most appropriate BAT or combination of BATs and implementation scheduling	No bottleneck was identified for this step: tools already exist for this.

482 Apart from the methodologies developed for the selection of BATs at local scale, some methods
483 allow, in the absence of reference at European level, to create a sectoral reference at the scale of an
484 administrative territory (region or country). They thus make it possible to carry out steps 1 to 3 at
485 sector level (Table 8), similarly to what is done by the Sevilla Process. In the following paragraph, the
486 possibility for an industrial operator to use this type of methods to create a BAT reference will be
487 studied.

488 *3.3. BAT-related methods at sector level*

489 Seven methods aim to determine or compare BATs at national or regional level, four of which also
490 allow the determination of BAT-AELs. In this section, these methods are broadly analyzed in relation
491 to the BAT determination steps they perform (Table 9). The analysis will begin with the definition of
492 the scope and objectives, an essential step of this type of demonstration, to finish by the determination
493 of BAT-AELs.

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Table 9: Structuring of sectoral methods for determining BATs

Steps for identifying BATs at sectoral level	Dijkmans (2000) and Polders et al. (2012)	Carretero et al. (2016)	Mavrotas et al. (2009)	Evrard et al. (2018)	Zanatta et al. (2017)	Laso et al. (2017)	Barros et al. (2007, 2008)
Scope and objective definition	✓	✓	✓	✓	✓	✓	✓
Identification of representative installations	✓	-	✓	✓	-	-	-
Identification of candidate techniques	✓	✓	-	-	✓	✓	✓
Determination of BATs	✓	✓	✓	✓	✓	-	-
Determination of BAT-AELs	✓	✓	✓	✓	-	-	-

✓ : presence of the characteristic - : absence of the characteristic

500 As done in the BREFs, prior to any BAT selection, an analysis of the main generic steps of the process
501 is needed to identify the potentially related environmental aspects in order to define the technical and
502 environmental perimeter on which BATs should be determined. For certain methodologies, scope and
503 objectives are defined based on expert judgment regarding the need to build a reference system for a
504 given activity (Carretero et al., 2016; Dijkmans, 2000; Evrard et al., 2018; Zanatta et al., 2017) or
505 known environmental issues on a given territory (Mavrotas et al., 2009). This step can also be carried
506 out via a MEFA based on scientific and technical literature (Barros et al., 2007) or an LCA (Laso et
507 al., 2017). In the study by Laso et al. (2017), the information needed to conduct the LCA is gathered
508 through questionnaires developed by a group of technical experts and completed by the industrial
509 operators of the sector located in Cantabria region (Spain), or taken from life cycle inventory
510 databases. However, the authors point out that the reported LCA results are rare in the BREFs, which
511 makes this methodology difficult or, at least, time-consuming to reproduce.

512 After determining the hotspots of the process, a series of candidate techniques targeting these hotspots
513 is proposed for the anchovy canning industry of Cantabria (Laso et al., 2017). The evaluation of these
514 BATs was not done in the article, but the authors tease that it will be conducted in a future study to
515 elaborate a thorough BREF document for anchovy canning products. Likewise, the method developed
516 by Barros et al. (2007, 2008), called BAT analysis, aims to determine candidate BATs, whether
517 environmental management practices, preventive or curative techniques, for a given sector. This is
518 thus not a BAT selection method either, but rather a guide to the production of technical datasheets on
519 sectoral candidate BATs. These techniques are not necessarily those observed in a panel of facilities as
520 in the study by Laso et al. (2017), but are found in scientific or technical literature. On the model of
521 the “*Techniques to consider in the determination of BATs*” chapter of the BREF, these datasheets are
522 meant to give the operator and local authorities all the relevant information to easily determine specific
523 BATs at local level.

524 In France, due to the large number of intensive livestock facilities concerned and a desire to ease the
525 review process of permit conditions for this sector, the professional agricultural organizations and the
526 technical institutes requested that commonly used techniques that are equivalent in efficacy to those
527 mentioned in BATc are officially recognized as BAT equivalent. Thus, the Ineris methodology aims to

528 validate certain techniques as equivalent to BATs of the IRPP BREF (Zanatta et al., 2017). In the
529 absence of field data on most of the techniques reported by professional organizations and technical
530 institutes, the Ineris opted for an assessment of these techniques inspired by the Environmental
531 Technology Verification (ETV) approach, which is an environmental assessment protocol for
532 innovative technologies. This evaluation consists of the analysis of the quality and robustness of
533 publications and pilot tests carried out under actual operating conditions provided by the profession.
534 The resulting conclusions are validated through an exchange of information with the representatives of
535 the profession and the government before making the final decision public.

536 In the same spirit, The Flemish BAT Center, hosted by the Flemish Institute for Technological
537 Research (VITO), was asked to propose BATs for some industrial sectors for which gaps had been
538 identified (Dijkmans, 2000). For a given sector, candidate BATs are those observed during plant visits,
539 proposed by industry experts or found in literature. Then, to determine BATs, this methodology
540 proceeds by elimination by filtering the techniques through three successive technical, environmental
541 and economic screens to keep only those having passed all these stages successfully. At each stage,
542 candidate techniques are qualitatively scored on the basis of the judgment formalized by a group of
543 technical experts called Sector Working Group (SWG), considering that the Sevilla Process relies
544 mainly on expert judgment at European level. Thus, the BAT determination process, even through
545 expert judgment, is transparent, and it is possible to trace why a candidate technique has been ruled
546 out.

