BEST AVAILABLE TECHNIQUES (BAT) FOR PREVENTING AND CONTROLLING INDUSTRIAL POLLUTION

Activity 6: Cross Country analysis of BAT and BAT-associated emission and environmental performance levels in the Thermal Power Plants, Cement and Textile industries

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A cooperative agreement among **FAO, ILO, UNDP, UNEP, UNIDO, UNITAR, WHO, World Bank and OECD**

Foreword

The OECD has been working on the Best Available Techniques (BAT) project since 2016 to help governments prevent and control industrial pollution. The project aims to identify and exchange best practices amongst countries that already have a BAT-based policy in place, and to assist those that are considering adopting this approach for the first time. Furthermore, the BAT project is designed to contribute toward the United Nations' Sustainable Development Goals (SDGs), especially Target 12.4 on the environmentally sound management of chemicals, which relates to SDG 12 on ensuring sustainable consumption and production patterns.

The OECD's BAT project is advised by an Expert Group (i.e. EG on BAT), which consists of members from governments in OECD member and non-member countries, along with environmental non-governmental organisations (NGOs), industry, academia, and inter-governmental organisations. The Expert Group is a platform to carry out exchanges of expertise and experiences in implementing BAT approaches. The project has developed five publications, which are available on oe.cd/bat:

i. Activity 1, Policies on BAT or Similar Concepts Across the World (OECD, 2017[1]), describing how BAT are defined and embedded in national legislation in different countries and regions;

ii. Activity 2, Approaches to Establishing BAT Around the World (OECD, 2018[2]), presenting various jurisdictions' procedures to determine BAT;

iii. Activity 3, Measuring the Effectiveness of BAT Policies (OECD, 2019[3]), analysing methodologies and data for the evaluation of the effectiveness of BAT-based policies in a range of countries and regions;

iv. Activity 4, Guidance document on determining BAT, BAT-associated emission and environmental performance levels, and BAT-based permit conditions (OECD, 2020[4]); and

v. Activity 5, Value chain approaches to determining BAT for industrial installations, studying potential challenges and opportunities to effectively consider an industry's entire value chain when determining BAT (OECD, 2021[5]).

This report, as the 6th Activity, is on cross-country comparisons of BAT and BAT-associated emission and environmental performance levels for selected industrial sectors. The difference between Activity 6 and the other activities of the OECD BAT project is the focus on industrial sector level BAT Reference Document (BREF) information. Therefore, this report does not include other more general matters covered by the other BAT project's activities (BAT website), notably:

- How BAT is generally defined, applied, or implemented – see Activities 1, 2 and 4
- Policy effectiveness, including actual emissions achieved at the sector or installation level – see Activity 3
- Enforcement and compliance of requirements in local regulations and issued permits
- Individual installation permits or monitored performance data

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Acronyms

ACI	Activated carbon injection (or carbon adsorbent injection)
AOX	Adsorbable Organic Halogen
BAT	Best Available Techniques
BAT-AEL	BAT-Associated Emission Levels
BAT-AEELs	BAT-Associated Energy Efficiency Levels
BAT-AEPL	BAT-Associated Environmental Performance Levels
BAT-AE(P)Ls	BAT-Associated Emission Levels and/or Environmental Performance Levels
BEP	Best Environmental Practice
BREF	BAT Reference Document
BOD	Biochemical Oxygen Demand
CBA	Cost-Benefit Analysis
CCGT	Combined cycle gas turbine
COD	Chemical Oxygen Demand
DEFRA	Department for Environment, Food and Rural Affairs (UK)
DG ENV	Directorate-General for Environment
DMR	Discharge Monitoring Report Database
EC	European Commission
EGUs	Electric generating units
EIPPCB	European Integrated Pollution Prevention and Control Bureau
EU	European Union
ELV	Emission Limit Value
EPA	Environmental Protection Agency
EPEP	Environmental Performance Enhancement Programme
ESP	Electrostatic Precipitation
FDG	Flue Gas Desulphurisation
FF or BF	bag/fabric filter, baghouse
GATPPC	Guidelines of Available Technologies for Pollution Prevention and Control
HAP	Hazardous Air Pollutant
IMPEL	European Union Network for the Implementation and Enforcement of Environmental Law
IPPC	Integrated Pollution Prevention and Control
KEIs	Key Environmental Issues
MACT	Maximum Achievable Control Technologies
NESHAP	National Emission Standard for Hazardous Air Pollutants
OECD	Organisation for Economic Co-Operation and Development
SAB	Science Advisory Board
SCR	Selective Catalytic Reduction
SDG	Sustainable Development Goal
NGO	Non-governmental organisation
PRTR	Pollutant Release and Transfer Registers
TWG	Technical Working Group
US	United States
VOC	Volatile organic compounds

Executive summary

Exchanges of information between stakeholders carry great importance in informing actions to tackle the environmental impacts of human activities. Industrial facilities play a major role in environmental consequences as their processes may use large amounts of raw materials and energy, and in return, may release significant amounts of pollutants into the air, water and soil. As part of their operational obligations, industrial facilities are required to meet various regulatory requirements in the form of emission limitations and/or standards of performance and environmental quality objectives at the local level.

Many regulatory authorities identify Best Available Techniques (BAT)[1] as part of deriving their industrial emission standards and other performance parameters process. The approaches may vary, however, in general, these jurisdictions aim to identify:

- BAT, i.e. the most effective and efficient methods for controlling emissions;
- BAT-Associated Emission and Environmental Performance Levels (BAT-AE(P)Ls), i.e. the expected standards from applying BAT;
- Associated monitoring practices specific to the techniques and the sectors;
- How these may be applicable in a more general sense as a regulatory benchmark for the sector concerned.

BAT reference documents (BAT Reference or BREF) or BREF-like documents are developed and used by many national jurisdictions globally to assist with the development of bases for setting permit conditions for industrial facilities or for entire industrial sectors.

Some countries are just developing their own BAT-based emission standards, including the associated monitoring and technical requirements. Other countries with existing BAT-based emission standards are in the process or may plan on updating their BREF based on the technological advancements and operational improvements made in the sectors. Establishing BAT, BAT-AE(P)Ls and developing or updating BREFs are complex and time-consuming matters. Therefore, information exchange and sharing experiences between governments may facilitate the BREF development or update processes, lead to harmonisation and streamlining of these approaches taken, and may ultimately lead to global standards. However, the detailed local issues requiring specific considerations may influence the final outcomes, therefore, the global standards may be aligned but leave flexibilities for particular circumstances. To contribute to this objective, the Expert Group on BAT conducted cross-country analyses of BREFs for three selected industrial sectors; thermal power plants (TPP), cement production and textile manufacturing. The three sectors selected were determined by the Expert Group.

[1] EU definition of *techniques* in Article 3(10)a of IED 2010/75/EU states that '*techniques*' *includes both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned*´.

This cross-country comparison study examined seven BREFs for TPP, five BREFs for cement production, and six BREFs for textile manufacturing from countries/organisations, including China, India, Japan, South Korea, the US, the EU, Belgium (Flanders), and the World Bank.

The BREFs submitted were categorised into three types: guidance documents, minimum regulatory standards and hybrid-approach documents, to better explain the variations in their status and coverage, including their legislative implications. The BREFs, referred to as guidance documents, were used to inform installation operators/managers and local environmental authorities of available technologies and process options for reducing their environmental impacts. The BREFs categorised as minimum regulatory standards had a more direct legal status and impact on the local authorities. The BREFs categorised as taking a hybrid approach were combinations of (usually national) minimum standards coupled with local flexibility that allowed setting more stringent standards and optimising opportunities that may change locally.

The majority of the BREFs provided descriptions of technical approaches and emission levels as BAT, however, there were wide differences with regard to the degree of detail included. Some BREFs contained detailed explanations of the techniques, such as equipment types and approaches that are considered BAT. Other BREFs focused on describing either non-technical approaches to be considered or only particular key processes, such as abatement systems. Among these BREFs, some included information on sets of technical approaches that may be used in combination at a specific site to have a better environmental impact.

In comparing the specific BAT and BAT-AE(P)Ls identified in the BREFs for three sectors, the BAT and BAT-AE(P)Ls were classified in terms of the key environmental issues (KEIs) within each sector. The selected KEIs per sector are as follows:

- Thermal power plant (TPP) sector: For coal and gas-fuelled installations, KEIs were determined only for emissions to air. For coal-fired plants, the KEIs targeted for this analysis included: particulate matter (PM- without distinguishing the size of the PM), oxides of sulphur (SO_x), oxides of nitrogen (NO_x), mercury (Hg) and carbon dioxide (CO_2). For the gas-fuelled plants, the emissions focussed on NO_x and CO_2. In addition to these emissions, energy efficiency BAT for both coal and gas-fuelled installations were considered.
- Cement production sector: BAT were considered for the production of Portland Cement. The KEIs were determined only for emissions to air: PM (regardless of its size), SO_x, NO_x, and CO_2.
- Textiles manufacturing sector: BAT were considered specifically for the two processes used in the production of textile, i.e. pre-treatment and dyeing. The KEIs were determined only for releases to water: pH, AOX (Adsorbable Organic Halogen), BOD (Biochemical Oxygen Demand), COD (Chemical Oxygen Demand), metals (chromium, copper, nickel, and zinc), and water consumption.

For each of the KEIs selected, many common techniques were indicated as BAT that showed that the regulators and industry often identified the same solutions to addressing potentially polluting emissions. However, there were some variations noted for BAT-AELs set for selected KEIs between the BREFs for all sectors. The underlying reasons for these variations in quantitative performance (i.e. BAT-AELs) levels were not clear. Possible reasons may be attributed to the differences in the legal status of the BREFs (i.e. guidance or legally-binding minimum standards) or the technical-economic status of a given jurisdiction, including factors such as the local history of BREF production and development of environmental protection policy, legal and institutional frameworks regarding the prevention and control of industrial emissions. Specific BAT standards may also be influenced by differing expectations of the citizens that are affected by industrial releases.

This report aimed to compare many BAT-AELs for selected KEIs, however, it is highlighted here that, in some cases, the degree of direct comparability was hampered by a lack of definitions in supplied measurements and data averaging approaches for the three sectors. Differences with regard to measurement conditions may result in substantial differences in the recorded emission values. As such, many numerical comparisons and the conclusions drawn should be regarded as tentative. The reader must bear in mind that there may be significant differences in the measurements and assessment conditions. This includes averaging periods for continuous measurements (e.g. daily, monthly, and yearly average values), the sampling/analysis methods (self-monitoring vs standardised methods), the correction factors for the reference oxygen content (vol.% O_2), standardization for the humidity, temperature and, pressure, and consideration of measurement uncertainties.

This report gathered a large volume of qualitative and quantitative information from BREFs around the world for TPP, cement production, and textile manufacturing sectors that may assist national bodies of countries in charge of BREF development and update by providing comparative and relevant information about the regulatory perspectives, BAT and the BAT-AELs of different countries. This collective information from various jurisdictions may encourage and assist countries in their progress towards developing sector specific BREFs. Beyond that, this comparative analysis may indicate the areas of possible harmonisation between countries, and also highlight the structures or parts of the BREFs that may need expanding or updating for better environmental impact considerations.

1 Introduction

Background

A large number of governments are in the process of developing or updating their BREFs to be aligned with the advanced technologies (or techniques) used at the industrial installations. The OECD was tasked in 2018 by the 58th Joint Meeting of the Chemicals Committee and the Working Party on Chemicals, Pesticides and Biotechnology to carry out a comparative study of the best available techniques (BAT) and BAT-associated emission and/or environmental performance levels (BAT-AE[P]Ls) for selected sectors. This cross-country comparison study aims to showcase the similarities and differences in the regulatory contexts included in the BREFs, such as the extent of their applicability, BAT and BAT-AE(P)Ls reported on identified key environmental indicators (KEIs) for those sectors. This collection of both qualitative and technical information from BREFs for the selected sectors may be utilised by the countries in the process of setting up their BAT-based permits and policies with key information on identifying BAT and BAT-AE(P)Ls for their national systems. Furthermore, in the long term, this report may contribute to facilitating greater international harmonisation of information provided in the BREFs, by providing considerations to governmental bodies in charge of updating their BREFs with comparative information available from various countries.

The OECD's Expert Group on BAT (i.e. EG on BAT) agreed to focus on three sectors; thermal power plants, cement production and textiles manufacturing. A number of KEIs and environmental media for each sector were selected for the cross-country comparison. Sub-groups of each sector were established, with experts nominated from the EG. The proposed scope of the study was discussed and agreed upon by the members of the sub-groups on each sector at their kick-off meetings. Following this, the Secretariat collected the targeted information from the BREFs by a questionnaire survey from the experts who submitted them. There were seven BREFs for TPP, five BREFs for cement production and six BREFs for textiles manufacturing submitted for this cross-country comparison. This report was drafted based on the responses provided by the experts in the subgroups and the literature reviews of the BREFs supplied.

Structure and contents of this report

The main structure of this report consists of categorising issues by their qualitative and technical points to better compare the variety of information presented in the BREFs. The OECD examined BREFs provided in three chapters as follows:

- *Chapter 2 on Higher level issues* - compared general BREF information that was common for all sectors, such as their production and update process, and specific to the individual sector, such as their scope. This qualitative information was specific to the country's BAT policy frameworks and essential for an extensive comparison of selected BREFs for each sector within this study.

- *Chapter 3* on *BAT approaches* - compared the processes and designs to prevent and reduce emissions of the selected KEIs for each sector in the BREFs.
- *Chapter 4 on Quantitative BAT* - presented and compared information on the emission and performance levels (e.g., BAT-AE(P)Ls) noted for the sector-specific KEIs.

Selected sectors and Key Environmental Issues (KEIs) for this study

The three selected sectors were covered separately within each chapter, except for Chapter 2 on Higher level issues which also included commonalities noted from the BREFs. Brief descriptions of the sectors and the KEIs considered for this report are described as follows:

- *Thermal power plant sector:*

  Thermal power plants are installations that produce electrical power from coal and/or natural gas fuel combustion. BREF information was categorised according to installation fuel types; coal and gas-fuelled installations. The KEIs were determined for emissions to air. For coal-fired plants, the KEIs selected were *particulate matter (PM- without distinguishing the size of the PM), oxides of sulphur (SOx) and nitrogen oxides (NOx), mercury (Hg), and carbon dioxide (CO_2).* For the gas-fuelled plants, the emissions focused on were *oxides of nitrogen (NOx) and carbon dioxide (CO_2).* In addition to these emissions, *energy efficiency* techniques were collected to remark the practices included in the BREFs.
- *Cement production sector* :

  Cement production plants are installations that manufacture Portland cement (including clinker, which is the principal component of cement). Portland cement is the most widely used cement in concrete construction and is manufactured by inter-grinding cement clinker with sulphates (EIPPCB, 2013[6]). The KEIs selected were *Particulate matter (PM- without distinguishing the size of the PM), oxides of sulphur (SOx) and nitrogen (NOx) and carbon dioxide (CO_2)* emissions to air during the production of Portland cement.
- *Textile manufacturing sector* :

  Textile manufacturing plants are installations that use pre-treatment and dyeing techniques during the manufacture of textiles. Given the complicated nature of the sector, BREFs comparisons were limited to two processes used in the manufacturing; pre-treatment and dyeing (i.e. pre-treatment including its sub-processes of desizing, bleaching and mercerizing). The KEIs selected were *pH, AOX (Adsorbable Organic Halogen), BOD (Biochemical Oxygen Demand), COD (Chemical Oxygen Demand),* and *metals (Chromium, Copper, Nickel, and Zinc)* for releases to water, *water consumption,* and *chemicals substitution*.

It should be noted that this study by no means provides a complete set of the most relevant environmental impacts caused by the three sectors and relevant for permitting of those industrial installations. The scope and parameters defined in this study were determined by considering the interest of the participating experts, comparability between the BREFs, as well as the resources available in the EG on BAT. The following KEIs and parameters were discussed at the EG meetings but were not included in the study:

a. Wastewater releases from large combustion plants (LCP); such as by using wet abatement techniques to remove sulphur dioxide from the flue gases (EIPPCB, 2017[7]).

b. Mercury (Hg) emissions to air from cement production plants;

   i. Cement production (through clinker production) is still a major source of Hg emissions to air. It is addressed under Article 8 of the Minamata Convention on Mercury which covers the point source emissions of Hg to air (UNEP, 2019[8]; UNEP, n.d.[9]) .

ii. The Guidance on Best Available Techniques (BAT) and Best Environmental Performances (BEP) in Article 8 covers Hg emissions from coal-fired power plants and coal-fired industrial boilers, smelting and roasting processes used in the production of non-ferrous metals (e.g. lead), waste incineration facilities and cement clinker production facilities (UNEP, 2019[8]).

c. Other processes of textile manufacturing industry (e.g. finishing) and parameters (e.g. colour, persistent and toxic chemicals). Also, relevant emissions to air depending on the products (e.g. surfactants) used in the processes of textile manufacturing.

2 Higher level issues

Section introduction

This chapter comprises contextual and overarching issues (*the higher-level issues)* which define how the BREFs are used or may be interpreted. BREFs are generally considered to provide a basis for the control of emissions and environmental impacts from installations within defined industrial sectors.

In addition to the sector-specific approaches, there are common factors surrounding these BREFs, such as their production and update processes, regulatory contexts that explain the environmental issues covered and/or cross-referencing to other supporting documents, and the financial cost issues that present the economic points of applying a BAT indicated in the BREFs.

The term 'BREF' is originally used in the BAT policy of the EU and the other countries with similar policy styles. For convenience, this report refers to all the technical documents provided by the experts and used in determining emission standards for environmental permits (BREF-like documents) as 'BREF' regardless of whether originally titled BREF.

