



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

Marie Dellise, Jonathan Villot, Rodolphe Gaucher, Anne Amardeil, Valérie Laforest

► To cite this version:

Marie Dellise, Jonathan Villot, Rodolphe Gaucher, Anne Amardeil, Valérie Laforest. Challenges in assessing Best Available Techniques (BATs) compliance in the absence of industrial sectoral reference. Journal of Cleaner Production, 2020, pp.121474. 10.1016/j.jclepro.2020.121474 . hal-02539130

HAL Id: hal-02539130

<https://hal.science/hal-02539130>

Submitted on 22 Aug 2022

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution - NonCommercial 4.0 International License

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

Marie Dellise ^a, Jonathan Villot ^a, Rodolphe Gaucher ^b, Anne Amardeil ^c, Valérie Laforest ^{a, *1}

^a Mines Saint-Etienne, Univ Lyon, CNRS, UMR 5600 EVS, Institut Henri Fayol, F - 42023 Saint-Etienne, France

^b Ineris, Parc Technologique Alata - BP 2 - 60550 Verneuil-en-Halatte, France

^c EDF, DIPDE, 154 Avenue Thiers, 69458, Lyon, France

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

*Corresponding author. Tel: +33 (0)477426621. E-mail address: laforest@emse.fr (V. Laforest)

1. Introduction and legal context

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

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.	