547 The determination of BATs, for example via the methodology of Dijkmans (2000), as well as the
548 availability of emission data and background information, is a prerequisite for the application of the
549 methodology of Polders et al. (2012) for the determination of BAT-AELs. This methodology consists
550 of five stages of processing data collected on representative installations, which mainly consist in
551 exclusion rules of data considered to be beyond the performance levels associated with BATs. In order
552 to set the high range of BAT-AELs, the experts must therefore be able, on the basis of the guidelines
553 given, to detect values that are not representative of the application of BATs under normal operating
554 conditions. The lower range is determined by performance levels that are considered too ambitious at
555 sector level. For example, some facilities face very stringent requirements due to specific local
556 environmental conditions. However, it may not be necessary or viable to impose such constraints on
557 the entire sector. Thus, by introducing an objective and transparent formal framework for the
558 determination of BAT-AELs, the methodology of Polders et al. (2012) aims to limit the extent to
559 which expert judgment and negotiation processes between authorities can be exercised. In the same
560 will, Carretero et al. (2016) propose the use of the DMAIC (Define, Measure, Analysis, Improve and
561 Control) method as part of the revision of the BREFs in a will for rigor and transparency of the Sevilla
562 Process. At each stage of the Sevilla Process, from the sampling stage to the determination of BATs,
563 including the processing of raw data, simple statistical tools are proposed in order to overcome expert
564 judgment rather than simply bind it. Other authors propose the use of more complex mathematical
565 tools.

566 For instance, Mavrotas et al. (2009) and Evrard et al. (2018) both propose quantitative approaches to
567 set BAT related performance levels through the identification of representative sites in the region of
568 interest, the first one using Goal Programming and interactive filtering, and the second one using
569 Principal Component Analysis (PCA) coupled with hierarchical clustering (parangon approach). This
570 step of identifying representative facilities is reminiscent of the Sevilla Process, as emphasized by

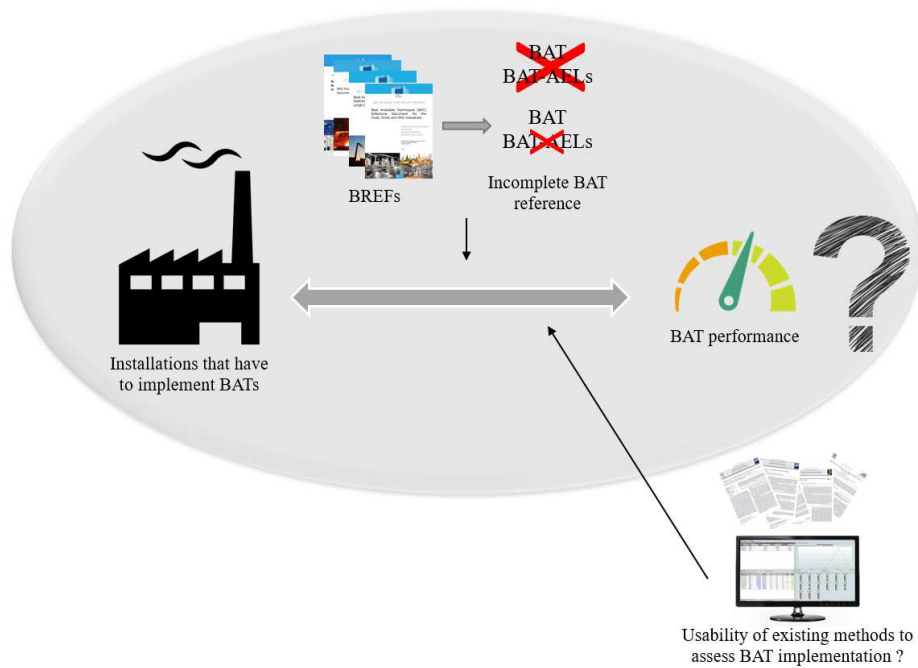
571 Evrard et al. (2016) in their literature review. These two approaches differ however in terms of the
572 objectives set. Indeed, Mavrotas et al. (2009) focus on eco-efficiency by performing a cost-benefit
573 analysis, while Evrard et al. (2018) favor the environmental performance by applying a Pareto Front,
574 assuming that if techniques are applied in the sampled sites, this means that they are economically
575 affordable and technically feasible. As observed by Evrard et al. (2016), these approaches also differ
576 in the relationship between the determination of BAT-AELs and that of BATs. Indeed, on the model
577 of the Sevilla Process, Evrard et al. (2018) and Mavrotas et al. (2009) determine BAT-AELs on the
578 basis of the performances observed over the whole geographical area and deduce the corresponding
579 BATs, while Polders et al. (2012) identify BAT-AELs as achievable targets based on previously
580 identified BATs.

581 Beyond the methodological foundations and the relevance of the tools mobilized, the use of sectoral
582 approaches in a local context raises two major questions. First, because of their proximity to the
583 Sevilla Process, they do not allow the local conditions of industrial installations to be taken into
584 account, in particular the specificities of the natural environment in which they are located. Second,
585 the absence of BATc for a given sub-sector or environmental aspect in the BREFs is often due to data
586 collection problems (insufficient number of facilities or unsuccessful data collection) or the difficulty
587 of reaching a consensus at European level. Thus, the implementation of a national or regional
588 approach in a similar context remains highly questionable, time-consuming and uncertain. In addition,
589 assuming that these approaches are feasible, none of them seems suitable or adaptable for use by a
590 single industrial operator, given the need to collect data from representative sites and / or to mobilize a
591 working group of technical experts.

592 **4. Discussion and perspectives**

593 *4.1. General conclusion on the methods*

594 As a reminder, the purpose of this article is to study the extent to which current methods make it
595 possible to compare the performance of a given installation with those of BATs in the particular
596 context of lack of BAT references (Figure 5). The review analysis was thus focused both on the
597 description of the existing methods and their use in the case of a lack of BAT reference.