General considerations for all sectors

The Activity 3 of the BAT project informs about the production and potential update procedures of the BREFs in detail (OECD, 2019[3]). This section supplements the information collected for the Activity 3 report and provide further information on general concerns covered in the BREFs by each government

BREF production and update process

The production and update processes of the nine BREFs in total analysed for the three sectors are summarised below:

People's Republic of China

The Ministry of Environment (MEE) publishes the requirement to evaluate BAT in target sectors, such as thermal power plants and cement production, to initiate the BREF production process, namely Guidelines on Available Technologies of Pollution Prevention and Control (GATPPCs). The technical supporting organization then starts the research through literature review, onsite review, and expert consulting process. The information collected is reported to the MEE, and revised accordingly by the MEE and associated experts into a final publication as a BREF[2].

2 Available from: http://www.mee.gov.cn/gkml/hbb/bgth/201610/W020161009327656624121.pdf

European Union

To identify BAT and BAT-AELs for various industrial sectors, an information exchange (i.e. Sevilla process[3]) about BAT that leads to the drawing up and review of BREFs has been established under Article 13 of the IED.

The process for drawing up and reviewing BREFs is detailed in the Commission Implementing Decision 2012/119/EU document (often referred to as the "BREF guidance"). This document establishes the rules concerning guidance on the collection of data and the development of BAT reference documents and their quality assurance referred to in Directive 2010/75/EU of the European Parliament and of the Council on industrial emissions.

Flanders, Belgium

The sectors or activities to develop BAT are selected by a steering committee consisting of representatives from the Flemish authorities responsible for environmental and economic affairs. Each year, a working program is set up to develop new BAT or review Flemish BAT studies (and activities at EU-level – BREFs). Flemish BAT studies are developed by VITO BAT Centre in close collaboration with an advisory committee – similar to a TWG in the EU – which consists of representatives from the Flemish Government, industry via business federations and/or companies, and other associations and experts. The advisory committee assists in the data collection and presents their views on technical feasibility, the cross-media aspects and the economic feasibility of candidate BAT.

India

India's policy framework for preventing and controlling the emission of industrial pollutants is based on legally binding emission standards or discharge limit values specific to each industrial sector, such as the Minimal National Standards (MINAS), which are developed under the Pollution Control Law Series (OECD, 2019[3]; CPCB, 2021[10]). The MINAS are not based on BAT but, the techniques for prevention and control of industrial emissions, named Best Techno-Economically Available Techniques, and are considered as a part of the MINAS development. They may be presented in the accompanying Comprehensive Industry Documents Series (COINDS), which forms a set of sector specific guidelines. Under the Pollution Control Law Series, there is a requirement to obtain consent for any industrial operation related to treatment or disposal of effluent or emissions of pollutants into air, water, or land. The Ministry of Environment, Forests and Climate Change, the Central Pollution Control Board (CPCB) and State Pollution Control Boards (SPCBs), along with other agencies and in collaboration with leading technical institutions, assess environmental programmes periodically to develop and revise policies, guidelines and standards, such as the MINAS and the COINDS. These assessments may be based on peer reviews.

One of the mandates envisaged under both the Acts included framing and notifying ambient and emission standards. The legislative jurisdiction to implement the mandate under both Acts rests with the SPCBs. The emission norms were incorporated in the COINDS document formulated by the CPCB. To specify the division of jurisdiction between the Union and States, the Indian Constitution mentions three lists, namely the Union list, the States list and the Concurrent list. Indian Constitution defined

[3] In order to reduce emissions to air, water and soil, the European Union regularly reviews and updates the environmental norms for more than 52.000 agro-industrial installations. To achieve this, experts from Member States, industry, environmental NGOs and services of the Commission discuss together every detail of these norms. This participatory, rigorous and transparent approach is known internationally as the Sevilla Process (EIPPCB, n.d.[112]).

water-related subjects under the State list and air in the Concurrent list, both Central and State Governments have the legal jurisdiction to establish legislations.

The Environment (Protection) Act (1986) encompasses all pollution matters in the country, including water and air. The Environment (Protection) Act is implemented under the Central Government that notifies standards for the quality of the environment and emission or discharge of environmental pollutants from various sources. These emission standards are included in the COINDS document prepared by the Central Pollution Control Board. The ambient or emission standards developed by CPCB are notified by the Ministry of Environment Forest & Climate Change under the Environment (Protection) Act, 1986.

The MINAS for each sector is a standalone document, although, the CPCB began to update the COINDS document for the textile manufacturing, which is aimed to be finalised in 2022. The update procedures for the document are aimed to follow a similar pathway to the procedures taken by the EU.

As the BREFs are considered minimum emissions standards, there is no specific update process or any foreseen update planned for the TPP and cement production sectors.

Japan

The BAT reference table published on the energy efficiency of TPP was regarded as the BREF for the cross-country comparison in this report. This reference table was produced by the Japanese government to address the issue of stable supply of electricity, reducing fuel costs while considering better environmental protection. The governmental meeting agreed on publishing a BAT reference table based on the idea that it is important to constantly promote the advancement of power generation technology, improve international competitiveness, and contribute to environmental protection.

In principle, the table was planned to be reviewed annually following its publication in 2014 and updated as necessary. However, the table was updated only in 2017 and 2020 after its publication.

South Korea

Korean BREF documents (also referred to as K-BREF) for an industry in general take three years to publish. This process consists of a survey conducted in the first year, preparation of the initial draft of the K-BREF within the second year and the final review of the draft K-BREF for its publication in the final year.

The first version of the K-BREF for TPP sector was produced in 2016 and revised according to the needs identified in 2017. The second version is expected to be published in 2022.

The first version of K-BREF for textiles manufacturing was produced in 2019 and adjusted according to the needs identified in 2021. An update is planned for 2025.

United States

The US EPA promulgates final rules under “notice and comment” procedures. Upon issuance of a proposed rule, the EPA solicits comments and feedback from the public and stakeholders. After a defined period, the EPA evaluates the submitted comments, and after consideration of those comments, prepares a final rule.

As for its update process, under section 111(b)(1)(B) and section 112(d)(6) of the Clean Air Act (CAA), the US EPA is required to periodically review and revise standards of performance to reflect improvements in emission reduction technology. A review of the rules is done at least every 8 years. Updates can also be undertaken due to a petition for reconsideration from the public or a voluntary reconsideration at the discretion of the US EPA. There have been several updates to TPP and cement production air-related rules as recent as February 2012 and June 2017, respectively.

The effluent discharge rule for textile mills was developed by the US EPA as specified in legislation commonly referred to as the Clean Water Act. The development document contains a detailed examination of the Textile Industry and all known sources of effluent discharge. This includes specifics about the quality and quantity of effluent discharge along with the treatment technology, if any, used at the individual plant. Economic and environmental considerations were then taken into account in writing the final effluent discharge rule.

All industrial effluent discharge rules are reviewed on a periodic basis (usually every two years) to determine if additional studies are needed to consider revising and updating the effluent discharge rules. This review process is designed to address industries contributing most to the toxic properties of contaminated effluent; some industries may not 'rise to the top' during this process. This is the case for textiles effluent guidelines. Because the industry does not rank near the top of this toxicity ranking, its effluent guidelines have not been modified since 1983.

World Bank

Decisions to invest in the review of World Bank Group Environmental, Health, and Safety Guidelines (known as the EHS Guidelines) for any given sector are taken by one or more members of the World Bank Group within the context of the World Bank Group strategy on climate change.

The following revision process for the EHS Guidelines is envisioned:

I. Round-one: an online consultation on existing guidelines is carried out for 30 days, which consists of a listening phase and collection of comments.
II. The guidelines are revised according to the public comments received.
III. Round-two: a second online consultation is carried out to prepare the final version based on the feedback collected. The final guidelines are then translated and disseminated.

Environmental Non-governmental Organisation (NGO) BREF on Electricity generation

At a late stage of this study, the European Environmental Bureau (EEB) submitted their in-house BREF on Electricity generation, namely EEB Reference Environmental Standards for Energy Techniques (RESET) guidance (EEB, 2021[11]). This guidance provides insights about the impacts of energy technologies and BAT on energy generation with lower environmental impact. Some relevant information from this BREF is included in the Appendices as a reference (see 0 NGO BREF document on Thermal Power Plant sector).

BREF regulatory contexts

All BREFs examined for this study contain comprehensive information about the sectors assessed, however, they do not provide the full coverage of all environmental regulations relevant to the sectors. BREFs were considered for whether they covered various environmental issues, making them a standalone document for a sector, or taking a more focused approach with a single environmental issue and cross-reference to other supporting documents, such as other key legislations. Some BREFs adopted elements of the comprehensive coverage and focussed issue approaches which were considered as taking a hybrid approach.

Most BREFs analysed in this study were complementary to more general documents to supplement detailed sector specific information. The country-specific information below provides an overview of the BREFs submitted to this study:

People's Republic of China

The Environmental Permits are used to implement requirements within the GATPPC for installations by taking a hybrid approach. These permits are listed in the documents of emission standards such as:

- Emission Standard of Air Pollutants for Thermal Power Plants (GB 13223) (MEE, 2012[12])
- Emission Standard of Air Pollutants for Cement industry (GB 4915) (MEE, 2014[13])

The GATPPC cross-references to other relevant national standards (Section 2 Normative References), and some examples are:

- Management technical specification of the operation of flue gas treatment facilities of thermal power plant (HJ 2040) (MEE, 2014[14]).
- Engineering technical specification of flue gas selective catalytic reduction denitrification for thermal power plant (HJ 562) (MEE, 2010[15]).
- Engineering technical specification of flue gas selective non-catalytic reduction denitration for thermal power plant (HJ 563) (MEE, 2010[16]).

European Union

The EU BREF on Large Combustion Plants (LCP) is a comprehensive document to be used in the context of the Industrial Emission Directive[4], which stipulates that every LCP in the EU with a total rated thermal input of 50 MW or more requires an integrated BAT-based permit. The BAT are designed to cover all environmental media by taking an integrated approach. The key chapter of the LCP BREF is titled "BAT conclusions" and is published also as a stand-alone, legally binding document in the Official Journal of the European Union. The BAT and BAT-AELs are legally binding for all EU Member States. Competent authorities in the EU Member States are required to ensure that emissions of installations do not exceed the emission levels associated with the best available techniques (BAT-AELs) as laid down in the BAT conclusions or to justify derogations under limited criteria. Newly published BAT provisions have to be complied with by all existing plants within a time period of 4 years.

Flanders, Belgium

The Flemish BAT study (i.e. VITO-BREF) of textile manufacturing supplements the existing Flemish BAT study for textile processing (Jacobs A., 1998[17]) and is used as an input for the review of the EU BREF for the textiles industry (EU TXT BREF). The study was aimed at textile companies that implement finishing activities and thus, use bromine-based flame retardants, antimony trioxide, perfluorinated tensides, nonylphenols and/or nonylphenol ethoxylates. Wherever relevant, a link was made with activities that are:

- Upstream: Producers of chemicals and formulators (integrated into the textile company in some cases);
- Downstream: Qualified waste processing companies (e.g. paper bags, concentrated process baths) and drum cleaners (e.g. Intermediate Bulk Containers).

4 The EU LCP BREF is supported by the general provisions of the Industrial Emissions Directive (Directive EU/2010/75), notably Article 18 on compliance with environmental quality standards, as well as specific minimum requirements for LCP in Annex V. The IED also sets other requirements such as public participation provisions, inspections, reporting provisions etc.

India

The minimum standards document (MINAS) of India for all relevant sectors are legally binding and are considered standalone documents for emissions control and prevention in each sector within this study.

Japan

The BAT reference table is taken as a reference point in the national Environmental Impact Assessment (EIA) procedure, which is used to determine the final Environmental permit for the installations.

South Korea

The K-BREFs for all sectors provide the optimal available technique under Article 24 (2) 5 of the Integrated Environmental Management Act and the range of emissions allowed (NIER, 2020[18]; NIER, 2016[19]) by taking a hybrid approach. However, the legal obligations of the facility operators that are imposed by social consensuses, such as TWG meetings with industry, its associations and the Central Environment Policy Committee, are regarded above the regulatory implications posed by the K-BREF.

United States

The US EPA regulates pollution through media-specific regulations. There are no standardised BAT or technology reference documents that apply across programmes, although data gathered and analysed during the development of the standards are documented.

- The New Source Performance Standards (NSPS) are applicable to criteria air pollutants, under the Clean Air Act. The National Emission Standards for hazardous air pollutants (NESHAP) apply to hazardous air pollutants through the application of technology-based emissions standards referred to as Maximum Achievable Control Technology (MACT)[5]. National regulations specify minimum required standards, and standards require initial performance testing and ongoing monitoring to demonstrate compliance with established standards for the source category.

[5] Maximum achievable control technology (MACT) are national emissions standards that reflect the average emissions of the best performing sources in the source category. These standards may be based on control technologies or work practice requirements for major stationary sources of air toxics. MACT standards are applied under NESHAP to control emissions of hazardous air pollutants.

The terms "RACT," "BACT," and "LAER" are acronyms for different program requirements under the Clean Air Act (CAA) New Source Review (NSR) permitting program (otherwise referred to as a preconstruction permitting program). The NSR permitting program applies standards to emissions of criteria air pollutants (NO_2, SO_2, PM, Pb, CO, O_3) based on National Ambient Air Quality Standards.

- RACT, or Reasonably Available Control Technology, is required on existing sources in areas that are not meeting national ambient air quality standards (i.e., non-attainment areas).
- BACT, or Best Available Control Technology, is required on major new or modified sources in clean areas (i.e., attainment areas).
- LAER, or Lowest Achievable Emission Rate, is required on major new or modified sources in non-attainment areas. BACT and LAER (and sometimes RACT) are determined on a case-by-case basis, usually by State or local permitting agencies.

The NSR program applies to all facilities, regardless of size, that are new construction or undergoing modification. As noted in the descriptions, application of these technology standards depends on the facility and surrounding environmental characteristics. For a more comprehensive explanation of the US CAA regulation and permitting programs refer to Activity 2, specifically section 3.2.2 National Ambient Air Quality Standards (OECD, 2018[2]).

- Effluent guidelines are written for specific industries to address direct discharges to surface waters and indirect discharges to municipal wastewater treatment plants. For each sector, relevant pollutants are selected from lists of priority pollutants, conventional pollutants and nonconventional pollutants. These national regulations are minimum required standards.

There are cross-references to other legislation included on an as-needed basis specific for rules. Various legislative requirements combine to form the overall set of regulations for each sector.

World Bank

The EHS Guidelines are technical-reference documents with general and industry-specific examples of best practices. These guidelines are intended to sit within the framework of other national and local regulations. World Bank group requires the members to implement the relevant levels and measures indicated in the guidelines, and in the cases when the local regulations are different from the EHS guidelines, projects will be required to achieve whichever is more stringent.

The industry-specific guidelines are expected to be used together with the General EHS Guidelines that provide information on cross-cutting environmental, health, and safety issues potentially applicable to all industry sectors (IFC, 2007[20]).

Financial cost issues

During the BREF production process, it is generally recognised that there is a need to consider the costs and benefits of applying certain performance levels or techniques. The country-specific information on considerations given for financial factors influencing the BREFs are reported below:

People's Republic of China

The GATPPC documents provide only some qualitative descriptions of financial factors, for example, the GATPPC on TPP adds that the Low-NOX combustion technique requires low initial investment and has low associated operational costs[6]

European Union

Generally, the costs associated with the application of a certain technique are addressed in the detailed description (section on economics) of the technique in the descriptive part of the BREF document. When the application of a specific technique implies excessive cost, this may be reflected in the applicability clause of this technique (e.g. in LCP BREF[7], technique BAT 17(e) where in its applicability clause it is stated: "Generally applicable to new plants. In the case of existing plants, the relocation of equipment and production units may be restricted by lack of space or by excessive costs")[8].

6 Guideline on available technologies of pollution prevention and control for thermal power plant: Chapter 5, 5.4.2.2, page 13 ; 5.4.3.2, page 14 ; 5.4.4.2, page 15

7 LCP BREF: Chapter 10: Best available techniques (BAT) conclusions, Section 10.1.7. p. 754 pdf p. 798

8 EU BREF cost issues are addressed in definition of Best Available Technique – when a technique is "available", it means that can be used in power plants - is developed on a scale which allows implementation in the relevant industrial sector, under economically and technically viable conditions. Based on that it is therefore assumed that, in general, all techniques in the EU BREF contain a cost assessment element. However due to the wide variety of facilities and techniques of fuel combustion the financial costs aren't taken into account in EU BREF – there are no discussions of implementation costs of techniques on Technical Working Group preparing BREFs. Based on Industrial Emission Directive (a framework for BAT implementation in EU) the financial costs of certain techniques

Article 15(4) of the IED provides for a possibility to derogate from BAT-AELs in case of disproportionality higher costs compared with environmental benefits, although plant operators still need to be in line with other BAT-Conclusions provisions. This should be assessed on a case-by-case basis. The granting of derogations is subject to strict conditions described under the same Article and may apply only where an assessment shows that the achievement of emission levels associated with the BAT as described in BAT conclusions would lead to disproportionately higher costs compared to the environmental benefits.

Flanders, Belgium

Economic feasibility is one of the three criteria for the evaluation of candidate BAT (Dijkmans, 2000[21]). According to the Flemish environmental legislation, a candidate BAT is considered economically acceptable if (i) it is feasible for an average well-managed enterprise of the sector and (ii) if the cost/environmental benefit ratio is not unreasonable.