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

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

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

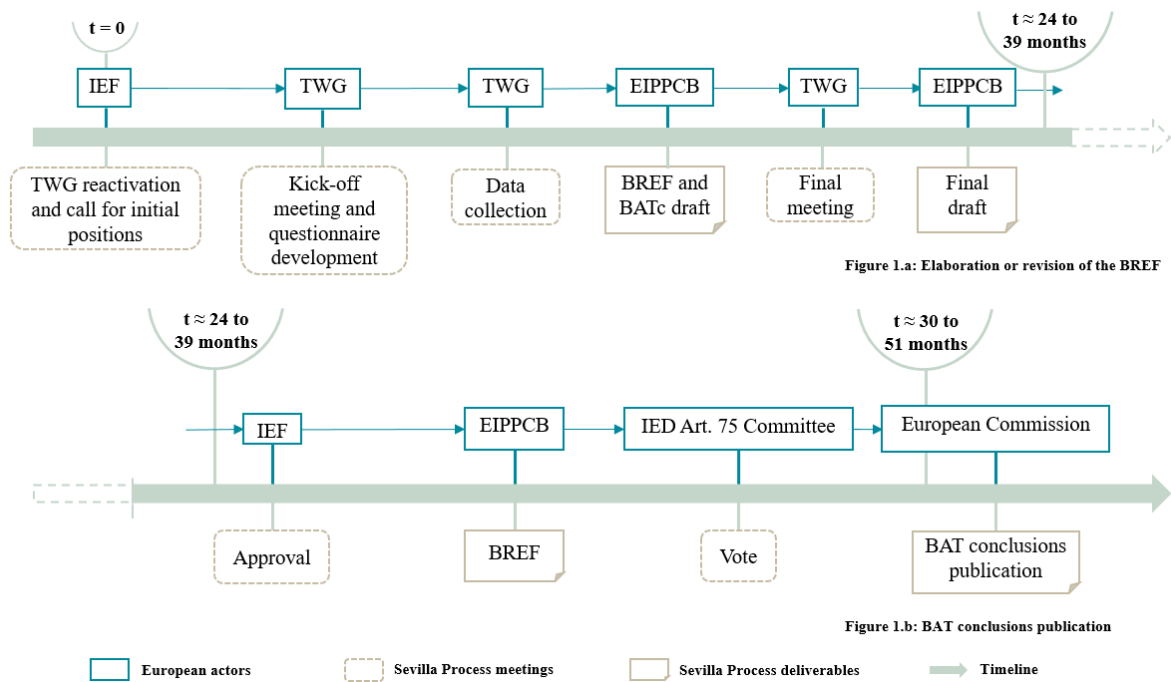


Figure 1: Sevilla process steps for a given industrial sector

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

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

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

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

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

2. Search method for the literature review

2.1. Inventory of articles

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

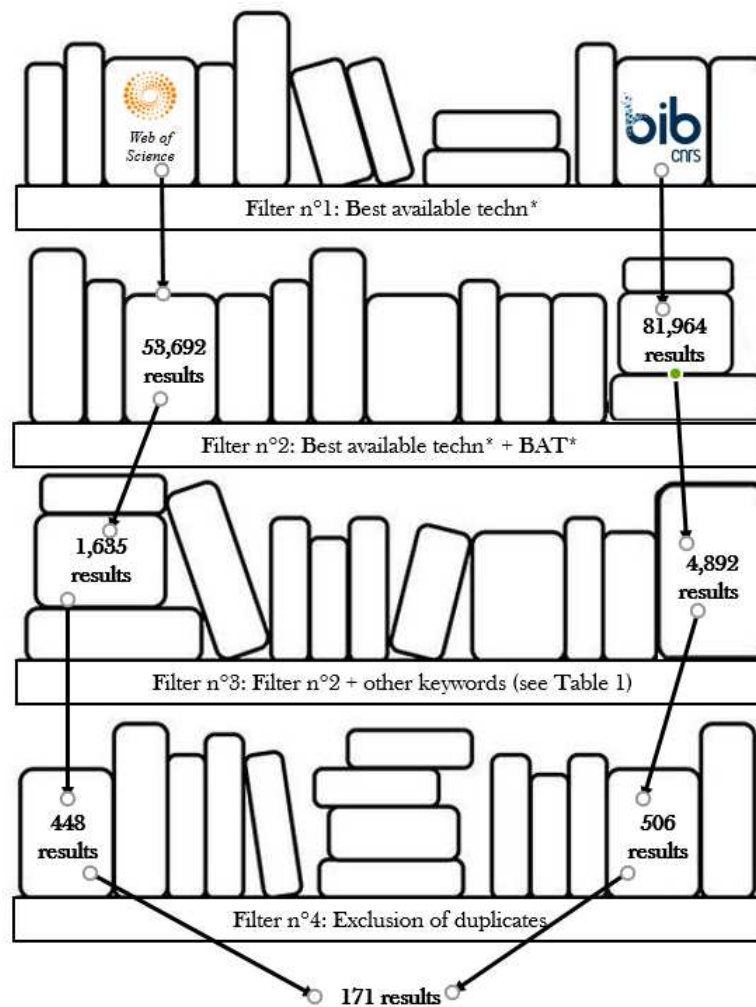


Figure 2: Methodology of research on scientific databases

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.

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			
Keywords associated with “Best Available Techn*” and “BAT*”	IPPC	IED	BREF	Total	IPPC	IED	BREF	Total
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.