598

599

Figure 5: Schematic representation of the research question

600 The literature review shows that the methods for determining sectoral BATs developed in the
 601 framework of European research work are intended for policy-makers. Although most of these sectoral
 602 methods deal with the lack of information in the BREFs, they cannot be used by industrial operators in
 603 their regulatory proceedings, mainly because of the lack of data at their disposal and / or the central
 604 role of the expert, or even of the consensus among experts. Quantitative sectoral tools (Carretero et al.,
 605 2016; Evrard et al., 2018; Mavrotas et al., 2009) could only be used by large groups with enough sites
 606 to have a large amount of data to process / analyze within the proposed statistical approaches. In
 607 contrast, the use of qualitative tools, which notably require expert judgment, risks being biased by the
 608 company's subjectivity, regardless of its size (Dijkmans, 2000; Polders et al., 2012). In the case of
 609 small and medium-sized enterprises (SMEs), none of these methods appears conceivable for
 610 determining BATs. Moreover, these methods do not allow the consideration of the local conditions of
 611 the installation, whether technical, environmental or economic.

612 In the absence of sectoral references, it would therefore be interesting to be able to define a BAT
 613 reference system directly adapted to these local conditions.

614 At local level, none of the methods for comparing the performance of an existing installation with
 615 those of BATs enables to deal with the problem of lack of information since, despite very different
 616 approaches, they all require the use of an existing BAT reference system for comparison. The only
 617 generic methods that make it possible to overcome the need for expert judgment offer no flexibility
 618 with respect to the BATs listed in the BREFs (Cakir et al., 2016; Di Marco and Manuzzi, 2018),
 619 whereas the IED lays down an obligation of results, and not means (European Commission, 2010, art.
 620 12). In addition, only one of the methods for assessing compliance with BATs allows for consideration
 621 of local environmental conditions (Cikankowitz and Laforest, 2013). As the BAT reference is already
 622 fixed in the BREF, this element is judiciously oriented as an element of planning / prioritization of the
 623 actions to be implemented. As part of the construction of a local BAT reference system, the use of
 624 local environmental sensitivity could help to highlight the techniques that best limit the environmental
 625 burden on the most sensitive compartments. This logic could already be adopted in the BAT selection

626 methods to implement, whether in the selection of local KEIs or in the selection of BATs in itself. In
627 practice, this is only recommended (PNUE, 2004; Smets et al., 2017), but none of the inventoried
628 methodologies actually demonstrates how to proceed. The local conditions taken into account in the
629 latter type of methodology are rather geographical (Georgopoulou et al., 2008; Giner-Santonja et al.,
630 2012; Laforest, 2014), technical (Barros et al., 2009; Cakir et al., 2016; Cristóbal Andrade et al., 2014;
631 Laforest, 2014; Midžić Kurtagić et al., 2016) or economic (Georgopoulou et al., 2008; Smets et al.,
632 2017), but never environmental. In this respect, the Environmental Impact Assessment studies provide
633 a solid basis for operators to know the main environmental issues of their site and take into account the
634 local sensitivity of the different environmental compartments (European Commission, 2012c). The use
635 of these documents in the context of comparison to BATs seems therefore relevant, if not unavoidable,
636 towards the protection of the environment as a whole and compliance with the applicable regulation.
637 Generally speaking, the analysis of local methods shows a constant incompatibility between
638 objectivity and flexibility. What can be highlighted, however, is that they are predominantly
639 qualitative. Indeed, at all scales of study, users constantly face the lack of data on techniques,
640 especially when few feedback is recorded (Laforest, 2014; Zanatta et al., 2017). It therefore seems
641 appropriate, in a situation of lack of reference, to continue along this path. However, the qualitative
642 evaluation of the techniques at local level shall in any case require the expert opinion, nor leave
643 entirely room for the subjectivity of the evaluator. It has been observed that expert judgment in the
644 BAT selection process is required by a large part of the reviewed methods, sectoral and local. Experts
645 can be required to intervene in the definition of the scope of the BAT study (environmental issues,
646 main emission sources of the site) (Barros et al., 2007, 2009, 2008), in the development of
647 questionnaires for data collection (Laso et al., 2017), in the choice of indicators to assess the
648 performance of candidate techniques (Krajnc et al., 2007), when choosing candidate techniques
649 (Barros et al., 2007, 2009, 2008; Dijkmans, 2000), in the evaluation of candidate techniques regarding
650 BAT performance (Geldermann et al., 2003; Giner-Santonja et al., 2012), during the selection of
651 BATs (Dijkmans, 2000) and BAT-AELs (Polders et al., 2012). The user of the methodology must be
652 able to be autonomous in the evaluation of the performance of his installation, as it would be difficult,
653 if not impossible, to mobilize experts for all the installations concerned. However, this evaluation must
654 be sufficiently guided and framed not to be biased.