India

The COINDs documents for the three sectors do not include specific considerations for financial costs associated with the BAT or the standards set. However, it was noted that in the COINDs for cement production, there were recommendations for dust collectors for different sections in a cement plant and the capital costs assocated with selecting a BAT. Also, for the COINDs on textiles manufacturing, there is a brief discussion about various costs of treatment of the wastewater from the textiles production, but no further information was provided on dealing with issues such as the costs of achieving specific BAT-AELs or for the use of certain techniques.

Japan

The BAT table (i.e. BREF) just listed technologies which are already commercialized.

South Korea

In the K-BREF, there are some descriptions given which consider additional costs, but they were not noted to be the main subject of the document.

United States

The US EPA develops Regulatory Impact Analyses (RIAs) to support the development of national air pollution regulations. The RIAs describe and evaluate all of the potential costs and benefits associated with the final regulatory actions. A companion RIA was issued for TPP (US EPA, 2020[22]) and for cement production (US EPA, 2010[23]) rules.

The US EPA evaluates the cost versus pollutant reduction benefits associated with implementing and updating national wastewater discharge regulations. For textiles, these regulatory options and their economic impacts are outlined in Appendix A of the Development Document for Textile Mills Effluent Guidelines (US EPA, 1982[24]).

is analysed within permit reconsideration administrative procedures. If costs are excessive in particular case, and disproportionately higher compared to the environmental benefits, operator can have a derogation (in line with IED 15.4).

World Bank

The EHS Guidelines contain the performance levels and measures that are generally considered to be achievable in new facilities by existing technology at reasonable costs.

For the consideration of economic approaches, the EHS Guidelines propose the use of higher energy conversion efficiency technology, subject to its technical suitability for the application and financial feasibility. The choice of technology depends on a cost-benefit analysis of the environmental performance of different fuels, the cost of controls, and the existence of a market for NOx, SOx and PM control by-products. For example, during the development of thermal power projects, the proponents should consider alternative solutions, including technical suitability and trade-offs between capital and operating costs involved in the use of different technologies, with documented reasoning of why the selected technology is the most feasible option.

Sub-Chapter conclusion of general considerations

This section summarised the general considerations that are common to all BREFs submitted, such as their production and update processes, regulatory contexts and financial cost issues considered in the documents. Activity 3 of the BAT project reported in detail the production and potential update procedures of these BREFs (OECD, 2019[3]), therefore, this section aims to supplement the information collected for the Activity 3 report and cover these applications taken by each government in their BREFs.

The BREFs included in this report are most commonly produced and, in certain intervals, updated by government-appointed technical institutions. During these processes, there are collaborative actions taken by typically involving technical working groups that include industry representatives and non-governmental organisations (NGOs). All of the BREFs, from their production, consultation, and to their adoption stages, are indicated to involve complex and lengthy procedures, with production periods of commonly more than 3-5 years. While less information is provided about the update or revision processes, it is noted that similar levels of resources and timetables may be required.

Some BREFs on TPP brought together many sector-specific environmental issues to provide a comprehensive single standalone document that integrates a wide range of environmental requirements. Others deal with fewer or very specific sector issues, whilst also cross-referencing other wider environmental regulatory requirements (or indeed other BREFs) that also relate to the sector. Regarding the cement production sector, the majority of documents are classified as either hybrid or focused and none as standalone. This indicates that there is a good degree of acceptance that BREFs for the sector cannot themselves cover all relevant issues, and that the regulatory framework they sit within will cover issues beyond what may be achieved in the BREFs. For example, the EHS Guideline on cement manufacturing of the World Bank refers to a General EHS Guideline which is noted to apply to all industrial sectors. As for the BREFs submitted on textiles manufacturing, many sector-specific environmental issues are considered to provide a more comprehensive single standalone document that integrates a wide range of environmental requirements. Others are more focused and deal with fewer or very specific sector issues, whilst drawing on a wider environmental regulatory framework or other BREFs related to the sector.

Financial cost issues associated with the BAT (and BAT-AELs) are mostly covered under the umbrella of their economic feasibility. Aside for the COINDs and the energy efficiency table of Japan, the other BREFs provided some considerations of financial aspects of BAT determination, such as including further information about a technique having low maintance (or setting up) costs while retaining a high efficiency of preventing or controlling the emission/releases of targeted pollutant(s).

Sector-specific information

Each industrial sector has specific considerations in addition to the general perspectives covered above. This section summarised the sector-specific information of the three sectors, such as their regulatory depth, including legislative coverage, scope, technical depth, environmental issues covered in each BREF, and age or investment cycles for TPP and cement production installations, and effluent treatment plants (ETP) for textile manufacturing installations.

BREFs submitted were categorised into three types to better explain the variations in their statuses, coverages and legislative implications: guidance documents, minimum regulatory standards and hybrid-approach documents. The BREFs, referred to as guidance documents, are used to inform installation operators/managers and local environmental authorities of available technologies and process options for reducing their environmental impacts. The BREFs categorised as minimum regulatory standards have a more direct legal status and impact over its implications at the local authorities. There are also hybrid approaches that are considered as combinations of (usually national) minimum standards coupled with local flexibility that allows setting more stringent standards and optimising opportunities that may change locally.

Thermal Power Plants (TPP)

BAT Reference documents (BREFs) on TPP assessed in this study

Standard information, such as full publication titles, authors, publication dates, implementation (or effective) dates, and the expected update date, was examined for the seven TPP BREFs gathered for this cross-country comparison. In summary, the TPP BREFs are prepared by national or international bodies or government technical institutes and were published or updated in the last decade, most within the last 5 years.

National, regional, and local legislations provide the frameworks which determine the context for the BAT standards set out in a specific BREF. Therefore, it is highlighted during the BREF comparison that if a BAT or emission/performance levels are set as a mandatory minimum standard, they may not be considered the same specification as to when they are stated as a guideline. Table 1 presents the production, update and legal status of each BREFs on TPP submitted below:

Table 1 Background information of BREFs on TPP included in the analyses

Country/ Organization	BREF title	Issuing authority	Most recent publication date and update (expected)	Type of BREF
China	Guideline on available technologies of pollution prevention and control (GATPPC) (HJ 2301-2017) (MEE, 2017[25])	Science and Technology Standards Department of the Ministry of Environmental Protection and organized by the Ministry of Ecology and Environment (MEE)	Published and implemented in 2017	Legally binding documents that fall under the Minimum standard category. The environmental permits are listed in GB 13223-2011- Emission standard of air pollutants for thermal power plants (MEE, 2012[12]).
European Union	Best Available Techniques (BAT) Reference Document for Large Combustion Plants (EIPPCB, 2017[7])	European Commission, Joint Research Centre, European IPPC Bureau (EIPPCB)	August 2017. Review foreseen in every 8 – 10 years as a standard procedure for all BREF documents by the Recital 13 of the Industrial Emissions	EU-BAT conclusions within the EU-BREFs are legally binding documents for all EU Member States. BAT Conclusions (BAT-C) provide the reference for Member States to set permit conditions and can be

Country/ Organization	BREF title	Issuing authority	Most recent publication date and update (expected)	Type of BREF
			Directive (IED)	considered as taking a hybrid approach since it allows flexibility to operators to apply other techniques as long as at least an equivalent level of environmental protection is ensured
India	Minimal National Standards (MINAS) Thermal Power Plants and Environment (Protection) Amendment Rules (CPCB, 1986[26])	Central Pollution Control Board (CPCB) and by the Ministry of Environment, Forest and Climate Change	Minimal Standards was published in 1986 and the Amendment Rules were on 7th of December 2015 and 28th of June 2018.	CPCB sets minimal standards and are considered legally binding by the authorities
Japan	Reference Table on BAT (METI and MOE Japan, 2020[27])	Ministry of Economy, Trade and Industry and the Ministry of the Environment, Japan	First edition was published in April 2013 and revised in January 2020.	Reference table is not a legally binding regulation, but is regarded as a reference of information for the Thermal Power Plant (TPP) installations. Environmental Impact Assessment (EIA) approach is taken to assess if a given installation is using a BAT and also, provide recommendations between BAT- A and BAT-B [9]categories to those installations
Korea	Best Available Techniques (BAT) Reference Document (K-BREF) on Electricity and Steam Production (NIER, 2016[19])	National Institute of Environmental Research (NIER)	First edition was published in 2016. Updated second edition is expected to be published in 2022.	K-BREF is referred to as a guideline for the industry and stakeholders. However, the generic BAT and the upper level of BAT-AEL in K-BREF are provided to make legal regulation of the rule of facility installation and the maximum permit standard, respectively.
United States	The following rules address air emissions from power plants: National Emission Standards for Hazardous Air Pollutants From Coal- and Oil-Fired Electric Utility Steam Generating Units and Standards of Performance for Fossil-Fuel-Fired Electric Utility, Industrial-Commercial-Institutional, and Small Industrial-Commercial-Institutional Steam Generating Units (NESHAP/NSPS) (US EPA, 2012[28]); Standards of Performance for	US Environmental Protection Agency (US EPA)	NESHAP/NSPS in February 2012, Standards of Performance for GHG in October 2015, and several recent Clean Air Markets Program regulation updates between 2000 to 2017.	The US BAT-related documents covering TPP emissions to air establish minimum national standards for the sector. Rules are published in the U.S. Federal Register with requirements authorized by national legislation such as the Clean Air Act (CAA) and codified in the US Code of Federal Regulations. Data, analysis, and reasoning supporting decisions are summarised in the Federal Register notice that accompanies the regulations, and are accessible in a

[9] BAT-A: State-of-the-art power generation technology that is already in operation as a commercial plant with no economic or reliability problems. BAT-B: Power generation technologies that have already started construction as commercial plants (including commissioning periods, etc.) and those that have been decided to be adopted as commercial plants and are undergoing environmental assessment procedures.

Country/ Organization	BREF title	Issuing authority	Most recent publication date and update (expected)	Type of BREF
	Greenhouse Gas Emissions From New, Modified, and Reconstructed Stationary Sources: Electric Utility Generating Units (GHG)[10] Various rules to support Clean Air Markets Regulatory Programs[11]			searchable rulemaking docket. The US EPA also maintains a searchable database of air pollution technologies and emission limitations that have been required from stationary sources.
World Bank	Environmental, Health and Safety (EHS) Guidelines for Thermal Power Plants (IFC, 2008[29])	International Finance Corporation (IFC)	Draft for second public consultation was made available between May-June 2017 (IFC, 2017[30])	EHS Guideline is not legally binding to the IFC-WB members and is not comparable to legally binding BAT-based standards. All EHS Guidelines are thus different from other documents on BAT used for setting permit conditions. They carry no direct legislative impact, but have a broad scope of application including countries where legislative frameworks may be less well developed or absent.

Scope comparison

All BREFs on TPP included in this study initially explained the thermal power generation, and then provided further definitions of their scope of coverage and application. The scope of each BREF is derived from the legislation that provided their basis. These scope definitions are commonly considered the following elements and are summarised in Table 2:

- Scope coverage– how the BREF coverage and application are defined
- Fuel and technology types – e.g., solid, liquid, gaseous fuels and which technologies are applied
- Capacity/scale – usually in terms of thermal input capacity
- Installation boundaries - such as whether fuel mining, supply and storage, or downstream solid residue or effluent handling are included. Air emissions abatement is usually included in the scopes and is considered a key issue for this sector.
- Installation age – usually how the BAT identified relates to an existing or new plant

[10] https://www.govinfo.gov/content/pkg/FR-2015-10-23/pdf/2015-22837.pdf

[11] https://www.epa.gov/airmarkets

Table 2. Scope comparisons of BREFs on TPP

BREFs	Fuel / technology	Capacity	Boundary	Age
China	BAT-AELs in GATPPC are not explicitly targeted for the whole plant, but a separate emission limit for single BAT or process. Some limits are not final emission concentrations in the outlet of the plant, but only the emission concentration limits for single dust removal or desulphurisation process. In addition to coal-fired boilers, there are boilers with oil, natural gas, and other gases.	100MW and above	Specified in GB 13223, among which the flue gas pollution prevention technology and wastewater processing is included. Raw material production or extraction is not included.	--
European Union	Any solid, liquid and/or gaseous combustible material including: solid fuels (e.g. coal, lignite, peat); biomass (as defined in Article 3(31) of Directive 2010/75/EU); liquid fuels (e.g. heavy fuel oil and gas oil); gaseous fuels (e.g. natural gas, hydrogen-containing gas and syngas); industry-specific fuels (e.g. by-products from the chemical and iron and steel industries); waste except mixed municipal waste as defined in EU legislation	Combustion of fuels in installations with a total rated thermal input of 50MW and above Gasification 20MW and above Waste co-incineration >3t/h non-haz, >10 t/d haz, only when this activity takes place in the above-mentioned combustion plants"	Upstream and downstream activities directly associated, including the emission prevention and control techniques applied. The definition of "installation" in the IED has as follow: 'installation' means a stationary technical unit within which one or more activities listed in Annex I or in Part 1 of Annex VII are carried out, and any other directly associated activities on the same site which have a technical connection with the activities listed in those Annexes and which could have an effect on emissions and pollution; In the EU BREF for TPP, the direct discharges of wastewater to a receiving water body from flue-gas treatment are considered (see Section 10.1.5 Water Usage and emissions to water). For waste, section 10.1.6 is related to the on-site waste management. For a detailed description of what is considered in the context of the "combustion plant" see Section 1.3 Key environmental issues.	Distinctions are made between new and existing plant
India	--	--	--	--
Japan	Coal and gas fired plants		Focus on the plant operations phase.	
Korea	Biomass, Coal, Heavy fuel oil, Light fuel oil, and Natural gas	Electricity and Stream production facilities defined by Electricity Generation Law, Korea	Distinctions among installation time shown by Air Law EMS (Environmental Management System), Monitoring, Environmental and Combustion Performance, Energy Efficiency, Air and Water Pollution Prevention by fuels	Different emission limitations of performance for existing and new plants, depending on the air release of *dust*, SO_x and NO_x. The BAT-AELs for *dust* apply as "before June 2001", "from July 2001 to December 2014", and "after January 2015" The BAT-AELs for SO_x and NO_x apply as "before June 1996", "from July 1996 to December

BREFs	Fuel / technology	Capacity	Boundary	Age
				2014", and "after January 2015"
United States	New, Modified, and Reconstructed Stationary Sources: Electric Utility Generating Units	Affects only steam-generating thermal power plants and stationary combustion turbines that are > 25 MW and that supply greater than one-third of their potential electrical output to the national grid.	The rules only impact air pollutant emissions at defined emission points (i.e., stacks). The rules do not cover fugitive emissions or non-air pollution. The rules do not cover air pollution emissions associated with fuel preparation (e.g., coal washing or pulverizing) or with handling of residuals (e.g., coal ash, scrubber solids, etc.). Effluent limitation guidelines (ELGs) are covered under a different statutory authority.	There are separate emission limitations and standards of performance for existing and new plants.
World Bank	Gaseous, liquid and solid fossil fuels and biomass for electrical power, mechanical, steam, heat (but not wastes). Combustion, gasification and pyrolysis	50 MWth input (HHV)	Recommendations to avoid, minimise, and offset emissions of carbon dioxide from new and existing thermal power plants included to consider fuel cycle emissions and off-site factors such as fuel supply, proximity to load centres, potential for off-site use of waste heat, or use of nearby waste gases (blast furnace gases or coal bed methane) as fuel	

Technical depth

The BREFs were examined for the level of technical detail on the techniques and emission or performance levels specified. There were a mixture of approaches noted from the BREFs submitted. Several BREFs included definitions of technical approaches (and emission levels) which are considered BAT. Some BREFs only included explanations of higher-level or key processes or sets of technical approaches that may be used in combination at a specific site. In some cases, BREFs provided criteria for specific situations to override the requirements of the BREFs to adopt variant approaches, including those above the BAT-based environmental permits.

The BREFs that included both techniques and emission levels are the GATPPC, EU-BREF, K-BREF and the EHS Guideline.

- The EU BREF (BAT conclusions chapter) stated that the techniques listed and described in the BAT conclusions are neither prescriptive nor exhaustive. Other techniques may be used that ensure at least an equivalent level of environmental protection.

BAT-based documents and standards from India, Japan and the US have the emission values specified, but the techniques are not included. The table submitted for the Japanese regulation focuses only on the efficiency values. The US-technology based performance standards indicated that techniques considered during the setting of standards are described in supporting documents available through the regulatory docket[12] .

Environmental Issues coverage

The country-specific information on the environmental media coverage of the BREFs, whether having a multi-media approach by including various environmental media such as air, water, soil, or a single-media focus is provided in Table 3 below:

[12] A docket is a collection of documents made available by an agency for public viewing (US EPA, n.d.[116]).