Web of Science

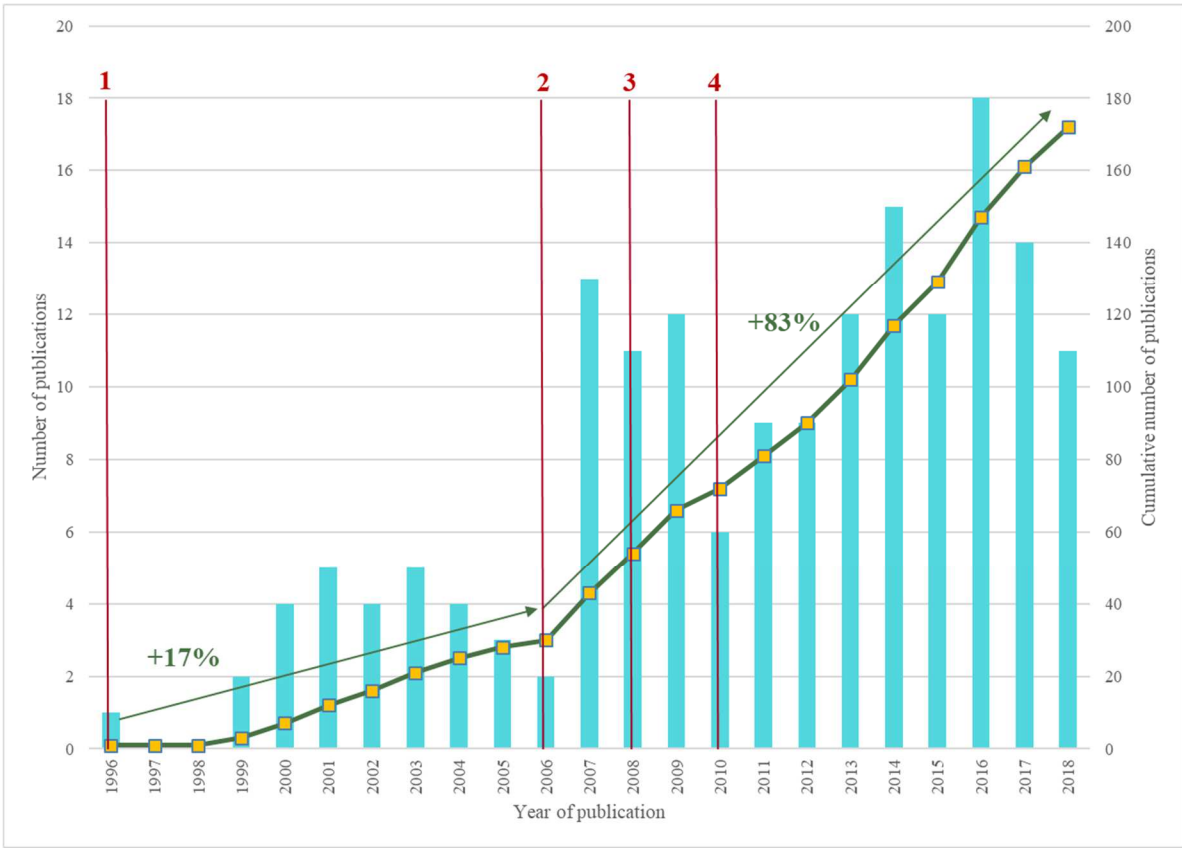
The screenshot shows the Web of Science search interface. At the top, there's a 'Tools' dropdown and a 'Searches and alerts' link. Below that, a 'Select a database' dropdown is set to 'Web of Science Core Collection'. The 'Basic Search' tab is selected. The search criteria are entered in four rows, each with a search term and a 'Topic' dropdown: 'Best available Techn*', 'BAT*', 'IPPC', and 'method*'. The rows are connected by 'And' operators. A 'Search' button is at the bottom right. Below the search criteria, there's a 'Timespan' dropdown set to 'All years (1975 - 2019)'. At the bottom right, there are links for '+ Add row' and 'Reset'.

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

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.

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

This continuous evolution can demonstrate that several bottlenecks and scientific stakes have been 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

2.2. Selection of articles to be analyzed in depth

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

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

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

3. Results of the literature review

3.1. General aspects

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

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

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

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)
	Qualitative	Environmental and economic	Policy-makers	Mavrotas et al. (2009)
		Technical, environmental, economic	Policy-makers	Dijkmans (2000) and Polders et al. (2012)
			Policy-makers, business federations	Barros et al. (2007, 2008)
		Environmental	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)
		Environmental		Yılmaz et al. (2015)
				Nicholas et al. (2000)
	Quantitative and qualitative	Environmental		Cristóbal Andrade et al. (2014)
				Rodríguez et al. (2011)
				Barros et al. (2009)
	Qualitative	Technical, environmental, economic, social	Industrial operators	Geldermann et al. (2003)
		Technical, environmental, economic	Industrial operators, technology suppliers	Midžić Kurtagić et al. (2016)
		Environmental, economic, social	Industrial operators, decision-makers	Laforest (2014)
	Guidelines	Technical, environmental, economic	Industrial operators	Giner-Santonja et al. (2012, 2019)
				PNUE (2004)
				Smets et al. (2017)

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

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

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

3.2. BAT-related methods at installation level

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

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

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

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

techniques with the BATs of the BREF. No indication is nonetheless given on the extent to which a site would not be in compliance with BATs, especially in cases where other techniques than the ones cited as BATs in BATc are applied on-site and no associated performance level is provided.