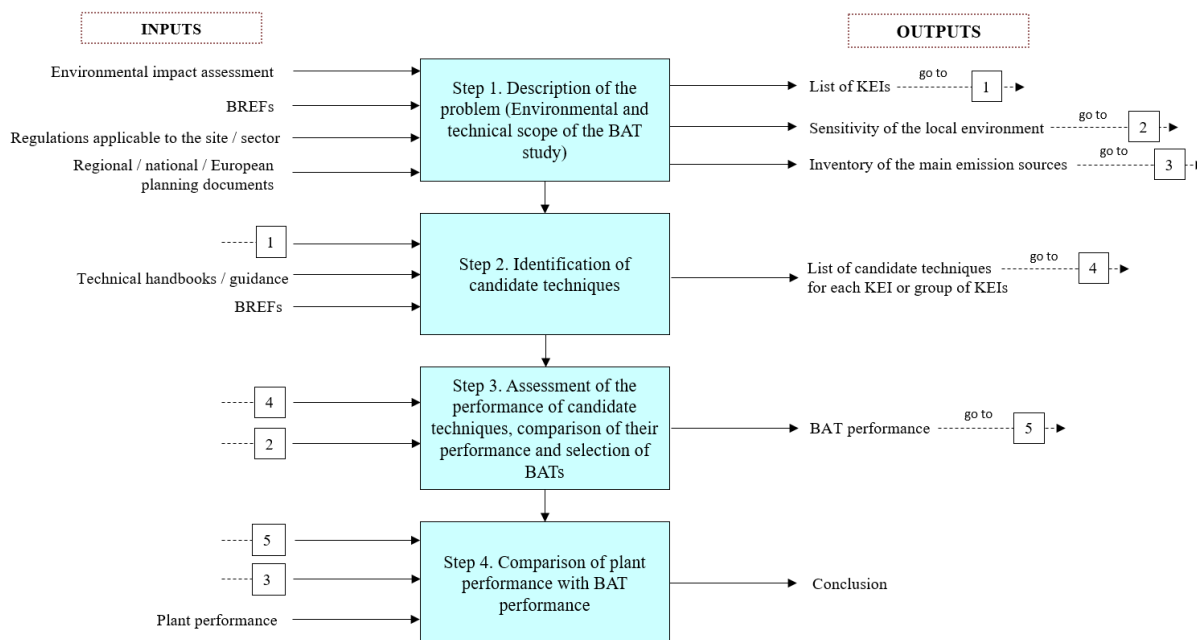
655 To conclude, no method currently allows to answer the problem raised. Methods approach it, but they
656 have limiting elements. The ideal way to answer this problem should be to build a local BAT reference
657 to evaluate the performance of a given installation against it. It would therefore be a judicious
658 compilation of the three main types of methodologies that we have met during this literature review
659 (Table 5). This decision-making tool should enable the operator to conclude his analysis with "my
660 installation is BAT-compliant or not". Beyond the technical, environmental and economic criteria
661 normally dealt with at sector level and which must be taken up at local level as part of the BAT
662 assessment in the absence of reference, the site should also be assessed regarding technical
663 specificities, local environmental conditions and the geographical location of the site (Barros et al.,
664 2009; Giner-Santonja et al., 2019; Laforest, 2014; Midžić Kurtagić et al., 2016; PNUE, 2004; Smets et
665 al., 2017). It should enable SMEs to do the work by themselves, thus enabling them to meet their
666 regulatory constraints.

667

668

669 4.2. Key specifications

670 Considering the elements composing the different methodologies that have been identified and
 671 analyzed in this state of the art, key specifications for a suitable methodology to handle the problem
 672 can be proposed (Figure 6). First, the main steps that were identified (Table 8) can be used as a work
 673 basis. Some structuring improvements can be proposed for steps where bottlenecks were pinpointed
 674 (steps 1 to 4).



675
 676 *Figure 6: Flow diagram illustrating the main steps of the proposed methodology*

677 4.2.1. Description of the problem (Step 1)

678 To identify the application scope of BATs for a given installation, it is important to first refer, from a
 679 technical point of view, to the definition of an "installation" provided by the IED (European
 680 Commission, 2010). In most of the local methodologies mentioned in this review, it is the generic
 681 process steps that are used to identify hotspots. The advantage of working at local level is that it is
 682 possible to go further in terms of precision on the process studied and really select the parts of the site
 683 concerned by the need or obligation to implement BATs.

684 Then, once the technical perimeter is set, the KEIs linked to this perimeter must be defined. This step
 685 must therefore provide an answer to the following question: which environmental issues should BATs
 686 respond to? Thus, a methodology to identify KEIs for a given installation is needed. In existing local
 687 methods, when KEIs are defined, this is done mostly by a MEFA or an LCA, therefore on quantitative
 688 aspects. Indeed, these tools only allow the selection of significant environmental aspects based on their
 689 flow. Admittedly, this makes it possible to identify the major incoming and outgoing flows of the site,
 690 as well as to target the most contributive process steps, but not to identify environmental issues that do
 691 not relate directly to material and energy flows (noise, thermal discharges, microbiological risks...
 692 Indeed, the vast majority of methodologies focus on the pollution of water or air by substances.
 693 However, the definition of "pollution" in the sense of the IED is: "the direct or indirect introduction,
 694 as a result of human activity, of substances, vibrations, heat or noise into air, water or land which may
 695 be harmful to human health or the quality of the environment, result in damage to material property,

696 *or impair or interfere with amenities and other legitimate uses of the environment*". Moreover, MEFA
697 only allows a prioritization of the issues in terms of quantity and not in terms of risks, nor with regard
698 to the sensitivity of the environment. However, environmental issues are also defined by the
699 vulnerability of the local environment (Cikankowitz and Laforest, 2013) and the risks to
700 environmental and human health (European Commission, 2012c). Working on the identification of
701 KEIs on these three aspects will make it possible to prioritize them, and to be able to proportion the
702 exercise of determining BATs to these issues along two main axes: (1) planning according to the
703 urgency of the issues to be addressed and (2) the details of the evaluation to be carried out. On this
704 step, a first proposal was presented by Dellise et al. (2019).

705 *4.2.2. Identification of candidate techniques (step 2)*

706 Where BATc do not give any indication on BATs for a given environmental issue, sub-sector or
707 emission source, operators are free to look for examples of techniques that can address a given issue in
708 other sources of information. These sources are not necessarily adapted to their activity sector and / or
709 do not necessarily present techniques officially recognized as BATs. It might be interesting to
710 prioritize these sources according to their relevance regarding these two criteria.