Table 3 Environmental issues covered within the BREFs on TPP

BREFs	Media-covered	KEIs covered	Further notes
China	Multi-media	Emissions to air, water and noise	Installation point source emissions are the main focus for the GATPPC document, whereas wider issues such as emissions of chemicals that contribute to climate change (e.g., CO_2 emissions) are not specifically addressed.
European Union	Multi-media	Emissions to air, water, energy efficiency, water consumption, waste management and noise emission	The EU BREF for LCP (LCP BREF), following the IED approach for integrated prevention and control of pollution, tackles all identified Key Environmental Issues. The carbon dioxide (CO_2) emissions are indirectly addressed by BAT considerations linked to fuel choice and requirements on energy efficiency. GHG emissions are subject to carbon pricing via the EU Emissions Trading Scheme (EC, 2003[31]) and this Directive (Art 26) provides for a limitation for permit writers to set GHG emission limits, not for the EU BREFs to address this Key environmental issue.
India	Multi-media	Emissions to air, water and land.	Emissions levels are set for a range of environmental issues separately for different media, and India follows a multimedia approach within the context of environmental issues identified.
Japan			The BAT table focuses just on the energy efficiency of newly established TPP, hence information on its media approach was not determined. There are not emission levels indicated for CO_2.
Korea	Multi-media	Emissions to air, energy efficiency, water usage and emission to water, waste management and noise emission	The K-BREF contains all important Environmental Issues related to electric and steam production plants. There are no emission levels for CO_2 and its emissions are separately regulated by another law related to climate change.
United States	Single-media (only BREFs specific to air were reviewed)	Emissions to air. Water and land are covered by other BREFs.	Key environmental issues for TPP are addressed via federal regulations, and separate legislation under these regulations set emissions limits to each medium. For example, wastewater discharges are covered under Effluent Guidelines authorised under the Clean Water Act (US EPA, 2020[32]) and disposal of waste (e.g., coal ash) is covered under rules authorised by the Resource Conservation and Recovery Act (US EPA, 2015[33]).

BREFs	Media-covered	KEIs covered	Further notes
			The US-BREF documents such as the NESHAP and NSPS only relate to air emissions. Under section 111(b) of the Clean Air Act, a standard of performance or limitation for CO_2 emissions is set based on application of the Best System of Emission Reduction (BSER).
World Bank	Multi-media	Emissions to air, energy efficiency and Greenhouse Gas (GHG) emissions, including a CO2 level, water consumption and aquatic habitat alteration, effluents, solid wastes, hazardous materials and oil; and noise.	

Age or Investment cycles

While thermal power plants are often established to operate in excess of two or three decades, there may be expectations to have considerable environmental engineering design improvements during the plant lifetime, and the possibility that older installations or approaches become outdated with regard to their emission or other performances. Retrofitting may yield upgraded performances, but generally, new design installations are expected to achieve a more optimal and cost effective performance, including with regard to key environmental issues such as emissions and efficiency.The country-specific information from the BREFs submitted are reported below.

People's Republic of China

In the Emission Standard of Air Pollutants for Thermal Power Plants (GB 13223), distinctions for the existing and new installations are defined, as well as different limit values set (Table 1, (MEE, 2012[12])). In general, the limit values for the newly built units are lower than the existing ones.

European Union

In the EU BREF for LCP, different BAT-AELs for emissions to air and BAT-AEELs (BAT-associated energy efficiency levels) are derived for new and existing plants. The distinction between new and existing plants is given in the definitions section of the BAT conclusions chapter (EIPPCB, 2017[7]). All information in the BREF is based on existing information provided at a given cut-off date (2010 for the revised LCP BREF), except for Energy Efficiency data that also is from 2012.

India

In the MINAS document, there are variant emissions standards set for the existing and the newer power plants.

Japan

The BREF document does not consider the remaining lifetime of plants, but rather focuses on the new installations. Therefore, the BREF does not define BAT for existing plants.

South Korea

There are different BAT and BAT-AELs for existing plants and new plants

United States

There are separate emission limitations and standards of performance for existing and new plants. Newly constructed plants are expected to achieve more stringent emission limitations as they will likely be better equipped to incorporate the best performing emission controls into their original design.

World Bank

The EHS Guidelines contain the performance levels and measures that are considered to be achievable in new facilities by existing technology.

Application of the EHS Guidelines to existing facilities may involve the establishment of site-specific targets, based on environmental assessments and/or environmental audits as appropriate, with an appropriate timetable for achieving them.

Sub-chapter conclusion for Thermal power plants sector

This section evaluated the sector-specific information from BREFs submitted on thermal power plants. As there were common considerations given for each industrial sector, there are also variations in the coverage and technical perspectives that are particular to the three sectors assessed in this report.

Most BREFs submitted included a section on their scope. For the TPP sector, the definitions included fuel and technology types of thermal power plants and their capacities. In some cases, there were distinctions made between existing and new installations or between older (commissioned in the 1980-1990s) and newer plants. Generally, the extraction and supply of fuels were regarded as an upstream activity outside the scope of the BREFs - i.e., the BREFs focused upon co-located "site" activities from pre-combustion fuel storage on-wards, with the main focus upon fuel combustion and abatement systems (mostly the abatement of emission to air). The waste storage on-site was noted within some BREFs, but most commonly not as the subsequent treatment and the use of the residues (mostly ashes) for other sectors. There is a potential for on-site operations to influence downstream waste management issues, noting in particular that there is significant use (potential) of TPP residues in the construction sector. Examples include the use of fly ashes in construction blocks, and flue-gas desulphurisation (FGD) gypsum residues to manufacture construction material, e.g. wall-board.

Many BREFs addressed a range of environmental issues and aimed to balance these by considering cross media impacts, while others considered a single media approach. Reducing emissions to air has long been identified as the key environmental issue for the TPP sector. Some BREFs also included information on power generation efficiency, releases to water, and solid waste production. During the production of such integrated multi-media BREFs, there may be a potential for conflicts when certain techniques or emission levels are specified.

This report also included information on which other environmental media were covered in the BREFs submitted, although the main focus was on air emissions. The GATPPC, EU BREF, MINAS, K-BREF and the EHS Guideline had a multi-media approach (air, water, air, waste) whereas US BAT-related documents specified on taking a single-media approach for the TPP sector.

Although CO_2 emissions are usually noted as a significant issue for the sector, they were not directly addressed in the BREFs. However, the connection to energy efficiency was made in some cases, and there is commonly a reliance upon other regulatory mechanisms e.g. EU Emissions Trading Scheme.

There were cut points of age/investment cycles of plants considered in most BREFs submitted. Most BREFs also made a certain level of distinctions between new plants and existing (older) plants, to which different legislative and technical approaches were taken, with the exception of the efficiency table by Japan that only focused on the new installations.

Cement Production

BAT Reference documents (BREFS) on Cement production assessed in this study

Standard information, such as full publication titles, authors, publication dates, implementation (or effective) dates, the expected update date and the legal status of the five BREFs submitted on cement production are summarised in Table 4.

The BREFs submitted were categorised into three types: guidance, minimum standards and hybrid. The guidance documents are used to develop specific plant designs and later on permit constraints by the local plant developers and regulatory bodies. The minimum standards are considered to have a direct legal status and set out the regulatory standards. The BREFs rendered to have a hybrid approach are combinations of mostly national standards and are required to be applied as a minimum, coupled with the flexibility to determine others more locally according to assessments of local constraints and optimisation opportunities.

Table 4 Background information of BREFs on cement production included in the analyses

Country/ Organization	BREF title	Issuing authority	Most recent publication date and update (expected)	Type of BREF
China	Guidelines for feasible technologies for pollution prevention in the Cement industry (Draft) under Guidelines on available technologies of pollution prevention and control (GATPPC) (MEE, 2014[13])	Ministry of Environmental Protection and organized by the Ministry of Ecology and Environment (MEE)	The Guidance is currently on trial.	The GATPPC document for Cement industry is considered a minimum standard and legally binding to the respective applicants
European Union	Best Available Techniques (BAT) Reference document for Production of Cement, Lime and Magnesium Oxide (CLM) (EIPPCB, 2013[6])	European Commission, Joint Research Centre, Unit B5, European IPPC Bureau (EIPPCB).	EU BREF data was collected before 2010. The BREF and its BAT-Conclusions were published in 2013. Review foreseen in every 8–10 years as a standard procedure for all BREF documents by the Recital 13 of the Industrial Emissions Directive (IED).	EU-BAT conclusions within the EU-BREFs are legally binding documents for all EU Member States. BAT Conclusions (BAT-C) provide the reference for Member States to set permit conditions. However, they can be considered as taking a Hybrid approach since it allows flexibility to operators to apply other techniques as

Country/ Organization	BREF title	Issuing authority	Most recent publication date and update (expected)	Type of BREF
				long as at least an equivalent level of environmental protection is ensured. The cement installations with a production capacity above the threshold in Annex I of the IED operated in the European Union are obliged to hold a permit (IED Articles 4, 5, 10) (and comply with relevant environmental quality standards Art 18).
India	Comparative Evaluation of Treatment Technologies for Cement industry (MEFCC India, 1994[34]) And Environment (Protection) Amendment Rules	Ministry of Environment, Forest and Climate Change	1994 in force from 2014 and 2016	The Environment (Protection) Amendment Rules are legally binding minimum emission standards for all cement-manufacturing units that are obliged to hold an environmental permit.
United States	There are no standardised BAT or technology reference documents that apply across programmes, although data gathered and analysed during the development of the standards are documented. The following rules address air emissions from the cement sector. National Emission Standards for Hazardous Air Pollutants for the Portland Cement Manufacturing Industry and Standards of Performance for Portland Cement Plants (NESHAP/NSPS) (US EPA-NSPS, 2015[35]) (US EPA-NESHAP, 2018[36]). Other pollutants and media are addressed in	US Environmental Protection Agency (US EPA)	NESHAP in August 2017; NSPS in July 2015.	The US BAT-related documents covering cement emissions to air establish minimum national standards for the sector. Rules are published in the U.S. Federal Register with requirements authorized by national legislation such as the Clean Air Act (CAA) and codified in the US Code of Federal Regulations. Data, analysis, and reasoning to support decisions are summarised in the Federal Register notice that accompanies the regulations, and are accessible in a searchable rulemaking docket. The US EPA also maintains a searchable database of air pollution technologies and emission limitations that

Country/ Organization	BREF title	Issuing authority	Most recent publication date and update (expected)	Type of BREF
	othermedia-specific regulations (US EPA-NSPS, 2015[35]).			have been required from stationary sources.
World Bank	Environmental, Health, and Safety (EHS) Guidelines for Cement and Lime Manufacturing (IFC, 2018[37])	International Finance Corporation (IFC)	2018.	EHS Guideline carry no legal force and is not legally binding to the IFC-WB members and is not comparable to legally binding BAT-based standards. All EHS Guidelines are thus different from other documents on BAT used for setting permit conditions. They carry no direct legislative impact, but have a broad scope of application including countries where legislative frameworks may be less well developed or absent.

Scope comparisons

All BREFs included in this study consisted of explaining cement production, and then provided further definitions of their scope of coverage and application. The scope of each BREF is derived from the legislation that provided their basis. These scope definitions are commonly considered the following elements and are summarised in Table 5:

- Cement types manufactured
- Fuel types
- Technology types, e.g. wet and dry cement processes
- Capacity/scale – usually in terms of throughput capacity
- Installation boundary related, e.g. whether fuel mining, supply & storage, or downstream solid residue or effluent handling is included – air emissions abatement is usually included
- Installation age – usually how the BAT identified relates to existing or new plant

Table 5. Scope comparisons of BREFs on Cement production

BREFs	Cement type	Capacity	Boundary	Age
China	Entire production process of the cement industry and New dry process cement production process	-	Utilisation and disposal technology of self-produced waste in cement plants.	-
European Union	Production of cement, lime and magnesium oxide	Production of cement clinker in rotary kilns with a production capacity exceeding 500 tonnes per day or in other kilns with a production capacity exceeding 50 tonnes per day	Production of cement raw materials–storage and preparation fuels–storage and preparation use of waste as raw materials and/or fuels – quality requirements, control and preparation products–storage and preparation packaging and dispatch.	The document on the CLM BAT conclusions contains definitions regarding the distinction between "new" and "existing" plants.
India	Cement Plant (with and without co-processing), Standalone Clinker Grinding Plant or, Blending Plant	Not mentioned explicitly for every type	No Boundary defined	No variation
United States	Portland cement manufacturing facilities. with wet or dry processes (NSPS) or any processes (NESHAP)	Production of cement from source categories consisting of each kiln and in-line kiln/raw mill clinker and/or alkali bypass and/or inline coal mill.	These rules only impact air pollutant emissions at defined emission points (i.e., kilns, clinker coolers). Primary and secondary crushers associated with non-metallic mineral processing are not covered by NESHAP for cement manufacturing. Kilns and in-line kiln/raw mills that combust hazardous waste are covered under NESHAP for hazardous waste combustors instead of cement manufacturing.	There are separate emission limitations and standards of performance for existing and new plants. Varying standards based on construction, reconstruction, or modification after August 17, 1971 and June 16, 2008;

			Non-air media pollution is covered under other regulations.	
World Bank	Cement and lime manufacturing processes.' Extraction of raw materials, which is a common activity associated with cement manufacturing processes, is covered in the EHS Guidelines for Construction Materials Extraction		Section 1 provides a summary of EHS issues associated with cement and lime manufacturing that occur during the operational phase, along with recommendations for their management. Recommendations for the management of EHS issues common to most large industrial facilities during the construction and decommissioning phases are provided in the General EHS Guidelines	-

Technical depth

The BREFs were examined for the level of technical detail on the techniques and emission or performance levels specified.. The BREFs with both emission values and techniques included were the GATPPC, EU-BREF, US-NSPS and World Bank EHS Guideline. The MINAS and US-NSPS only specified the emission limits/standards but not the techniques. For the US-NSPS, the techniques are only considered during the setting of standards and are described in supporting documents available through the regulatory docket.

Environmental issues coverage

The country-specific information on the environmental media coverage of the BREFs, whether having a multi-media approach by including various environmental media such as air, water, soil, or a single-media focus is provided in Table 6 below:

Table 6 Environmental issues covered within the BREFs on cement production

BREFs	Media-covered	KEIs covered	Further notes
China	Multi-media	Emissions to air, noise and water	CO_2 and carbon capture (CCS Technology) are also covered.
European Union	Multi-media	Emissions to air, waste management and noise, including metal emissions	The EU-BREF in general considers approaches aside solely focusing on the main environmental issues faced in the sector. The following measures indicated in the document are: • Monitoring, • Energy consumption and process selection, energy efficiency, • Use of waste as a raw material/fuel • Waste generation • Fuel choice, including Waste feeding into the kiln, • Safety management for the use of hazardous waste materials,
India	Multi-media	Emissions to air and wastewater, such as service wastewater with co-processing of wastes and stormwater.	
United States	Single-media (only BREFs specific to air were reviewed)	Emissions to air. Water and land are covered by other BREFs.	Key environmental issues for the sector are addressed via Federal regulations, and separate legislations under these regulations set emission limits per medium. For example, wastewater discharges are covered under effluent limitation guidelines (US EPA, 1977[38]) authorised under the Clean Water Act and disposal of waste (e.g., cement kiln dust waste) is covered under rules authorised by the Resource Conservation and Recovery Act (US EPA, 1978[39]). The US-BREF documents such as the NESHAP and NSPS only relate to air emissions.
World Bank	Multi-media	Emissions to air, wastewater (General EHS Guidelines) and solid waste.	Also, energy use in production, greenhouse gas emissions (GHGs), especially CO_2. are covered

Age or Investment cycles

The lifetime of an installation is a factor affecting its emission or other performance levels. Newer installations have the advantage of better environmental designs, which generally result in lower emission levels and improved efficiencies compared to the older installations. Therefore, different regulations are established to consider the age or investment cycles of cement production plants, as in most other sectors. The country-specific information from the BREFs submitted are reported below.

European Union

EU-BAT conclusions contained definitions distinguishing "new" and "existing" plants. All information in the BREF is based on existing information provided at a given cut-off date (2013 for the revised CLM BREF). A plant introduced on the site of the installation following the publication of these BAT conclusions or a complete replacement of a plant on the existing foundations of the installation following the publication of these BAT conclusions are considered a new plant and for which the BAT conclusions directly apply.

India

There are distinguishes between new and existing plants by the way of cut-off date and indirect classification of plants as Rotary Kiln and Vertical Kiln.

United States

There are separate emission limitations and standards of performance for existing and new plants. Newly constructed plants are expected to achieve more stringent emissions limitations as they will likely be better equipped to incorporate the best performing emissions controls into their original design. New plants are generally those that commence construction after June 16, 2008.

World Bank

The EHS Guideline indicated that a typical project facility lifespan is at least 40 to 50 years. There are distinctions made between existing and new installations for the emission levels set, and in some cases, selection of the BAT, e.g. the performance levels and measures that are generally considered to be achievable in new facilities by existing technology at reasonable costs.

Sub-chapter conclusion for Cement sector

This section evaluated the sector-specific information in the BREFs submitted on cement production. As there are general and common considerations given for each sector, there were also variations in the coverage and technical perspectives particular to the three sectors assessed in this report. All BREFs submitted were either published or updated in the last decade, most within the last 5 years.

All BREFs submitted had defined scopes on the production of cement, some also included lime production, which involves similar manufacturing processes. There were distinctions made for the technology on wet or dry processing in the GATPPC and US BAT-related documents.

The BREFs with both emission values and techniques included were the GATPPC, EU-BREF, US-NSPS (i.e. US BAT-related document) and the EHS Guideline. The MINAS only specified emission limits and US-NSPS only emission standards but neither included information techniques. The ELVs are the emission limit values prescribed in permits (based on BAT-AELs) for many countries.

Emissions to air, particularly dust emissions, were the main focus throughout the BREFs for this sector, in addition to which noise, air and water emissions were also commonly covered. The GATPPC, EU-

BREF, India and IFC World Bank's BREFs had a multimedia approach, whereas US NSPS and NESHAP documents followed a single-media approach to cover environmental issues relating to air emissions.

The CO_2 emissions are recognised as a key issue for cement production, and while cross-references to other legislations were included (e.g. EU CLM BREF), but were not directly addressed in the BREFs, except for the GATPPC and the EHS Guideline.