Flexibility, which is a central principle of the IED, does not seem to have any place in such an approach where the techniques implemented and the techniques of the BREF are put face to face without further analyzing their equivalence, which is however the most common way of proceeding in permit applications.

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

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

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

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

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

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

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

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

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

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

3.2.2.2. Identification of the main environmental aspects of the site

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

3.2.2.3. Inventory of candidate techniques

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

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

3.2.2.4. Use of multicriteria analysis in the selection of BATs

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

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

3.2.2.5. Consideration of the local conditions

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

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

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

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

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

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

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

3.2.3. Conclusion on the analysis of local methods

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

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

Main steps of the determination of BATs at local level		Description of the step	Main bottlenecks in the absence of BAT reference
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.

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

3.3. BAT-related methods at sector level

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

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

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

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

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

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

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

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

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

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

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

4. Discussion and perspectives

4.1. General conclusion on the methods

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

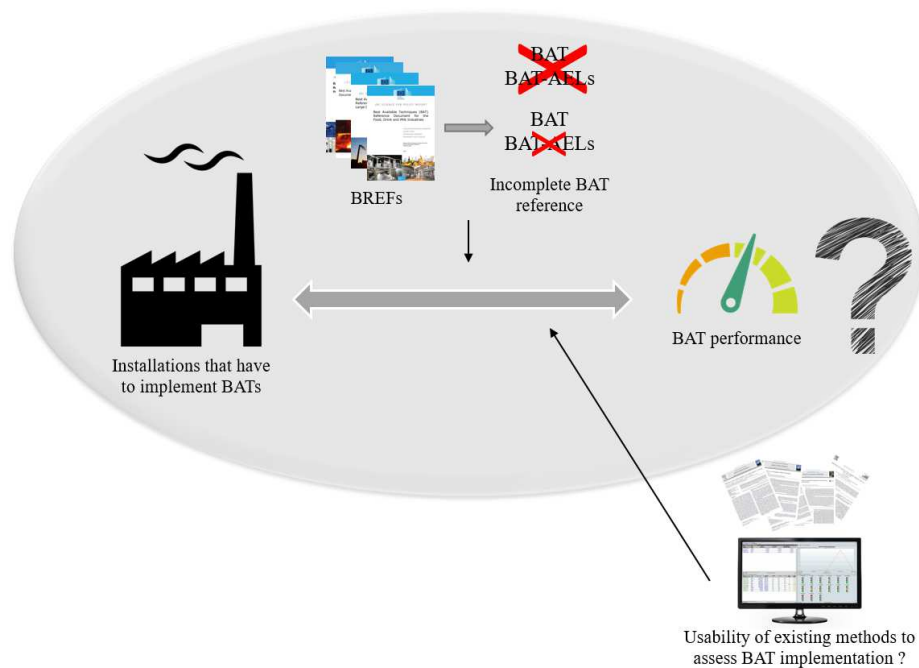


Figure 5: Schematic representation of the research question

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

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

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

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

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

4.2. Key specifications

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

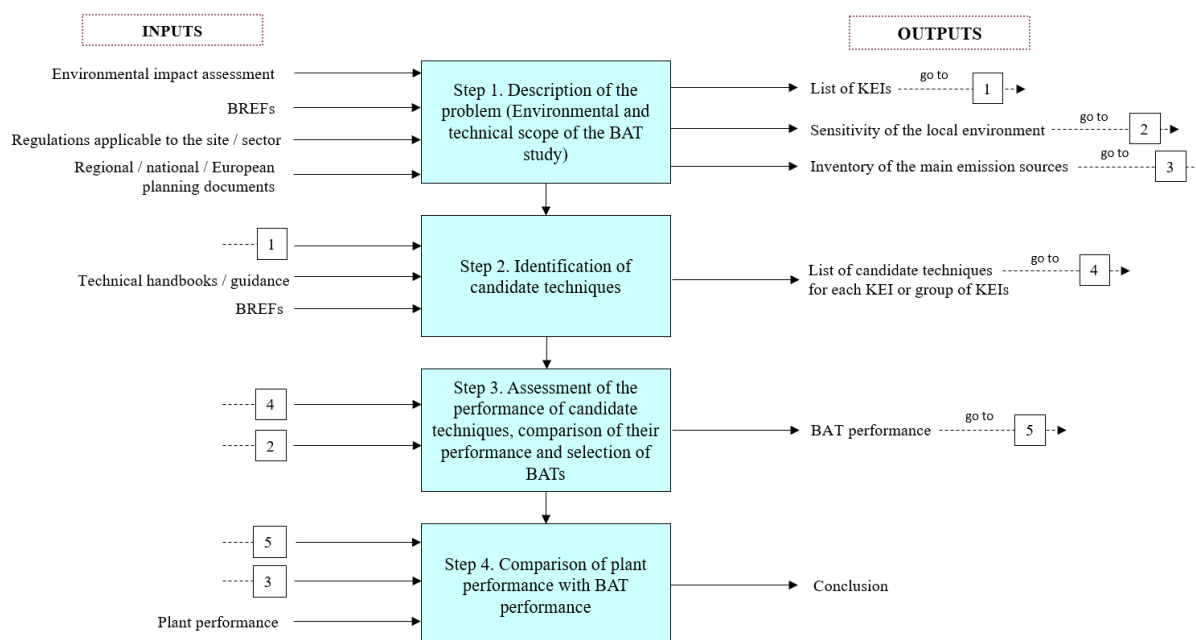


Figure 6: Flow diagram illustrating the main steps of the proposed methodology

4.2.1. Description of the problem (Step 1)

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