711 *4.2.3. Assessment of the performance of the candidate techniques, comparison of their performance 712 and selection of BATs (step 3)*

713 *4.2.3.1. Evaluation criteria*

714 According to Raymond (2009), a criteria is : "*a character or sign that distinguishes a thing, a notion
715 or serves as a basis for a judgment of appreciation. It is therefore an element to which one refers to
716 make a judgment, an appreciation. The criteria represent the topics against which the evaluation will
717 be done to achieve the objective(s)*" As stated by Laforest (2014), "*despite the existence of the 12
718 criteria given by the European Directive on industrial emissions, few researchers use them as a
719 departure point for assessment methodology*". However, this is one of the only assessment features
720 available to industrial operators to determine BATs in the absence of reference (European
721 Commission, 2010, art. 14). In addition, they are a source of inspiration for applying the concept of
722 integrated approach as required by the IED. These criteria are therefore essential to BAT
723 determination, but they must be restructured in order to be used (Laforest, 2014; Laforest and
724 Berthéas, 2005), and it should be possible to evaluate these criteria via generic indicators for which
725 information is available.

726 Despite the fact that these criteria are predominantly environmental, BATs must, by definition, be
727 technically and economically feasible (see Appendix A and B). In the absence of reference BATs at
728 sector level, technical and economic criteria should therefore be included in the assessment to ensure
729 the feasibility of the candidate techniques. Indeed, techniques considered as BATs in the BREFs are
730 assumed to be technically and economically feasible because there is proof that they are well-
731 established within the sector.

732 *4.2.3.2. Methodology for evaluating candidate techniques with a view to classifying them BAT or not 733 BAT*

734 The main obstacle to evaluating techniques lies in the unavailability of quantitative data to
735 characterize them (Conti et al., 2015). As stated before, a qualitative method would therefore be more
736 appropriate for this purpose. This method should, however, enable to limit the subjectivity of the user

737 as much as possible. This could be solved by weighting the evaluation criteria. This weighting could,
738 for example, integrate the sensitivity of the local environment.

739 Another question is whether the technical, environmental and economic dimensions should be
740 evaluated successively (Dijkmans, 2000; PNUE, 2004; Smets et al., 2017) or simultaneously (Giner-
741 Santonja et al., 2012; Laforest, 2014; Midžić Kurtagić et al., 2016). A successive evaluation allows to
742 phase down the number of techniques a little more at each filter to keep only those that meet the three
743 criteria satisfactorily. The risk however lies in the fact of evacuating too quickly a technique that could
744 be interesting. On the contrary, a simultaneous evaluation, via an MCA, makes it possible to obtain an
745 optimum on the whole set of criteria. Most authors, however, use total aggregation methods (AHP,
746 weighted sum) that do not prevent the compensation between the different criteria. A prefilter is
747 therefore, in this case, desirable in order to eliminate techniques that do not meet the essential criteria.
748 This gives a mixture of the two methods: a first filter on the prohibitive criteria, and then an MCA on
749 the remaining criteria to obtain an optimal result on these ones only.

750 This method of evaluation should be able to be carried out by the SMEs themselves, regardless of their
751 activity sector. It should be generic, simple and quick to use, but robust and objective. In order to be
752 used in the context of the environmental permit application or review, it should be able to serve as a
753 basis for discussion with the competent authority, and therefore be transparent and flexible.

754 4.2.3.3. *Selection of BATs*

755 The major difference between sector and local BAT determination methods lies in the way to classify
756 techniques.

757 At sector level, several techniques can be retained as illustrative of what is BAT, which does not mean
758 that other techniques cannot have an equivalent performance to theirs or be BAT in a particular local
759 context. Thus, an operator could implement a technique that has not been selected as BAT at sector
760 level, but which is BAT in his case. There is nevertheless a pass / fail approach, in the sense that a
761 technique will be BAT (1) if it is part of the BAT referenced in the applicable BREFs or selected by
762 one of the above-mentioned sectoral methods, or (2) if it is proven to have an equivalent performance
763 to BATs. If it is less performant, it is not BAT.

764 On the contrary, when selected at local level, techniques are rather prioritized from best to worst in
765 terms of performance on the chosen criteria, which makes sense since the goal of the existing methods
766 is to choose the most suitable for the installation in order to implement it. However, the purpose of the
767 desired methodology is to build a local BAT reference as the one available in the BREFs, thus offering
768 the possibility to have several BATs, which would give the method the required flexibility. Polders et
769 al. (2012) state that “*reduction techniques typically have more cross-media effects, and are only*
770 *considered as BATs where prevention techniques are not yet available to reach a high level of*
771 *environmental protection*”. As one of the main principles of the IED is to focus on reduction at the
772 source, this aspect should be integrated as a decision-making element.

773 4.2.4. *Comparison of plant performance with BAT performance (step 4)*

774 Once the BAT reference is built, the operator must be able to position his installation against BATs. In
775 the context of the Sevilla Process, when both BATs and BAT-AELs are available, the only obligation
776 is to prove that the installation achieves performance levels within the range of BAT-AELs, regardless
777 of the cross-media effects. One of the criteria for assessing the facility in the absence of reference

778 should therefore be that it achieves performance levels equivalent to those of locally defined BATs on
779 the KEI. However, it is not because BATs are determined in order to respond to a given environmental
780 problem (*e.g.* the KEI) that it is the only criterion to consider. Indeed, a technique that has a high
781 performance on a given KEI might also have non-negligible negative indirect effects. To ensure the
782 protection of the environment as a whole, other criteria should therefore be verified, such as the
783 minimization of cross-media effects. If the same criteria are used to determine BATs and to compare
784 the performance of the facility with theirs, it could be envisaged to couple steps 3 (assessment of the
785 performance of the candidate techniques, comparison of their performance and selection of BATs) and
786 4 (comparison of plant performance with BATs) in order to immediately have a positioning of the
787 technique in place relatively to other candidate techniques.

788 **5. Conclusion and perspectives**

789 This article has brought to light a certain dichotomy between the sectoral and local scales in the
790 context of BAT implementation. On the one hand, the methodologies designed to be used at the
791 industrial sector level are rather intended for the creation of a BAT reference system by policy makers.
792 On the other hand, the local methodologies aim to use this BAT reference within the regulatory
793 procedures applicable to each installation concerned by the obligation to implement BATs.