All BREFs submitted made distinctions between new plants and existing (older) plants, to which different legislative and technical approaches are taken, with the exception of the EHS Guideline that only informed about the lifespan of a typical cement installation.

Textile Manufacture

BAT Reference documents (BREFs) on textile manufacturing assessed in this study

Standard information, such as full publication titles, authors, publication dates, implementation (or effective) dates, and the expected update date and the legal status of the six BREFs[13] submitted on textiles manufacturing are summarised in Table 7.

The BREFs submitted were categorised into three types: guidance, minimum standards and hybrid. The guidance documents are used to develop specific plant designs and later on permit constraints by the local plant developers and regulatory bodies. The minimum standards are considered to have a direct legal status and set out the regulatory standards. The BREFs rendered to have a hybrid approach are combinations of mostly national standards and are required to be applied as a minimum, coupled with the flexibility to determine others more locally according to assessments of local constraints and optimisation opportunities.

Table 7 Background information of BREFs on textile manufacturing included in the analyses

Country/ Organization	BREF title	Issuing authority	Most recent publication date and update (expected)	Type of BREF
European Union	Best Available Techniques (BAT) Reference document for the Textiles Industry (TXT BREF) (EIPPCB, 2022[40])	European Commission, Joint Research Centre, Unit B5, European IPPC Bureau (EIPPCB)	July 2003. *Foreseen publication of the revised TXT BREF in the second half of 2022*	EU-BAT conclusions within the EU-BREFs are legally binding documents for all EU Member States. BAT Conclusions (BAT-C) provide the reference for Member States to set permit conditions. However, they can be considered as taking a hybrid approach since it allows flexibility to operators to apply other techniques as long as at least an equivalent level

[13] China adopted their Guideline on available techniques of pollution prevention and control (GATPPC) for textile industry in 2021. The OECD Secretariat was not able to include this GATPPC document within the cross country comparison of BREFs submitted due to its publication date, however would like to acknowledge its value here (MEE, 2021[113]).

Country/ Organization	BREF title	Issuing authority	Most recent publication date and update (expected)	Type of BREF
				of environmental protection is ensured.
Flanders, Belgium	Best Available Techniques (BAT) for the textile industry (reducing emissions of some micro-pollutants via wastewater - brominated flame retardants, di-antimony trioxide, perfluorinated tensides, nonylphenols, nonylphenol ethoxylates (VITO, 2010[41]) and polycyclic aromatic hydrocarbons) VLAREM II : The sectoral ELV's for Flemish TXT installations can be consulted online via EMIS Navigator (VLAREM-II, n.d.[42])	VITO (Flemish Institute for Technological Research) as part of the BAT/EMIS/EP Reference Task of the Flemish Government in Belgium	2010 *No update is foreseen**	VITO-BREF is considered as a guidance for the installations in the Flanders region of Belgium. The BAT report as such is not legally binding, but it is used as a basis for the (updated) sectoral emission limit values (ELVs) for the Flemish Textile Industries. The BAT, BAT-AELs and/or ELVs became legally binding once incorporated in the Flemish Environmental Regulation – Sectoral Emission Limit Values or Techniques for textile industries (VLAREM II). (VLAREM-II, n.d.[42])
India	Comprehensive Industry Document Series (COINDS) on Textile Sector (CPCB, 2000[43])	Central Pollution Control Board (CPCB) of India	January 2000. Minimal National Standards (MINAS) are updated regularly and, the latest update was on 1 October 2016.	The Minimal National Standards (MINAS) are legally binding to the textiles manufacturing installations in the country.
South Korea	Best Available Techniques (BAT) Reference Document for Textile Dyeing (K-BREF for Textiles) (NIER, 2019[44])	National Institute of Environmental Research (NIER) of South Korea	2019 *Updated version is planned to be published in 2025.*	K-BREF is regarded as a guidance to the sector and the stakeholders However, the generic BAT and the upper level of BAT-AEL in the K-BREF are provided to make legal regulation of the rule of facility installation and the maximum permit standard, respectively.
United States	There are no standardised BAT or technology reference documents that apply across programmes, although data gathered and analysed during the development of the standards are documented. The following documents address water emissions from textiles. Effluent Guidelines for the Textile Mills Point Source Category (US EPA, 1982[45]) And Development Document for the textile guidelines.	US Environmental Protection Agency (US EPA)	Effluent guidelines: Amended 2 September 1982. *Effluent guidelines are reviewed every two years and updated if necessary* Development Document: September 1982	Effluent Limitation Guidelines for textiles production are legally binding. The Effluent Guidelines rule sets minimum standards that all local, state, tribal, protectorate, and territorial entities of the United States must meet. National rules are published in the US Federal Resister and authorized by national legislation such as the Clean Water Act and codified in the US Code of Federal Regulations. The Development document describes the

Country/ Organization	BREF title	Issuing authority	Most recent publication date and update (expected)	Type of BREF
	US EPA has also published regulations to cover pollutants to other media with associated supporting documents .			background process used to issue the effluent limitation rule (US EPA, 1986[46])
World Bank	Environmental, Health, and Safety (EHS) Guidelines for Textile Manufacturing	International Finance Corporation (IFC) (IFC, 2007[47])	April 2007.	The EHS Guideline for the textiles industry is considered a hybrid document. When a host WB country regulations differ from the emission levels and measures presented in the EHS Guidelines, projects are expected to achieve whichever is more stringent.

* VITO –BREF on Textiles may undergo a review depending the updates introduced to the revised EU BAT-conclusions for TXT BREF.

Scope comparisons

All BREFs included in this study consisted of explanations on textile manufacturing, and then provided further definitions of their scope of coverage and application. The scope of each BREF is derived from the legislation that provided their basis. These scope definitions commonly considered the following elements and are summarised in Table 8

- Processing stages, e.g. scouring, finishing, etc.
- Type of textiles used for pre-treatment and dyeing processes
- Capacity/scale – usually in terms of throughput capacity, possibly with lower limits of application
- Installation boundary related, e.g. whether energy production, effluent treatment, or waste management is included
- Installation age – usually how the BAT identified relates to an existing or new plant

Table 8. Scope comparisons of BREFs on Textiles manufacturing

BREFs	Processing stages	Capacity	Boundaries	Age
European Union	The scope of the TXT BREF under revision (Final draft published in March 2022) reads as follows (subject to changes): These BAT conclusions also covered the following activities when they are directly associated with activities specified in point 6.2 of Annex I to Directive 2010/75/EU: – coating; – dry cleaning; – fabric production; – finishing; – lamination; – printing; – singeing; – wool carbonising; – wool fulling;	These BAT conclusions concern the following activities specified in Annex I to Directive 2010/75/EU, namely: 6.2. Pre-treatment (operations such as washing, bleaching, mercerisation) or dyeing of textile fibres or textiles where the treatment capacity	The combined treatment of wastewater from different origins provided that the main pollutant load originates from activities covered by these BAT conclusions and that the waste water treatment is not covered by Directive 91/271/EEC. On-site combustion plants that are directly associated with the activities covered by these BAT conclusions provided that the gaseous products of the combustion are put into direct contact with the textile fibres or textiles (such as direct heating, drying, heat-setting) or when radiant and/or conductive heat is	BAT identified apply to both existing or new plant

BREFs	Processing stages	Capacity	Boundaries	Age
	– spinning of fibres (other than man-made fibres); – washing or rinsing associated with dyeing, printing or finishing'.	exceeds 10 tonnes per day[14] 6.11. Independently operated treatment of wastewater not covered by Directive 91/271/EEC provided that the main pollutant load originates from activities covered by these BAT conclusions.	transferred through a solid wall (indirect heating) without using an intermediary heat transfer fluid. It is noted that the definition of "installation" in the IED has as follows: 'installation' means a stationary technical unit within which one or more activities listed in Annex I or in Part 1 of Annex VII are carried out, and any other directly associated activities on the same site which have a technical connection with the activities listed in those Annexes and which could have an effect on emissions and pollution.	
Flanders, Belgium	The scope of a Flemish BAT study is decided in close collaboration with the sector-working group. Focus is on well-defined processes/activities at installation level. Wherever relevant, a link is made with up-stream or down-stream activities related to the main activity of the installation.	No scale or capacity limitations defined - applicable for all types of Flemish installations under the scope of the study (IPPC as well as non-IPPC)	The textile companies examined in the study during the economic analysis are those that are part of NACE-BEL categories: textile; textile processing; manufacture of rugs and carpets; manufacture of synthetic and artificial fibres. The remaining items are regarded as the textile industry as a whole, so long as the activities /implemented process are relevant to the scope of this study.	BAT identified in this study applies to both existing or new plant
India	--	--	--	--
South Korea	The K-BREF for textile dyeing is focused on pre-treatment and dyeing processes as well as Environmental Management System (EMS), water and energy saving techniques, and pollution prevention.	No scale or capacity limitations defined	The type of textile fabrics was considered for the pre-treatment processes; cotton and cellulose, polyester, wool, and others. Dyeing processes include dip-dyeing, printing, and finishing by textile fabrics. Also, Energy and water management, Emission gas management, and Wastewater management are included.	
United States	Textile Mills Category: Subcategories of Wool Scouring; Wool Finishing; Low Water Use Processing; Woven Fabric Finishing; Knit Fabric Finishing; Carpet Finishing; Stock and Yarn Finishing; Nonwoven Manufacturing; and Felted Fabric Processing.	Capacity is not a limiting factor	Applicable to textile mill or textile processing facilities with point source process effluent discharges to waters of the United States or municipal wastewater treatment systems. The effluent discharge rule is applied at a location as close to the industrial process being regulated as practicable. If that is not practicable, then provision are provided to modify the discharge limits to adjust for downstream dilution effects from non-process discharges.	Existing plants are considered those in operation prior to July 1, 1977. All other facilities are considered new sources.

[14] Some countries, such as the UK have developed Interpretation guidance to assist regulatory officers determine which sites have a "treatment capacity" of over 10 tonnes per day and hence require a permit to operate. This is a difficult area for regulators to determine due to the complex nature of textile processes being carried out on any one site. Countries may wish to consider developing their own guidance to help ensure sites are correctly permitted if following a similar treatment capacity threshold approach within their particular regulatory framework.

BREFs	Processing stages	Capacity	Boundaries	Age
World Bank	Textile manufacturing projects and facilities for natural fibres, synthetic fibres (made entirely from chemicals), and regenerated fibres (made from natural materials by processing these materials to form a fibre structure). This document does not include polymer synthesis and natural raw materials production	--	When host country regulations differ from the levels and measures presented in the EHS Guideline, projects are expected to achieve whichever is more stringent.	

Technical depth

The BREFs were examined for the level of technical detail on the techniques and emission or performance levels specified.

The BREFs with both emission values and techniques included were the EU-BREF, VITO-BREF, K-BREF and the EHS Guideline. Additional details on the technical approaches taken in the BREFs are provided below:

European Union

The draft BAT conclusions contained both generic BAT, for example, related to the Environment Management System or Chemicals Management System, and process-specific BAT. Apart from the management and process-specific requirements, BAT may be further specified as process-integrated or end-of-pipe techniques (abatement). Process-integrated BAT included process selection, raw materials selection/substitution, process control and optimisation (including monitoring).

Flanders, Belgium

The VITO study is aimed at textile companies that implement finishing activities, which focus on the reduction of dedicated micro-pollutant emissions to water. Although some chemicals (e.g. brominated flame-retardants) are not used by the installation itself, they are found in their wastewater. Therefore, environmental problems that occur via the use of materials prepared elsewhere or fibres were also taken into account. Prevention practices to tackle these problems, along with the historical pollution (i.e. no normal company conditions) of the wastewater treatment plant (WWTP), were included in the VITO study.

India

The COINDS (Comprehensive Industry Document Series) and MINAS (Minimal National Standards) documents provided the emission limitations, however; the associated techniques were not included. A number of operational processes are briefly described in the COINDS without labelling them as good practises.

South Korea

The K-BREF contained both generic BAT, such as practices related to Environment Management System or Chemicals Management System, and process-specific BAT. The K-BREF covered fabric dyeing techniques, reduction of water and energy usage, as well as pollutant emissions to air and water.

United States

In the Effluent Guidelines, national emission standards are specified, but not techniques. Techniques considered during the setting of standards are described in supporting documents. The textiles development document described practices and technologies used by the industry, but regulations do not require the use of those practices or technologies in meeting specified discharge requirements.

World Bank

The EHS Guideline on textiles included both the processes and techniques. Technical information about hazardous materials management, wastewater treatment, water consumption, emissions to air, energy consumption and solid and liquid waste was covered in the BREF.

Effluent Treatment Plants (ETP)

Effluent Treatment Plants (ETPs) are commonly used to treat the discharges from textile production plants. Some dedicated ETPs operate at the same site as the installation continues to manufacture textiles, and others may release their effluents into a combined system for treatment with other wastewater flows.The country-specific information on ETPs are provided below:

European Union

The EU-BREF provided information on the appropriate type and performance of ETPs, including BAT-associated emission levels operated on the site of a given textile installation. The draft TXT BREF contained BAT related to wastewater treatment and BAT-AELs for both direct and indirect discharges. It also contained BAT for waste gas emissions and associated BAT-AELs.

Flanders, Belgium

Wastewater treatment plants were dealt with in the VITO BAT study. When the wastewater treatment plant (WWTP) of the installation is not sufficiently equipped to remove the specific micro-pollutants, dedicated wastewater streams must be separated, stored, and disposed of via an external specialized processing company.

India

Based on the COINDS, the MINAS are mandatorily prescribed in the environment permits granted to installations and these standards are applied prior to the ETP processes.

The COINDS provided details on the Combined ETP and Common ETP (CETP) that are used in the textiles manufacturing facilities within the country.

South Korea

The K-BREF informed that in most cases, the wastewater is pre-treated at the textile manufacturing installations, and then moved to a separate WWTP.

United States

The Clean Water Act directs the EPA to draft separate regulations for direct discharges (directly from the facility) to surface waters and indirect discharge (pre-treatment standards) to municipal wastewater treatment plants. The development document described the different types of ETPs utilised by industry along with the effectiveness of their processes (US EPA, 1982[24]).

World Bank

Process Wastewater Treatment information was provided in the EHS Guideline; however, the main management of industrial wastewater and examples of treatment approaches are discussed in the General EHS Guideline.

Environmental Issues coverage

The country-specific information on the environmental media coverage of the BREFs, whether having a multi-media approach by including various environmental media such as air, water, soil, or a single-media focus is provided in Table 9:

Table 9 Environmental issues covered within the BREFs on textile manufacturing

BREFs	Media-covered	KEIs covered	Further notes
European Union	Multi-media	Emissions to air, emissions to water, consumption of energy and water use, amount of wastewater discharged, waste generation (for some types of wastes) and usage and management of chemicals	The TXT BREF under revision, following the IED approach for integrated prevention and control of pollution, aims to tackle many KEIs for all environmental media (and making it an integrated approach).
Flanders, Belgium	Single-media	Emissions to water	The focus in this framework is on brominated flame retardants, diantimony trioxide, perfluorinated tensides, nonylphenols, nonylphenol ethoxylates and polycyclic aromatic hydrocarbons, and the discharge of some micro-pollutants via textile wastewater. While the focus of the BAT is on reducing emissions to water, all relevant cross-media effects are taken into account.
India	Single-media	Emissions to water	The COINDS informed about the process modification and recovery-reuse however, no direct relations to wider environmental issues such as climate change, resource/energy efficiency and consumption issues, or hazardous material substitution are made.
South Korea	Multi-media	Emission to water, water usage, energy efficiency, waste management and noise emission.	

BREFs	Media-covered	KEIs covered	Further notes
United States	Single-media (only BREFs specific to water were reviewed)	Emissions to water (direct point-source discharges to water) Air and land are covered by other BREFs)	The KEIs for the sector are addressed via federal regulations, and separate legislation under these regulations set emission limits per medium. For example, emissions to air from printing, coating, and dyeing of fabrics and other textiles are regulated under the Clean Air Act, National Emission Standards for Hazardous Air Pollutants (NESHAP) (US EPA, 2020[48]). Effluent limitation guidelines are only related to water discharges.
World Bank	Multi-media	Emissions to water, air energy consumption, solid and liquid waste	

Sub-chapter conclusion for Textiles sector

This section evaluated the sector-specific information present in the BREFs submitted on textile manufacturing. As there are general and common considerations given for each sector, there were also variations in the coverage and technical perspectives that are particular to the three sectors assessed in this report. The BREFs examined within this study are prepared by their national or international bodies or government technical institutes. Most BREFs submitted were either published or updated in the last decade and most are planned to be updated within the next 5 years.

The summary showed that all BREF documents submitted included scope definitions of manufacturing processes. However, the scale or capacity limitations were not clearly defined or not defined at all in most BREFs. The BAT and BAT-AELs may differed depending on the processes included in the scope of the BREFs. The production scale and capacity information are essential factors in making a thorough comparison of the BAT in BREFs as the BAT implemented at the large integrated installations may differ compared to the small-scale installations. An example from the textiles manufacturing industry could be that the COD load may be twice as high for integrated plants carrying out all pre-treatment, dyeing and finishing activities as compared to the plants with the capacity of only pre-treatment and dyeing.

All BREFs examined in this study provided definitions of technical approaches that are considered BAT, but not all BREFs included emission limit values (ELVs) in detail or for all processes. ELVs are the emission limit values prescribed in permits (based on BAT-AELs) for most countries. Some BREFs specified more detailed technical approaches, whereas others allowed a combination of approaches that have both higher-level key processes or sets of technical approaches which may be used at a specific site. However, for the performance criteria, the BAT included in the BREFs were not directly associated with the specific emission values that may be attributed to a specific BAT.