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

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

4.2.2. Identification of candidate techniques (step 2)

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

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

4.2.3.1. Evaluation criteria

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

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

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

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

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

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

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

4.2.3.3. Selection of BATs

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

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

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

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

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

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

5. Conclusion and perspectives

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

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

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

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

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

Acknowledgments

Our thanks to our funding partners: Mines Saint-Etienne, the French National Institute of Industrial Environment and Risks (Ineris) and EDF.

References

- Barros, M., Bello, P., Roca, E., Casares, J., 2007. Integrated pollution prevention and control for heavy ceramic industry in Galicia (NW Spain). *J. Hazard. Mater.* 141, 680–692. <https://doi.org/10.1016/j.jhazmat.2006.07.037>
- Barros, M.C., Magán, A., Valiño, S., Bello, P.M., Casares, J.J., Blanco, J.M., 2009. Identification of best available techniques in the seafood industry: a case study. *J. Clean. Prod.* 17, 391–399. <https://doi.org/10.1016/j.jclepro.2008.08.012>
- Barros, M.C., Torres, M.T., Bello, P.M., Roca, E., Casares, J.J., 2008. Integrated pollution prevention and control in the surface treatment industries in Galicia (NW Spain). *Clean Technol. Environ. Policy* 10, 175–188. <https://doi.org/10.1007/s10098-007-0138-z>
- Cakir, N., Alp, E., Yetis, U., 2016. Evaluation of Environmental Performance Based on Proximity to Bat Associated Resource Utilization and Emission Values: A Case Study in a Steel-Making Industry. *Waste Biomass Valorization* 7, 975–993. <https://doi.org/10.1007/s12649-016-9493-5>
- Carretero, A.L., de la Rosa, J., Sanchez-Rodas, D., 2016. Applying statistical tools systematically to determine industrial emission levels associated with the best available techniques. *J. Clean. Prod.* 112, 4226–4236. <https://doi.org/10.1016/j.jclepro.2015.06.037>
- Cikankowitz, A., Laforest, V., 2013. Using BAT performance as an evaluation method of techniques. *J. Clean. Prod.* 42, 141–158. <https://doi.org/10.1016/j.jclepro.2012.10.005>
- Cikankowitz, A., Laforest, V., 2008. How to compare industrial techniques to Best Available Techniques? pp. 707–716. <https://doi.org/10.2495/WM080721>
- Commission Européenne, 2006. Reference Document on Economics and Cross-Media Effects.
- Conti, M.E., Ciasullo, R., Tudino, M.B., Matta, E.J., 2015. The industrial emissions trend and the problem of the implementation of the Industrial Emissions Directive (IED). *Air Qual. Atmosphere 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-](https://doi.org/10.1007/s00267-016-0657-7)
942 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