794 In the absence of an established sectoral benchmark, operators must still prove to their local authority
795 that they apply BATs on their site. However, this literature review has demonstrated that existing local
796 methods do not allow them to compare the environmental performance of their installations to BATs if
797 these latter have not been determined at first. In addition, the analysis of local and sectoral methods to
798 select BATs has shown that they do not allow operators to fill in the shortcomings of BREFs by
799 themselves due to the lack of genericity, reproducibility, autonomy, objectivity, or access to data.
800 Finally, none of them fully meets the requirements of the IED, *i.e.* they do not take into account
801 simultaneously the principle of flexibility, the definition and the 12 criteria of the Annex III and the
802 local conditions in the BAT determination process.

803 In spite of these limitations, the analysis of these methods made it possible to identify six steps
804 necessary to carry out the reconsideration of the authorization conditions. The first four ones allow to
805 demonstrate the implementation of BATs at local level in the absence of reference and the two last
806 ones to establish an action plan in case of non-compliance. For the first four ones of these steps, the
807 main current bottlenecks were highlighted and key specifications for a methodology to overcome them
808 has been proposed, based on the tools used in the different methodologies that were analyzed. In
809 particular, in the absence of official sectoral BATs, it is essential to define the scope of application of
810 BATs on the site, both from a technical and environmental point of view. Then, for each KEI, BATs
811 must not only ensure the protection of the environment as a whole, but also be accessible to the
812 operator, and therefore be technically and economically feasible.

813 Future perspectives to answer this problem would be to build a local BAT reference to evaluate the
814 performance of a given installation against it. The methodology needed for this purpose would
815 therefore be a judicious compilation of the three main types of methodologies that we have met during
816 this literature review. The main required specificity would be the accessibility to industrial operators,
817 which, at the present time, seems to characterize more qualitative methods than quantitative ones.
818 Indeed, these allow trends to be expressed, to apply large mesh filters concerning applicability and
819 performance of techniques using the information available, whatever their nature, and to leave some

820 leeway to the operator. On the contrary, quantitative methods make it possible to obtain a
821 classification of techniques that is more locked in, but also more objective, which however may not
822 leave room for discussion. These methods are very rarely used at the local level, in particular because
823 they require a large amount of data from several sites on techniques, both on KEIs and on cross-media
824 effects. It no longer has to be demonstrated that operational data obtained on a single site are not
825 always representative of the performance of a technique as it partly depends on local environmental
826 conditions and the way in which the process is designed. Thus, to make these data accessible to
827 operators, enormous progress remains to be made in terms of data collection and information
828 exchange. Furthermore, it is essential that these figures are expressed in comparable units and obtained
829 under similar monitoring and operating conditions. Finally, the quantitative methods inventoried do
830 not, to date, take into account the sensitivity of the local environment of an installation.

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834 **References**

- 835 Barros, M., Bello, P., Roca, E., Casares, J., 2007. Integrated pollution prevention and control for heavy
836 ceramic industry in Galicia (NW Spain). *J. Hazard. Mater.* 141, 680–692.
837 <https://doi.org/10.1016/j.jhazmat.2006.07.037>
- 838 Barros, M.C., Magán, A., Valiño, S., Bello, P.M., Casares, J.J., Blanco, J.M., 2009. Identification of
839 best available techniques in the seafood industry: a case study. *J. Clean. Prod.* 17, 391–399.
840 <https://doi.org/10.1016/j.jclepro.2008.08.012>
- 841 Barros, M.C., Torres, M.T., Bello, P.M., Roca, E., Casares, J.J., 2008. Integrated pollution prevention
842 and control in the surface treatment industries in Galicia (NW Spain). *Clean Technol. Environ. Policy*
843 10, 175–188. <https://doi.org/10.1007/s10098-007-0138-z>
- 844 Cakir, N., Alp, E., Yetis, U., 2016. Evaluation of Environmental Performance Based on Proximity to
845 Bat Associated Resource Utilization and Emission Values: A Case Study in a Steel-Making Industry.
846 *Waste Biomass Valorization* 7, 975–993. <https://doi.org/10.1007/s12649-016-9493-5>
- 847 Carretero, A.L., de la Rosa, J., Sanchez-Rodas, D., 2016. Applying statistical tools systematically to
848 determine industrial emission levels associated with the best available techniques. *J. Clean. Prod.* 112,
849 4226–4236. <https://doi.org/10.1016/j.jclepro.2015.06.037>
- 850 Cikankowitz, A., Laforest, V., 2013. Using BAT performance as an evaluation method of techniques.
851 *J. Clean. Prod.* 42, 141–158. <https://doi.org/10.1016/j.jclepro.2012.10.005>
- 852 Cikankowitz, A., Laforest, V., 2008. How to compare industrial techniques to Best Available
853 Techniques? pp. 707–716. <https://doi.org/10.2495/WM080721>
- 854 Commission Européenne, 2006. Reference Document on Economics and Cross-Media Effects.
- 855 Conti, M.E., Ciasullo, R., Tudino, M.B., Matta, E.J., 2015. The industrial emissions trend and the
856 problem of the implementation of the Industrial Emissions Directive (IED). *Air Qual. Atmosphere*
857 *Health* 8, 151–161. <https://doi.org/10.1007/s11869-014-0282-7>

858 Cristóbal Andrade, L., Bernal Pampín, M.A., Taboada Gómez, M.C., Bello Bugallo, P.M., 2014.
859 Optimization of Improvable Flows by combining BAT Analysis and process simulation. *Chem. Eng.*
860 *Res. Des.* 92, 1976–1987. <https://doi.org/10.1016/j.cherd.2014.04.025>

861 Dellise, M., Villot, J., Gaucher, R., Amardeil, A., Laforest, V., 2019. Assessing the implementation of
862 Best Available Techniques at the local scale in the absence of industrial sectoral reference: an issue for
863 compliance demonstration. Presented at the 14th Annual International Symposium on Environment,
864 27-30 May 2019, Athens, Greece, Athens, Greece.