This report briefly provided information on the wastewater treatment plants (WWTPs) covered in the BREFs. All BREFs included varying degrees of information on the ETP concept. The application stage of ETP were not clearly noted among BREFs, whether the emission levels are subjected before or after the ETP process. Only the COINDs indicated that the MINAS apply before the ETP. However, all BREFs with information on ETP provided further details on their operation and location (offsite or incorporated in the installations).

Most BREFs adopted an integrated approach, while some BREF focused more on a particular environmental medium given its importance for the sector, such as wastewater discharges and emissions to air. Releases to water have been the main KEI concerning the textile manufacturing industry. Some BREFs also included information on power generation efficiency, emissions to air, solid residue production and chemical substitution. During the production of such integrated multi-media BREFs, there may be a potential for conflicts when certain techniques or emission levels are specified. Furthermore, there may be a need to have an increased consideration of the other cross-media effects in the future, such as via volatilisation of pollutants within an aerobic ETP to air, along with the energy demands of such ETPs.

3 BAT approaches

Section introduction

This section provides an overview of the *technical approaches* specified as BAT in the BREFs submitted for the three focus sectors in this report. It aims to provide a comparison of BAT for the KEIs analysed for each sector, whether techniques are legally-binding, recommended, or form the basis for quantitative standards, and which technical processes are mentioned for KEIs control, including both pollution prevention and abatement systems.

Initial analysis of BREFs showed that BAT were determined as general and KEI specific technical approaches (as BAT). Each sector was evaluated considering the following:

- General BAT – good practices used in addition to the process-specific BAT
- The main techniques applied to control the KEIs identified – by comparing each of the BREFs for each selected KEI
- Sub-sector differences – consideration and grouping of techniques according to the fuel types for TPP, types of cement produced, and specific textile manufacture processes.

Thermal Power Plants (TPP)

General BAT conditions

General BAT conditions may be considered as good environmental practices and applicable to many sectors without a specific criteria, such as their fuel type or emissions to any environment media. The country specific information from EU-BREF, K-BREF and EHS Guideline on TPP is provided below:

European Union

There are General BAT specified in the EU-BREF in the general BAT-Conclusions[15] section of all EU-BREFs. In the EU-BREF for TPP, the matters covered include:

- Environmental Management Systems (EMS)
- Monitoring requirements – including for efficiency
- General environmental and combustion performance
- Energy efficiency general techniques and requirements
- Water usage techniques and emissions to water
- Waste management techniques, including prevention
- Noise emission techniques

[15] General BAT conclusions are given in BREF Chapter 10.1, with fuel specific sections 10.2 to 10.7

South Korea

K-BREF for TPP included the following information on general BAT related to the sector:

- Environment Management System (EMS)
- Monitoring
- Environmental and Combustion Performance
- Energy efficiency
- Diffuse emissions from unloading, storing and handling fuels and additives
- Water pollution discharge and water consumption
- Management of Waste, by-products and residues
- Noise emissions
- Prevention of soil and groundwater pollution
- Plant design and decommissioning

World Bank

The EHS Guideline for TPP is cross-referenced (Section 1.0) to the IFC General EHS Guideline (IFC, 2007[20]), which covered general aspects that go beyond the installation site specificities, such as site selection and project development.

Specific BAT Approaches to KEIs Control

There are a number of parameters influencing the selection of BAT, such as the fuel type, targeting certain emissions (e.g. SO_2) and plant size that are used for emissions abatement (IFC, 2017[30]). Most BREFs included in the study identified and, in some instances, selected technical approaches as BAT. In some cases, the national regulations focused on emissions or performance outcomes rather than identifying or recommending technical approaches. The country specific information is provided in Table 10:

Table 10. Availability of specific BAT approaches to control KEIs in the BREFs submitted

BAT Reference Document	Specific BAT for KEI control
China	The GATPPC document identified technical approaches usable in the sector.
European Union	The EU-BREF includes techniques specified as BAT.
India	No – KEI control technologies are not specified in the CBPC documents
Japan	The BAT table sets out efficiency target requirements only
Korea	The K-BREF includes techniques specified as BAT
United States	No - Control Technologies are not specified in the regulations. The best available technologies used as the basis for standards in regulation are noted in supporting decision

BAT Reference Document	Specific BAT for KEI control
	documents found in the docket. Other documents and resources describe available technology and mitigation approaches [16]
World Bank	The EHS Guideline identifies the technical approaches for the sector.

Descriptions of common BAT identified (TPP)

There are several common BAT identified among the BREFs evaluated, which are used to prevent or control the emissions found in the flue gas (i.e. combustion exhaust gas exiting a power plant) to the air. Brief descriptions of these techniques used for dust abatement in power plants with high efficiency of removing many key emissions to air are provided below:

- **Flue-gas desulphurisation (FGD)** is a process typically used for reducing air emissions, mainly sulphur dioxide (SO_2), from the exhaust gas system of coal-fired plants. The output materials vary from wet sludge to dry, powdered material depending on the process (Cheremisinoff, 2012[49]). There are other air emission controls used at TPPs that may modify the characteristics of the high-volume coal combustion products (CCP), such as solids produced by the FGD systems. These controls may potentially reduce impacts resulting from the CCPs. Some of these controls are in place for sulphur trioxide (SO_3), hydrochloric acid (HCl), nitrous oxides (NO_X), and mercury (Hg) emissions (K.J. Ladwig, 2017[50]).
- **Wet scrubbers (**also known as **wet FGD)** are a common FGD method used to remove acid gases from the gas stream. Scrubbing can be effective at removing a wide range of contaminants: particulates; chemical contaminants such as ammonia; heavy metals; chlorides; potentially sulphides, and nitrogen oxides (D.J. Roddy, 2012[51]; Miller, 2005[52]; Cheremisinoff and Rosenfeld, 2010[53])
- **Electrostatic precipitator (ESP)** is a filterless device that removes dust from a gas stream by using electrical energy to charge dust particles either positively or negatively. The charged particles are then attracted to collector plates carrying the opposite charge. The collected particles are either removed as dry material (dry ESPs) from plates or washed from the collector plates with water (wet ESPs) (US EPA, 2021[54]).
- **Bag filters (fabric filters, textile filters)** are filtration methods used to collect dust particulates from gases streams. They are efficient and cost-effective with a high level of collection efficiency for very fine particulates. Gases enter the filter device and pass through fabric bags. These filters can be made of different materials (e.g., woven or felted cotton, synthetic or glass-fibre material) depending on the properties of the flue-gas (UNEP, 2019[8]).
- **Selective catalytic reduction (SCR)** and **Selective non-catalytic reduction (SNCR)** are chemical processes used to control nitrogen oxides (NO_x) emissions. SCR process involves injecting the flue-gas with ammonia (NH_3) with a catalyst (SCR process) at temperatures of around 300– 400ºC to convert NO_x into nitrogen and water vapour. SNCR follows a similar technique but without the use of a catalyst and at higher temperatures of 870-1200ºC (Belyakov, 2019[55]).

BAT used in Both Gas-fuelled and Coal-fired power production

The KEIs selected in this study were emission to air, namely, PM, SO_x, NO_x, Hg, and CO_2, and energy efficiency.

[16] Emission control technology reports for a variety of sources and pollutants : https://www.epa.gov/catc/clean-air-technology-center-products#reports

Some BREFs presented different sets of BAT for NO_x, energy efficiency, and CO_2 depending on whether the installations were gas-fuelled or coal-fired. The other BREFs provided the same BAT regardless of the fuel choice of the plants.

This section includes a number of tables listing the techniques specified to control the selected KEIs at both gas-fuelled and coal-fired power plants.

Oxides of Nitrogen (NO_x)

The oxides of nitrogen (NO_x) are emitted by a gas-turbine power plant during combustion of the natural gas (Johnson and Smith, 1978[56]). The country-specific nitrogen oxides (NO_x) related BAT are summarised in Table 11:

Table 11. Oxides of Nitrogen (NO_x) related BAT specified for both coal-fired and gas-fuelled TPP

<table>
<tr><th rowspan="2">BAT Reference Document</th><th colspan="2">KEI-specific BAT</th></tr>
<tr><th>Coal-fired plants</th><th>Gas-fuelled plants</th></tr>
<tr><td>China</td><td colspan="2">BAT specified for NO_x emissions are the same for both coal-fired and gas-fuelled plants, which are:
• **Selective catalytic reduction (SCR)**
• **Selective non-catalytic reduction technology (SNCR)**
• Low-NO_x burner (LNB) technology, including:
a. Air staging combustion technology
b. Fuel staging combustion technology
• SNCR-SCR combined</td></tr>
<tr><td>European Union</td><td>• Combustion optimisation
• Combination of other primary techniques for NO_x reduction
• **Selective non-catalytic reduction (SNCR)**
• **Selective catalytic reduction (SCR)**
• Combined techniques for NO_x and SO_x reduction (e.g. **activated carbon** and DeSONOx)</td><td>1. *NG boilers:*
• Air and/or fuel staging
• Flue-gas recirculation
• **Low-NO_x burners (LNB)**
• Advanced control system
• Reduction of the combustion air temperature
• **Selective non-catalytic reduction (SNCR)**
• **Selective catalytic reduction (SCR)**
2. *NG turbines:*
• Advanced control system
• Water/steam addition
• **Dry low-NO_x burners** (DLN)
• Low-load design concept
• Low-NO_x burners (LNB)
• **Selective catalytic reduction (SCR)**</td></tr>
</table>

BAT Reference Document	KEI-specific BAT	
	Coal-fired plants	Gas-fuelled plants
		3. *NG engines:* • Advanced control system • Lean-burn concept • Advanced lean-burn concept • **Selective catalytic reduction (SCR)** 4. *Iron & steel process gases:* • **Low-NO_x burners (LNB)** • Air staging • Fuel staging • Flue-gas recirculation • Process gas management system • Advanced control system • **Selective non-catalytic reduction (SNCR)** • **Selective catalytic reduction (SCR)** 5. *Offshore platforms (gaseous and/or liquid fuels):* • Advanced control system • **Dry low-NO_x burners (DLN)** • Lean-burn concept • **Low-NO_x burners (LNB)**
India	The control technology of NOx is not specified in the regulation, however the technologies adopted for coal-fired plants are: • **Selective catalytic reduction (SCR)** • **Selective non-catalytic reduction technology (SNCR)** • **Low-NO_x burner (LNB) technology** • Air staging combustion technology	The control technology of NOx is not specified in the regulation.
Japan	The BAT table sets out energy efficiency target requirements only.	
Korea	• Ammonia injection system with **SNCR (Selective Non Catalytic Reduction)** • **SCR (Selective Catalytic Reduction) systems**	• **Dry NO_x burner(DLN)** • Air supply (ASU) Separate from ASU • Gas turbine combustion chamber Steam injection • **Selective catalytic reduction (SCR)**

BAT Reference Document	KEI-specific BAT	
	Coal-fired plants	Gas-fuelled plants
		• Combustion system management • Multi-stage air and fuel injection • Exhaust gas recirculation • **Selective non-catalytic reduction (SNCR)** • Computerization of process control • Water or steam injection • Computational management of process • Low load design • **Low NO_x burner** • Lean burning
United States	BAT are not specified in regulation, which sets out emissions level requirements only. Common techniques for managing NO_2 include using • **Low-NO_x burners** and installation of **SCR or SNCR**. The EGU NO_x mitigation strategies technical support document (US EPA, 2016[57]) includes information on control installation timing, cost of installation/operation, and performance of each control.	
World Bank	The EHS Guideline included the following primary and secondary controls: • **Low-NO_x burners** with other combustion modifications, such as low excess air (LEA) firing, over-fire air, or flue gas recirculation for boiler plants; • Dry low-NO_x combustors for combustion turbines burning natural gas; • Water injection for combustion turbines using liquid fuels. Water injection may not be practical for industrial combustion turbines in all cases depending on the availability of a suitable water supply. • Optimisation of operational parameters for existing reciprocating engines burning natural gas to reduce NO_x emissions; • Lean-burn, cool operating concept for new gas engines; • Use of Miller principle for reciprocating engines • **SCR and SNCR.**	

Energy Efficiency

Energy efficiency at plants aims to reduce the amount of energy required in the production, in this case, electricity, and contribute to reducing emissions to air from those installations. The country-specific energy efficiency-associated BAT are summarised in Table 12:

Table 12. Energy efficiency BAT used in coal-fired and gas-fuelled TPP

BAT Reference Document	KEI-specific BAT	
	Coal-fired plants	Gas-fuelled plants
China	The energy efficiency techniques are not specified in the GATPPC document.	
European Union	• Combustion optimisation • Optimisation of the working medium conditions • Optimisation of the steam cycle • Minimisation of energy consumption • Preheating of combustion air • Fuel preheating • Advanced control system • Feed-water preheating using recovered heat • CHP readiness • Flue-gas condenser • Heat accumulation • Wet stack • Cooling tower discharge • Fuel pre-drying • Minimisation of heat losses • Advanced materials • Steam turbine upgrades • Supercritical and ultra-supercritical steam conditions • Dry bottom ash handling (*for coal-fired plants)* • **Combined cycle (*gas-fired plants)* (CCGT)**	
India	The control technology to enable energy efficiency in the plants is not specified in the regulation	
Japan	The BAT table specifies energy efficiency levels, however not inform on the techniques to achieve those targets.	
Korea	• Supercritical Steam condition • Optimisation of operating parameters • Steam cycle optimisation • **Heat recovery by cogeneration (CHP)** • Heat storage type water supply heating • Preheating of combustion air • Steam turbine upgrade • Optimal computer control system • Wet chimney (Wet stack) • Fuel pre-drying • Fuel pre-heating	• Heat recovery from the gasification process • Gasification and combustion block • Dry fuel supply system • High temperature and high-pressure gasification • Design improvement • CHP Spare • Regenerative feed water heating • Compound cycle

BAT Reference Document	KEI-specific BAT	
	Coal-fired plants	Gas-fuelled plants
	• Complete combustion • High quality material • Minimisation of energy consumption • Exhaust gas condenser	
United States	Efficiency techniques are not specified in supplied information (which sets out emissions level requirements). However, energy efficiency is promoted through renewable energy programs, such as the Combined Heat and Power (CHP) Partnership (US EPA, n.d.[58]).	
World Bank	The EHS Guideline included various techniques for the energy efficiency, some of which are: • Choice of fuel and use of measures to increase energy conversion efficiency will reduce emissions of multiple air pollutants, including CO_2, per unit of energy generation of multiple air pollutants, including CO_2, per unit of energy generation. • Optimising energy utilisation efficiency of the generation process depends on a variety of factors, including the nature and quality of fuel, the generation cycle type chosen (e.g., reciprocating engine, single or **combined cycle gas turbine (CCGT)**, steam turbine), its configuration (e.g., electricity generation or co- or tri-generation of electricity, heating and cooling), the operating temperature of the combustion turbines, the operating pressure and temperature of steam turbines, the local climatic conditions, the type of cooling system used and potential for nearby heat users. There are other references included in the BREF related to energy efficiency technologies.	

Carbon Dioxide (CO_2)

The emissions of carbon dioxide (CO_2) from both coal-fired and gas-fuelled plants due to the burning of fossil fuels are still considered a major KEI for the sector, in addition to the NO_x and SO_x emissions. The country-specific information on BAT for CO_2 is presented below:

Table 13. Carbon Dioxide (CO_2) related BAT specified - TPP

BAT Reference Document	KEI-specific BAT
China	Not specified in the GATPPC document
European Union	The EU-BREF includes CO_2 reduction technologies as emerging techniques. The BREF also includes specific BAT on fuel choice, energy efficiency and a BAT-AEL on methane from ignite spark gas engines. Article 36 of the IED establishes the carbon capture readiness legal requirement for all plants of > 300MWe that meet the necessary conditions in terms of availability of suitable storage sites; technical and economic feasibility of transport facilities; and technical and economic feasibility of retrofitting for CO_2 capture[17].
India	The control technology of Carbon Dioxide (CO_2) is not specified in the regulation
Japan	The BAT table sets out energy efficiency target requirements only.
Korea	Carbon dioxide emissions are noted throughout the document,
United States	GHG emissions standards are based on techniques for preventing or reducing CO_2 emissions (US EPA, 2021[59]) . The 2015 GHG NSPS is based on the application of the best system of emission reduction (BSER), which was determined to be partial carbon capture and storage (partial CCS) for new coal-fired electric generating units (EGUs), and combined cycle combustion turbines (CTs) for new natural gas-fired EGUs (US EPA, 2015[60]). The US EPA previously issued Emission Guidelines for existing fossil fuel-fired EGUs in the Clean Power Plan (CPP) in 2015 and in the Affordable Clean Energy (ACE) rule in 2018. However, neither of those rules was ever put into effect due to legal challenges. EPA is currently assessing guidelines and rules in response to recent regulatory interpretation and as required by the Clean Air Act (US EPA, 2015[61]; US EPA, 2019[62]).
World Bank	New thermal coal power stations with a combined net electrical generating capacity at or over 300MWe are expected to evaluate Carbon Capture and Storage Readiness (CCR). The BAT included in the EHS Guideline are: • Use of less carbon intensive fossil fuels • Use of higher energy conversion efficiency technology • Use of high performance monitoring and process control techniques • Transmission and distribution loss reduction and demand side measures • Consider fuel cycle emissions and off-site factors

[17] The U.K. Environment Agency produced a guidance on Post-combustion carbon dioxide capture: best available techniques (BAT) which covers post-combustion carbon capture (PCC) plants that use amine-based technologies to capture CO_2 from the flue gases of power and CHP plants fuelled by natural gas and biomass (U.K. Environment Agency, 2021[114]).