865 Di Marco, G., Manuzzi, R., 2018. The recovery of waste and off-gas in Large Combustion Plants
866 subject to IPPC National Permit in Italy. *Waste Manag.* 73, 313–321.

867 Dijkmans, R., 2000. Methodology for selection of best available techniques (BAT) at the sector level.
868 *J. Clean. Prod.* 8, 11–21. [https://doi.org/10.1016/S0959-6526\(99\)00308-X](https://doi.org/10.1016/S0959-6526(99)00308-X)

869 European Commission, 2015. Best Available Techniques (BAT) Reference Document for the
870 Production of Pulp, Paper and Board.

871 European Commission, 2012a. Revision of the standard texts used in BREFs to adapt them to the IED
872 regime [WWW Document]. URL
873 https://eippcb.jrc.ec.europa.eu/reference/BREF/Codified_version_of_standard_text29_08_12.pdf
874 (accessed 9.25.19).

875 European Commission, 2012b. Commission Implementing Decision of 10 February 2012 laying down
876 rules concerning guidance on the collection of data and on the drawing up of BAT reference
877 documents and on their quality assurance referred to in Directive 2010/75/EU of the European
878 Parliament and of the Council on industrial emissions.

879 European Commission, 2012c. Directive 2011/92/EU of the European Parliament and of the Council
880 of 13 December 2011 on the assessment of the effects of certain public and private projects on the
881 environment, 2011/92/EU.

882 European Commission, 2010. Directive 2010/75/EU of the European Parliament and of the Council of
883 24 November 2010 on industrial emissions (integrated pollution prevention and control).

884 Evrard, D., Laforest, V., Villot, J., Gaucher, R., 2016. Best Available Technique assessment methods:
885 a literature review from sector to installation level. *J. Clean. Prod.* 121, 72–83.
886 <https://doi.org/10.1016/j.jclepro.2016.01.096>

887 Evrard, D., Laforest, V., Villot, J., Gaucher, R., Bouhrizi, S., Darmon, N., 2015. Identification of
888 Representative Installations to Determine Best Available Techniques: A Methodological Proposal.

889 Evrard, D., Villot, J., Armiyaou, C., Gaucher, R., Bouhrizi, S., Laforest, V., 2018. Best Available
890 Techniques: An integrated method for multicriteria assessment of reference installations. *J. Clean.*
891 *Prod.* 176, 1034–1044. <https://doi.org/10.1016/j.jclepro.2017.11.234>

892 Geldermann, J., Rentz, O., 2004. The reference installation approach for the techno-economic
893 assessment of emission abatement options and the determination of BAT according to the IPPC-
894 directive. *J. Clean. Prod.* 12, 389–402. [https://doi.org/10.1016/S0959-6526\(03\)00032-5](https://doi.org/10.1016/S0959-6526(03)00032-5)

895 Geldermann, J., Zhang, K., Rentz, O., 2003. Multi-criteria group decision support for integrated
896 technique assessment.

897 Georgopoulou, E., Hontou, V., Gakis, N., Sarafidis, Y., Mirasgedis, S., Lalas, D.P., Loukatos, A.,
898 Gargoulas, N., Mentzis, A., Economidis, D., Triantafilopoulos, T., Korizi, K., 2008. BEAsT: a
899 decision-support tool for assessing the environmental benefits and the economic attractiveness of best
900 available techniques in industry. *J. Clean. Prod.* 16, 359–373.
901 <https://doi.org/10.1016/j.jclepro.2006.12.002>

902 Giner-Santonja, G., Aragonés-Beltrán, P., Niclós-Ferragut, J., 2012. The application of the analytic
903 network process to the assessment of best available techniques. *J. Clean. Prod.* 25, 86–95.
904 <https://doi.org/10.1016/j.jclepro.2011.12.012>

905 Giner-Santonja, G., Vázquez Calvo, V., Rodríguez Lepe, G., 2019. Application of AHP and corrective
906 factors for the determination of best available techniques and emission limit values at installation
907 level: A case study in four cement installations. *Sci. Total Environ.* 660, 834–840.
908 <https://doi.org/10.1016/j.scitotenv.2018.12.473>

909 Ibáñez-Forés, V., Bovea, M.D., Azapagic, A., 2013. Assessing the sustainability of Best Available
910 Techniques (BAT): methodology and application in the ceramic tiles industry. *J. Clean. Prod.* 51, 162–
911 176. <https://doi.org/10.1016/j.jclepro.2013.01.020>

912 Krajnc, D., Mele, M., Glavič, P., 2007. Fuzzy Logic Model for the performance benchmarking of
913 sugar plants by considering best available techniques. *Resour. Conserv. Recycl.* 52, 314–330.
914 <https://doi.org/10.1016/j.resconrec.2007.05.001>

915 Laforest, V., 2014. Assessment of emerging and innovative techniques considering best available
916 technique performances. *Resour. Conserv. Recycl.* 92, 11–24.
917 <https://doi.org/10.1016/j.resconrec.2014.08.009>

918 Laforest, V., Berthéas, 2005. Ambiguïté entre technologies propres et meilleures techniques
919 disponibles. *Vertigo* 6. <https://doi.org/10.4000/vertigo.9657>

920 Laforest, V., Gaucher, R., 2015. Directive sur les émissions industrielles (IED) et meilleures
921 techniques disponibles. *Tech. Ing., Éco-conception et innovation responsable*, G4097 v1, 15 p.