BAT used in Coal-fired power production

Air pollution control systems are already widely used by coal-fired power plants in many countries to reduce their emissions of main air pollutants, such as particulate matter (PM), oxides of nitrogen (NO_x), mercury (Hg) and sulphur dioxide (SO_2) (UNEP, 2019[8]).

This section includes a number of tables listing technical approaches specified in the BREFs submitted for the control of the selected KEIs at coal-fired power plants:

Particulate Matter (PM)

PM emitted by fuel combustion is a major air pollutant and present in the form of filterable particulate matter (FPM) and condensable particulate matter (CPM) (Feng and Cui, 2018[63]). Condensable particulate matter (CPM) is gaseous at flue gas temperature (around 1200 °C) before discharge, but is formed as a PM after dilution and cooling in the plume. Filterable particulate matter (FPM) is another type of particulate that is commonly known as soot. Total particulate matter (TPM) is composed of CPM and FPM (Feng and Cui, 2018[63]). The country-specific PM-related BAT are summarised in Table 14:

Table 14. PM-related BAT specified - TPP

BAT Reference Document	KEI-specific BAT
China	• **Bag filters** • **Electrostatic precipitator, including** a. Low temperature electric dust removal technology b. Wet electric dust removal technology c. High frequency electric technology d. Dry electric dust collector and wet electric dust collector • Spraying devices, dry coal sheds • Open-air coal yard • Top dust collector • Electric bag composite dust removal • Metal filter material technology
European Union	• Fuel choice • **Electrostatic precipitator (ESP)** • **Bag filters** • Boiler sorbent injection (in-furnace or in-bed) • **Dry or Semi-dry flue-gas desulphurisation (FGD) system** • **Wet FGD**
India	The control technology is not specified in the regulation, however, the technologies adopted are reported as: • **Bag filter** • **Electrostatic precipitator (ESP)** • Wet dust collector and wet electric dust collector
Japan	The BAT table sets out efficiency target requirement only

BAT Reference Document	KEI-specific BAT
Korea	• Cyclone • **Electric dust collection facility (ESP)** • **Filter dust collection facility (BF)** • Boiler absorbent injection • **Dry or semi-dry FGD** (SDA, DSI) • **Wet FGD**
United States	• Techniques are not specified in regulation which set emissions standards • Supplemental documents and resources describe available technologies or approaches.
World Bank	• **ESP, fabric filter** or **wet scrubber** • Loading and unloading equipment • Water spray systems • Enclosed conveyors • Full enclosure during transportation and covering stockpiles • Design and operate transport systems • Storage of lime or limestone in silos • Wind fences in open storage

Oxides of Sulphur (SO_x)

Oxides of sulphur refer to many types of sulphur and oxygen containing compounds, such as sulphur dioxide (SO_2), which is the most commonly found type (EEA, n.d.[64]). Two thirds of SO_2 and one fourth of NO_X in the atmosphere come from power plants (US EPA, 2021[65]). During high-temperature gasification of coal, most of the sulphur component is released and converted to hydrogen sulphide (H_2S) and carbonyl sulphide (COS). H_2S and COS along with carbon dioxide (CO_2) are called acid gases. They are mostly removed from the synthetic gas (i.e. syngas) in the acid gas removal equipment prior to combustion in gas turbines for electricity production (NETL, n.d.[66])

Acid gas removal equipment can extract the majority of these compounds, and the small amount of residual sulphur that remains in the synthetic gas is converted to SO_2 in the combustion turbine and released to the atmosphere (NETL, n.d.[66]). The country-specific oxides of sulphur (SO_x) related BAT are summarised in Table 15:

Table 15. Oxides of Sulphur (SOx) related BAT specified - TPP

BAT Reference Document	KEI-specific BAT
China	• Limestone-gypsum wet **desulphurisation technology** • Flue gas cooling and defogging technology • Flue gas dewatering and reheating technology • Flue gas circulating fluidized bed desulphurisation technology • Ammonia desulphurisation • Seawater desulphurisation • Active coke desulphurisation technology • Organic amine desulphurisation technology

BAT Reference Document	KEI-specific BAT
	• Biological desulphurisation technology
European Union	• Boiler sorbent injection (in-furnace or in-bed) • **Duct sorbent injection (DSI)** • **Spray dry absorber (SDA)** • Circulating fluidised bed (CFB) dry scrubber • **Wet scrubbing** • **Wet flue-gas desulphurisation (wet FGD)** • Seawater FGD • Combined techniques for NOx and SOx reduction • Replacement or removal of the gas-gas heater located downstream of the wet FGD • **Fuel choice**
India	The control technology is not specified in the regulation, however the technologies adopted are: • Limestone-Gypsum wet desulphurisation technology • Boiler sorbent injection • **Dust sorbent injection (DSI)** • **Spray dry absorber (SDA)** • Circulating fluidised bed (CFB) dry scrubber • Wet scrubbing • **Wet FGD** • Seawater FGD
Japan	The BAT table sets out efficiency target requirements only
Korea	• **Fuel selection** • Boiler absorbent injection • Dry absorbent injection • Semi-dry absorption method • **Wet FGD** • Wet cleaning • **Spray Dry Absorber (SDA) Posterior**
United States	BAT are not specified in regulation, which sets out emissions level requirements only. Common techniques for managing SO_2 include: • Using a **wet FGD** scrubber • Using **dry sorbent injection (DSI)** • Firing very low sulphur content coal
World Bank	• Selecting low sulphur content fuels • Lime or limestone for integrated desulphurisation • **Wet FGD**

BAT Reference Document	KEI-specific BAT
	• semi dry FGD • seawater FGD

Mercury (Hg)

Coal-fired power plants (and coal-fired industrial boilers) are a large source of local, regional, and global atmospheric Hg emissions (UNEP, 2019[8]). Coals containing mercury are used for combustion throughout the world, and if abatement techniques are not applied, Hg is emitted along with other pollutants during the combustion process of the power plants (UNEP, 2019[8]). The country-specific mercury (Hg) related BAT are summarised in Table 16:

Table 16. Mercury (Hg) related BAT specified - TPP

BAT Reference Document	KEI-specific BAT
China	• Refuse the use of high-mercury coal • **Electric bag collaborative mercury removal technology**
European Union	• Specific techniques to reduce mercury emissions: ○ Carbon **sorbent** injection in the flue-gas ○ Use of halogenated additives in the fuel or injected in the furnace ○ Fuel pretreatment ○ Fuel selection • Co-benefit from techniques primarily used to reduce emissions of other pollutants: ○ **Electrostatic precipitator (ESP)** ○ **Bag filter** ○ Dry or Semi-dry FGD system ○ Wet flue-gas desulphurisation (wet FGD) ○ **Selective catalytic reduction (SCR)**
India	The control technology of mercury is not specified in the regulation, however, the technologies adopted are: • **Electrostatic precipitator (ESP)** • **Bag filter** • Dry or Semi-dry FGD system • Wet flue-gas desulphurisation (wet FGD) • **Selective catalytic reduction (SCR)**
Japan	The BAT table sets out energy efficiency target requirements only.
Korea	• **Filter dust collection facility (Bag Filters)** • Electric dust collection facility **- Electrostatic Precipitators (ESP)** • **Selective catalytic reduction (SCR)** • **FGD technique** • Fuel selection

BAT Reference Document	KEI-specific BAT
	• Carbon adsorbent (activated carbon) injection • Fuel or halogenated additives • Fuel pretreatment
United States	The BAT are not specified in regulation, which sets out emissions level requirements only. Common techniques at US power plants include combination of mercury-specific control technologies, such as: • **activated carbon injection** or oxidation additives • **co-benefit mercury controls** (e.g., SCR, wet FGD scrubbers, PM controls, etc.)
World Bank	• **Conventional secondary controls** (e.g. ESPs, FGD, sorbent injection) • Use of high dust **SCR** system along with powered activated carbon, bromine-enhanced Powdered Activated Carbon (PAC) or other sorbents

Sub-Chapter Conclusion

The BAT approaches used in the thermal power plants for a number of selected key environmental issues (KEIs) in China, the European Union, India, Japan, South Korea, the United States and the World Bank group were extracted from their relevant BREFs. The fundamental aim of this chapter was to indicate the BAT practices employed by several countries to prevent or control emissions to air based on the two selected fuel-type used by the plants. In addition to the air emissions, BAT used to ensure the energy efficiency of coal-fired and gas-fuelled power plants were collected from the BREFs submitted. As CO_2 is a primary greenhouse gas emitted from those installations, abatement technologies (BAT) used to address carbon dioxide (CO_2) emissions were also gathered for this chapter.

The general BAT conditions are existing general practices carried out by the regulatory institutions that can be considered as good environmental practices for all industrial sectors. The BREFs (or performance standards) from China, India, Japan and the US did not include a section that provided general BAT specified for this sector. The EU-BREF and K-BREF have a chapter focusing on general considerations for the sector, whereas the EHS Guideline point to a general EHS Guideline designed to be used together with the relevant industry-specific guidelines.

Particulate matter (PM), oxides of sulphur (SO_x) and mercury (Hg) emissions from coal-fired power plants were selected to compile BAT adopted in the seven BREFs submitted. There were differences in the level of detail and range of more detailed techniques indicated. However, it was noted that not all BREFs had specified techniques for the emissions selected. In those BREFs, broadly similar PM reduction techniques were specified, such were electrostatic precipitators (ESP), bag/fabric filters and wet flue-gas desulphurisation (FGD)/wet scrubbers. There are BAT frequently described for sulphur oxides (SO_x), such as SO_2, which were fuel selection and use of wet FGD (limestone) absorber. Mercury input control through fuel selection and pre-treatment was noted, and abatement systems commonly involve specific adaptations to technologies already applied to control other emissions e.g., for PM control.

In the Guidance document on Best Available Techniques (BAT) and Best Environmental Practices (BAT/BEP) of the Minamata Convention on Mercury for emissions to air (Article 8), there are five common techniques for emission reduction described, namely *fabric filters, electrostatic precipitators (ESP), wet scrubbers, dust cleaning devices, and sorbents and oxidizing agents* (UNEP, 2019[8]). These techniques were also noted in the majority of the BREFs submitted. Brief descriptions of these techniques are provided in the chapter section 0 Descriptions of common BAT identified (TPP).

Global coal-fired power generation has revived strongly in the first half of 2021 due to rising natural gas prices in Europe, the United States and economic activities in China (IEA, 2021[67]). By the second half of the year, there were prominent switches to the coal-usage in electricity generation in many regions such as the United States, Europe and Asia, which drove up the global CO_2 emissions (IEA, 2021[67]). Regardless of this economic influence in the selection of the fuel-choice, an estimated 98% of natural gas consumed currently shows a lower life cycle emissions intensity than coal used for electricity production (IEA, 2019[68]). The coal-to-gas fuel switching leads to reducing emissions by 50% when producing electricity and 33% when providing heat (IEA, 2019[68]).

For gas-fuelled power plants, BAT collected were listed with coal-fired power plants to provide visual comparability of the BAT, and for some BREFs, there were no distinctions in BAT made for the fuel-type for the selected KEI. The BREFs supplied from China, World Bank, and the United States did not differentiate between fuel-types for indicating BAT to prevent or control oxides of nitrogen (NO_x) or energy efficiency measures. In all of the BREFs analysed, there were approaches at the combustion stage and abatement techniques included for NO_x. Frequently specified BAT noted were staged/optimised combustion and use of lower NO_x burner techniques in general. All BREFs noted the use of both selective catalytic reduction (SCR) and selective non-catalytic reduction (SNCR) techniques to reduce nitrogen oxide emissions to air. The SCR method is more efficient at reducing NOx emissions compared to SNCR but, more costly due to the use of a catalyst (Rogoff and Screve, 2011[69]; Enviro BLR, 2003[70]). Another factor that may influence the selection of which selective reduction method to use is the constituents of the flue-gas produced at the plants and the appropriate available space to install an SCR reactor (Enviro BLR, 2003[70]). SNCR method still remains one of the cheapest, however, SCR is a sufficiently effective alternative to achieve NO_x emission limits set (Gal et al., 2017[71]). Summaries of these BAT are provided in the chapter section 0 Descriptions of common BAT identified (TPP).

Emissions of NO_x, SO_2 (SO_x) and CO_2 per unit of electricity and heat generated by conventional TPPs (i.e. the emissions intensity) decreased substantially from the early 90s (EEA, 2011[72]). The NO_x and SO_2 emissions have been particularly reduced with the employment of effective techniques such as low NO_x burners, FGDs, use of less polluting fuels and other end-of-pipe abatement techniques such as SCR/SNCR, which were also noted in the seven BREFs analysed for this report.

The energy efficiency of power plants gradually improved over the years, particularly due to the closure of older plants, improving existing technologies and/or installing new and more efficient technologies to the installations (EEA, 2018[73]). General approaches and fundamental matters, such as plant design and operational stage specificities, are typically considered during the project development of building installations. Beyond that, technical upgrades in plants coupled with switches from coal fuel to combined cycle gas turbines, as indicated in many of the BREFs analysed, were used to increase the energy efficiency levels of installations. Some BREFs specified energy efficiency techniques, such as combined heat and power (CHP) cogeneration and Steam cycle design optimisations.

Relatively few BREFs directly addressed CO_2 emissions from both coal-fired and gas-fuelled plants. The EU-BREF identified a range of CO_2 emission reduction technologies in a section on “Emerging Techniques”. The EHS Guideline included the fuel carbon intensity and efficiency measures, along with other wider system issues (transmission losses, fuel cycle) that are often acknowledged but then considered beyond the immediate “installation” scope of the other BREFs.

There are BAT commonly used in both TPP and cement production sector to prevent and control emissions of several KEIs to air, including the ones selected for this report. This could be attributed to the same KEIs selected, which are mostly originating through similar processes, such as the combustion of selected fuel. Depending on various preconditions of countries, such as the economic levels, there are advanced technologies available to employ in preventing and controlling air emissions related to thermal power plants.

Cement Production

Cement production is an energy intensive sector and a prominent contributor to many global air pollutants, e.g. CO_2 and mercury. Global efforts are taking place to target particular key environmental concerns, such as the Minamata Convention on Mercury[18] and Global Cement and Concrete Association[19], which revealed that cement production accounts for 11% of the global anthropogenic mercury emission at around 2220 tonnes per year (UNEP, n.d.[9]).

Portland cement is the most common type of cement in use that is manufactured from limestone and clay with lower amounts of gypsum (Hotza and Maia, 2015[74]). It is used for general construction purposes such as reinforced concrete buildings, bridges, and pavements (Yuan et al., 2021[75]).

The following information on BAT used in the cement production sector is gathered from the five BREFs submitted as explained in the Section Introduction.

General BAT conditions

General BAT conditions may be considered as good environmental practices and applicable to many sectors without a specific criteria, such as their fuel type or emissions to any environment media. The country-specific information is provided below:

European Union

There are General BAT specified in the EU-BREF in the general BAT-Conclusions[20] section of any BREF. In the EU-BREF for Cement, Lime and Magnesium Oxide production, the matters covered include:

- Environmental management systems (EMS)
  - In order to improve the overall environmental performance of the plants/installations producing cement, lime and magnesium oxide, production BAT is to implement and adhere to an environmental management system (EMS).
- Noise emission techniques
  - In order to reduce/minimise noise emissions during the manufacturing processes for cement, lime and magnesium oxide, BAT is to use a combination of techniques mentioned in the document.
- In addition to EMS and noise control measure, there are general primary techniques of:
  - Achieve a smooth and stable kiln process, operating close to the process parameter set points by using a number of techniques.

[18] Minamata Convention on Mercury: The Minamata Convention on Mercury is an international treaty designed to protect human health and the environment from anthropogenic emissions and releases of mercury and mercury compounds, adopted in 2013.

[19] Global Cement and Concrete Association : is an international industry association on Cement and Concreate that was established in 2018.

[20] General BAT conclusions for the cement, lime and magnesium oxides industries are given in BREF Chapter 4.1 while specific BAT conclusions for the cement industry are given in Chapter 4.2

- Carry out a careful selection and control of all substances entering the kiln.

World Bank

Recommendations for the management of environment, health and safety issues common to most large industrial facilities during the construction and decommissioning phases are provided in the General EHS Guidelines.

Specific BAT Approaches to KEI Control

Most BREFs submitted identified and, in some cases, selected technical approaches as BAT. In some instances, the national regulations focused on emissions or performance outcomes, and did not identify or recommend technical approaches. The country-specific information is provided Table 17 :

Table 17. Availability of specific BAT approaches to control KEIs in the BREFs submitted

BAT Reference Document	Specific BAT for KEIs control
China	The GATPPC document identified technical approaches usable in the sector
European Union	The EU-BREF includes techniques specified as BAT.
India	No - The control technologies are not specified in the BREF document.
United States	No - US regulations for cement set emission standards and without specification of control technologies. Best available technologies used as the basis for standards in regulation are noted in supporting decision documents found in the docket. Other documents and resources describe available technology and mitigation approaches (US EPA, n.d.[76]).
World Bank	The EHS Guideline identifies the technical approaches for the sector

Descriptions of common BAT identified (Cement)

Air emission abatement techniques are mostly the same for all sectors for the same emissions targeted, such as electrostatic precipitators (ESP), bag filters and selective non-catalytic/catalytic reduction (SNCR/SCR), in the installations (see section 0). In this section, other commonly used BAT in the cement sector are explained:

- Use of sorbent additives (absorbent), such as **Dry Sorbent Injection (DSI),** consists of an injection of reagents, such as hydrated lime or activated carbon in the flue gas flow. After that, the compound is collected by a particulate control device, such as an electrostatic precipitator (ESP) or a bag filter (Kong and Wood, 2011[77]).
- **Low NO_x burners** aim to create branched and larger flames by controlling the air and fuel mix at each burner. This creates reduced peak flame temperature, which leads to significantly less NOx formed in the whole process (Lopez-Ruiz, Alava and Blanco, 2021[78]; Atiofny, n.d.[79]).
- **Activated carbon adsorption** involves removal of gaseous pollutants from the air stream by transferring the pollutants to the solid surface of activated carbon. There is a limit on the mass of pollutants that can be collected, and when its reached, the adsorbent requires to be cleaned, meaning the pollutant is desorbed (removed) from the activated carbon (US EPA, 2021[80]).