922 Laso, J., Margallo, M., Fullana, P., Bala, A., Gazulla, C., Irabien, A., Aldaco, R., 2017. Introducing
923 life cycle thinking to define best available techniques for products: Application to the anchovy canning
924 industry. *J. Clean. Prod.* 155, 139–150. <https://doi.org/10.1016/j.jclepro.2016.08.040>

925 Lewandowski, E., 2018. Analyse et traitement des lacunes dans les référentiels européens de
926 performance environnementale des installations industrielles (Rapport de projet industriel ICM 3A).
927 Ecole des Mines de Saint-Etienne, Saint-Etienne.

928 Mavrotas, G., Georgopoulou, E., Mirasgedis, S., Sarafidis, Y., Lalas, D., Hontou, V., Gakis, N., 2009.
929 Multi-objective combinatorial optimization for selecting best available techniques (BAT) in the
930 industrial sector: the COMBAT tool. *J. Oper. Res. Soc.* 60, 906–920.
931 <https://doi.org/10.1057/palgrave.jors.2602618>

932 Midžić Kurtagić, S., Silajdžić, I., Vučijak, B., 2016. Selection and implementation of pollution
933 prevention techniques in small and medium enterprises in countries in transition. *Clean Technol.*
934 *Environ. Policy* 18, 1827–1847. <https://doi.org/10.1007/s10098-016-1237-5>

- 935 Nicholas, M.J., Clift, R., Azapagic, A., Walker, F.C., Porter, D.E., 2000. Determination of ‘Best
936 Available Techniques’ for Integrated Pollution Prevention and Control: A Life Cycle Approach.
937 *Process Saf. Environ. Prot.* 78, 193–203. <https://doi.org/10.1205/095758200530637>
- 938 OSPAR, n.d. Best Available Techniques (BAT) and Best Environmental Practice (BEP) [WWW
939 Document]. OSPAR Comm. URL <https://www.ospar.org/work-areas/rsc/bat-bep> (accessed 9.2.19).
- 940 Panepinto, D., Ruffino, B., Zanetti, M., Genon, G., 2016. A Standardized Procedure for a Pre-
941 evaluation of the IED Instance. *Environ. Manage.* 57, 847–855. <https://doi.org/10.1007/s00267-016-0657-7>
- 943 PNUE, 2004. Lignes directrices pour l’application des meilleures techniques disponibles (MTD), des
944 meilleures pratiques environnementale (MPE) et des technologies plus propres (TPP) dans l’industrie
945 des pays Méditerranéens. PNUE/PAM. Athènes, Grèce.
- 946 Polders, C., Van den Abeele, L., Derden, A., Huybrechts, D., 2012. Methodology for determining
947 emission levels associated with the best available techniques for industrial waste water. *J. Clean. Prod.*
948 29–30, 113–121. <https://doi.org/10.1016/j.jclepro.2012.02.008>
- 949 Raymond, G., 2009. Réduction des impacts environnementaux des ateliers de traitement de surface :
950 application de stratégies de production plus propre et plus sûre. École Nationale Supérieure des Mines
951 de Saint-Étienne, Saint-Etienne.
- 952 Rodríguez, M.T.T., Andrade, L.C., Bugallo, P.M.B., Long, J.J.C., 2011. Combining LCT tools for the
953 optimization of an industrial process: Material and energy flow analysis and best available techniques.
954 *J. Hazard. Mater.* 192, 1705–1719. <https://doi.org/10.1016/j.jhazmat.2011.07.003>
- 955 Smets, T., Vanassche, S., Huybrechts, D., 2017. Leidraad voor het bepalen van de Beste Beschikbare
956 Technieken op bedrijfsniveau. VITO, Mol, Belgium.
- 957 Yilmaz, O., Anctil, A., Karanfil, T., 2015. LCA as a decision support tool for evaluation of best
958 available techniques (BATs) for cleaner production of iron casting. *J. Clean. Prod.* 105, 337–347.
959 <https://doi.org/10.1016/j.jclepro.2014.02.022>
- 960 Zanatta, L., Gaucher, R., Ramel, M., 2017. Techniques équivalentes aux MTD en élevages intensifs de
961 porcs: évaluation de l’utilisation d’additifs pour la réduction des émissions d’ammoniac (No. INERIS-
962 DRC-17-163622-06436A). Ineris, Verneuil-en-Halatte.

963 **Appendix A: Definition of “Best available techniques” (European Commission, 2010)**

964 “best available techniques” means the most effective and advanced stage in the development of
965 activities and their methods of operation which indicates the practical suitability of particular
966 techniques for providing the basis for emission limit values and other permit conditions designed to
967 prevent and, where that is not practicable, to reduce emissions and the impact on the environment as a
968 whole:

969 (a) ‘techniques’ includes both the technology used and the way in which the installation is designed,
970 built, maintained, operated and decommissioned;

971 (b) ‘available techniques’ means those developed on a scale which allows implementation in the
972 relevant industrial sector, under economically and technically viable conditions, taking into

973 consideration the costs and advantages, whether or not the techniques are used or produced inside the
974 Member State in question, as long as they are reasonably accessible to the operator;

975 (c) 'best' means most effective in achieving a high general level of protection of the environment as a
976 whole.

977 **Appendix B: Criteria for determining best available techniques (European Commission, 2010)**

978 1. the use of low-waste technology;

979 2. the use of less hazardous substances;

980 3. the furthering of recovery and recycling of substances generated and used in the process and of
981 waste, where appropriate;

982 4. comparable processes, facilities or methods of operation which have been tried with success on an
983 industrial scale;

984 5. technological advances and changes in scientific knowledge and understanding;

985 6. the nature, effects and volume of the emissions concerned;

986 7. the commissioning dates for new or existing installations;

987 8. the length of time needed to introduce the best available technique;

988 9. the consumption and nature of raw materials (including water) used in the process and energy
989 efficiency;

990 10. the need to prevent or reduce to a minimum the overall impact of the emissions on the
991 environment and the risks to it;

992 11. the need to prevent accidents and to minimise the consequences for the environment;

993 12. information published by public international organisations