Portland cement production

Cement production is one of the highest pollutant emitting sectors functioning at a global level. There are various process emissions released during the limestone calcination to produce clinker (i.e. main ingredient in cement) as well as the combustion of fuels used in the production process (IEA, 2021[81]).

The main emissions from cement production are emissions to air from the kiln system. Particulate matter (PM) emissions mostly occur during the pre- and after-treatment stages of cement manufacture. Emissions from the kiln are a combination of combustion and process emissions. The main emissions are sulphur oxides (SO_x) and nitrogen oxide (NO_x) which are included in this report. Other concerning pollutants from kilns are carbon monoxide (CO), non-methane volatile organic compounds (NMVOC), ammonia (NH_3), and heavy metals (EEA, 2016[82]).

This section provides a country specific overview of the techniques specified in the BREFs submitted for the control of the selected KEIs at Portland cement production plants:

Particulate Matter (PM)

Most BREF documents specify abatement systems for particulate matter. The country-specific information is provided in Table 18 below:

Table 18. PM-related BAT specified in cement production

BAT Reference Document	KEI-specific BAT
China	The GATPPC on cement production reports on the following BAT: • **Filtering** • **Electric dust removal technology** • Electric-bag composite dust removal technology • Rotating electrode type **electrostatic precipitator technology**
European Union	*A. Diffuse dust emissions from dusty operations:* • Simple and linear site layout • Enclose dusty operations • Cover conveyors and elevators • Reduce air leakages and spillage points • Use automatic devices and control systems • Ensure trouble-free operations • Ensure proper and complete maintenance of the installation using mobile and stationary vacuum cleaning • Ventilate and collect dust in **fabric filters** • Use closed storage with an automatic handling system • Use flexible filling pipes *B. Diffuse dust emissions from Bulk storage area:* • Cover bulk storage areas or stockpiles • Use open pile wind protection • Use water spray and chemical dust suppressors

BAT Reference Document	KEI-specific BAT
	• Ensure paving, road wetting and housekeeping • Ensure humidification of stockpiles • Match the discharge height to the varying of the heap A maintenance management system which especially addresses the performance of filters are applied to dusty operations, other than those from kiln firing, cooling and main milling processes. Taking this management system into account, BAT is to use dry flue-gas cleaning with a filter. *C. Channelled dust emissions from Kiln firing & cooling and milling:* • **Electrostatic precipitators (ESPs)** • **Fabric filters** • Hybrid filters
India	The control technology is not specified in the regulation, however, the technologies adopted are reported as: • **ESPs** • **Filter Bag**
United States	There are supplemental resources on available and emerging technologies related to the cement industry such as AP-42 factors. Common techniques include: • **Fabric filters** • **ESP** • Gravel bed filters (US EPA, 2018[83]) • Paper/Nonwoven Filters - Cartridge Collector Type
World Bank	The EHS Guideline included two BAT: • For Mill operation**: Fabric filter** systems and • For Storage and Transportation: enclosed systems and automatic bag-filling

Oxides of Sulphur (SO_x)

Oxides of sulphur refers to many types of sulphur and oxygen containing compounds such as sulphur dioxide (SO_2), which is the most commonly found type (EEA, n.d.[64]). The country-specific information is provided in Table 19 below:

Table 19. Oxides of Sulphur (SO_x) related BAT specified in cement production

BAT Reference Document	KEI-specific BAT
China	The GATPPC on cement production indicates the following BAT used for the control of SO_x emissions: • Vertical mill technology • Optimisation of production process. • Optimisation of burner design • Kiln-mill

BAT Reference Document	KEI-specific BAT
	• **Bag filter** • **Absorbent injection** technology, • **Wet scrubbing** technology • Hot raw meal injection technology
European Union	The EU-BREF notes the **addition of absorbent** and **use of wet scrubber**
India	There are three BAT reported: • Optimisation of production process • Optimisation of burner design • **Bag filter**
United States	There are supplemental resources and emerging technologies available to the cement industry. The common techniques include the **use of adsorbents**.
World Bank	The EHS Guideline included: • Selection of low volatile sulphur content materials/fuels • Smoothing of kiln operations • Optimizing the oxygen concentration • Use of a vertical raw mill • **Injection of absorbents** • Use of **wet or dry scrubbers**

Oxides of Nitrogen (NO_x)

Nitrogen oxides (NO_x) are a family of poisonous, highly reactive gases. These gases are emitted by industrial sources such as power plants, industrial boilers, cement kilns, and turbines, as well as automobiles and other road vehicles (US EPA, 2000[84]; US EPA, 2019[85]). The country-specific information is provided in Table 20 below:

Table 20. Oxides of Nitrogen (NOx) related BAT specified in cement production

BAT Reference Document	KEI-specific BAT
China	The GATPPC on cement production indicates the following BAT used for the control of NO_x emissions: • **Low-NO_x burner** • Decomposition furnace staged combustion technology • **Selective non-catalytic reduction (SNCR)** • **Selective Catalytic Reduction (SCR)**
European Union	The EU-BREF separates BAT into primary and secondary/end-of-pipe techniques categories: • Primary techniques ○ Flame cooling

BAT Reference Document	KEI-specific BAT
	○ **Low-NO_x burners** ○ Mid-kiln firing ○ Addition of mineralisers to improve the burnability of the raw meal ○ Process optimisation • Secondary/end-of-pipe techniques ○ Staged combustion ○ **Selective non-catalytic reduction (SNCR)** ○ **Selective catalytic reduction (SCR)**
India	The following five BAT are reported: • Controls combustion air supply • Controlled combustion temperature • **Low-NOx** burner • **Selective non-catalytic reduction (SNCR),** • **Selective Catalytic Reduction (SCR)**
United States	Resources are available to the cement industry on NO_x control technologies (US EPA, 2000[84]).
World Bank	The EHS Guideline included the following five BAT: • **Low NO_x burners** • Developing a staged combustion process • Optimising primary and secondary air flow • Employing flame cooling • **Selective non-catalytic reduction (SNCR)**

Carbon Dioxide (CO_2)

Cement production is one of the main industries that lead to CO_2 emissions as a result of clinker production, which is the main component of cement. CO_2 is emitted due to the calcination of limestone during clinker manufacture and is also highly energy-intensive chemical process. Therefore, cement industry, due to clinker production, does not only have emissions from processes, but also leads to energy-related emissions by their selection of fuels (such as coal) to run the installations (IPCC, 2007[86]).

As indicated before in the TPP section, this KEI is included in this report based on its importance and relevance to the sector, regardless of its coverage under global climate agreements by many countries, such as the Paris Agreement (UN, 2015[87]). The country-specific information is provided in Table 21 below:

Table 21. Carbon Dioxide (CO_2) related BAT specified in cement production

BAT Reference Document	KEI-specific BAT
China	The GATPPC on cement production indicates the following BAT used for the control of CO_2 emissions:

BAT Reference Document	KEI-specific BAT
	• Vertical mill technology • Waste heat power generation technology • Frequency conversion speed regulation technology • The fourth-generation grate cooler technology
European Union	The EU BREFs do not address carbon dioxide emissions as Article 9(1) of the IED precludes the setting of emission limit values in permits where an installation is coveredby the EU's Emission Trading System (Directive 2003/87/EC) (EC, 2003[31]); unless it is necessary to ensure that no significant local pollution is caused. The EU BREF itself contains general information on CO_2 emissions resulting from cement activities, also referring to the corresponding EU Directives regulating CO_2 emissions resulting from industrial activities.
United States	Supplemental resources are available to industry, including a white paper on available and emerging technologies for reducing GHG emission from Portland cement (US EPA, 2010[88]).
World Bank	The EHS Guideline reported on two practises, which are to substitute with fuels with a lower ratio of carbon content and use of waste heat recovery power generation.

Sub-Chapter Conclusion

The BAT approaches used to address a number of selected key environmental issues (KEIs) in cement manufacturing by China, the European Union, India, the United States and the World Bank group were extracted from their relevant BREFs. The fundamental aim of this chapter was to indicate the BAT practices employed by several countries to prevent or control emissions of several major pollutants to air by the cement production plants.

The general BAT conditions are existing general practices carried out by the regulatory institutions that can be considered as good environmental practices for all industrial sectors. The BREFs (or performance standards) from China, India and the US did not include a section that provides general BAT specified for this sector. The EU-BREF have a chapter focusing on general considerations for the sector and the EHS Guideline direct to a general EHS Guideline designed to be used together with the relevant industry-specific guidelines

BAT adopted to abate emissions of particulate matter (PM), oxides of sulphur (SO_x), oxides of nitrogen (NO_x), mercury (Hg) and carbon dioxide (CO_2) were explored in the five BREFs submitted for this report. There were differences in the level of detail and range of more detailed techniques indicated. However, it was noted that not all BREFs supplied had specified techniques for the emissions selected. The fabric/bag filters and electrostatic precipitators (ESP) were the most commonly noted BAT for PM emissions. Several BREFs recommended absorbent injection and wet/dry scrubbers for the emissions of sulphur oxides. Furthermore, the selection of raw materials for the cement production and the fuel were noted among some of the BREFs. These two pre-treatment/input control practices have a significant impact on controlling SO_2 releases, (more so than on NO_x or PM). With these BAT implemented, only if their levels are still significant should the end of pipe solutions may be needed. For NO_x emissions, both primary and secondary (end-of-pipe) techniques were specified to some level in all BREFs submitted. For instance, low NO_x burners, flame cooling and staged combustion are described as the former, and selective non-catalytic reduction (SNCR) and selective catalytic reduction (SCR) as the latter techniques employed. The low NO_x burners have high capital cost at their installation to the plants, but have low operational costs. The SNCR method is a cheaper alternative to the SCR to achieve NO_x emission limits set as there is no catalyst added to the flue gas (Gal et al., 2017[71]). Some abatement systems through specific adaptations are applied to control other pollutants as well, such as PM and mercury. Summaries of these BAT are provided in the chapter section 0 and 0

As indicated before in the TPP section of this report, BAT on CO_2 emissions as a result of clinker production in the cement industry were explored as a KEI in this report based on its importance and relevance to the sector. The GATPPC and EHS Guideline included BAT used for the control of CO_2 emissions. Although the EU BREF does not mention carbon capture and storage (CCS) of CO_2 (i.e. not included in the emerging techniques), this may be reflective of the time period the data was collected for the BREF between 2006-2010. Since then, the test plants and fully operational kilns in Europe have adopted CCS.

The EU Cement industry commits to becoming carbon neutral by latest 2050[21]. The roadmap emphasises the need for CO_2 foot-printing of products that should be based on a cradle-to-grave lifecycle approach that goes beyond placing a product on the market and also takes into account the performance of the product during its use and after its useful life. For this, the following techniques options linked to production were highlighted:

- 8% reduction by decarbonised raw materials by 2050
- Substitution by alternative fuels (60% by 2030 containing 30% biomass and 90% with a 50% share of biomass by 2050). Reference installations are Schwenk (Allmendingen DE) and Lafarge Holcim in Reztnei (AT) and Brevik (NO).
- Thermal efficiency improvements of +4% by 2030 and +14% by 2050
- Carbon capture, utilisation and storage (CCUS), to reduce emissions by 42%.

There are BAT commonly used in both cement production and TPP sectors to prevent and control emissions of several KEIs to air, including the ones selected for this report. This could be attributed to the KEIs being the same and mostly originating through similar processes, such as the combustion of selected fuel. Depending on various preconditions of countries, including their economic levels, there are advanced technologies available to employ in preventing and controlling air emissions related to cement production.

Textile Manufacturing

Textile industry relies heavily on using water in its manufacture, including land for cotton and other fibres. Textile production is estimated to be responsible for about 20% of global clean water pollution from dyeing and finishing products (EP, 2021[89]).

This section is composed of information gathered from the BREFs submitted related to the textile manufacturing industry and the BAT used in the production of textiles, as explained in the Section Introduction.

General BAT conditions

General BAT conditions may be considered as good environmental practices and applicable to many sectors without a specific criteria, such as emissions to any environment media. The country specific information is provided below:

[21] CEMBUREAU 2050 carbon neutrality roadmap https://cembureau.eu/library/reports/2050-carbon-neutrality-roadmap/

European Union

The revised Textiles BREF (TXT BREF) contained both generic BAT and process-specific BAT (EIPPCB, 2022[40]). The general BAT included in the revised BREF are:

- General management techniques, such as environmental management system (EMS)
- Monitoring
- Water consumption and wastewater generation
- Energy efficiency
- Chemicals management, consumption and substitution
- Emissions to water
- Emissions to soil and groundwater
- Emissions to air
- Waste management

Flanders (Belgium)

The VITO-BREF included general BAT conditions in its technical scope. The VITO – BREF study is aimed at textile companies that implement finishing activities, which focus on the reduction of dedicated micro pollutant emissions to water.

India

The COINDS included descriptions of various operational processes however, these were not referred as general practices (or BAT).

South Korea

The K-BREF covered both process-specific BAT and generic BAT. The general environmental management systems noted were:

- Environment Management System or Chemicals Management System
- Monitoring
- Selection of chemical substances to be used
- Final emission reduction techniques (treatment of pollutants generated)

United States

The Effluent Guidelines and the development documents described techniques used in the textile manufacture. The effluent discharge rule regulates processes within the industry. The specific processes evaluated and those selected for regulation are described in the development document.

World Bank

The EHS Guideline for textile manufacturing is designed to be used together with the General EHS Guidelines.

Technical information about hazardous materials management, wastewater treatment, water consumption, emissions to air, energy consumption and, solid and liquid waste was included in the guideline.

Descriptions of processes selected and common BAT identified

The textile sector starts with the harvest of the raw material and moves on to its treatments, or also known as processes, to produce fabrics (EIPPCB, 2022[40]). There are a number of processes used in textiles manufacturing, namely pre-treatment, dyeing, printing, finishing and coating, including washing and drying (EIPPCB, 2022[40]). This section of the report describes the two selected processes; *pre-treatment* and *dyeing,* and the selected KEIs*:*

- The pre-treatment process cleans the fibres or fabric from impurities to make them fit for dyeing or for other end-product purposes. This process consists of several sub-processes, some of which are desizing, bleaching, mercerizing, singeing and scouring. All sub-processes mentioned involve chemical treatments applied to the fibres or fabric.
- The dyeing process involves an interaction between a dye and a fibre/fabric and generally has two chemical processes, adsorption of dye from the aqueous solution onto the fibre, and diffusion of dyes into the fibre (Shang, 2013[90]). This can be done using batch or continuous processes. In batch dyeing, textile is loaded into a dyeing machine where dye liquor and auxiliaries are added, which is then fixed using heat or chemicals. Unfixed dyes and other chemicals are removed by another wash. Continuous dyeing consists of dye application in a bath, dye fixation by heat or chemicals and a final washing conducted at speeds between 50 and 250 meters of fabric per minute (IFC, 2007[47]).
    - Wastewater effluents from dyeing process contain various compounds such as colour pigments, halogens, **metals** (e.g. chromium, copper, nickel and zinc). These effluents are also known to have high **BOD (biochemical oxygen demand)** and **COD (chemical oxygen demand)** levels. BOD represents the amount of oxygen consumed by microorganisms while they decompose organic matter by aerobic reactions at a specified temperature (USGS, 2018[91]). COD is the amount of oxygen that can be consumed by chemical reactions under a controlled environment (Li and Liu, 2019[92]) and is used to measure the amount of oxidizable pollutants present in wastewater, or in surface water (Li and Liu, 2019[92]). The BOD/COD ratio indicates the proportion of non-biodegradable organic matter present in the wastewater (Khan, Patel and Khan, 2020[93]).

The textile industry is highly dependent on water, and large amounts are used at all steps of the textile manufacturing process. All dyes and chemicals are applied to the textiles in water baths (Kumar and Pavithra, 2019[94]). Some of the common BAT identified to address releases to water are:

- **Coagulation** process is a frequently used BAT as a part of pre-treatment process in textile wastewater treatment plants. It uses a coagulant to decolorise textile effluents and reduce a total load of suspended solids (Karam, Bakhoum and Zaher, 2021[95]; Verma, Dash and Bhunia, 2021[96]). However, the efficiency of this treatment depends on the dosage of the coagulant (risk of excess sludge), the characteristics of raw wastewater, pH and temperature (Verma, Dash and Bhunia, 2021[96]).
- **Flocculation** is a recommended subsequent treatment to coagulation. The combined treatments lead to improved coagulation of effluents by enlarging the size of flocs and, consequently, causing rapid settling (Teh, 2016[97]).
- **Adsorption** is a commonly used technique for removing textile dyes from the effluents due to its low cost and easy operation (Herrera-González, Peláez-Cid and Caldera-Villalobos, 2017[98]). Many materials are employed as adsorbents, such as kaolin, starch and polymers (e.g. polyelectrolytes). Adsorption is based on attracting molecules (of textile dyes) with opposite charge to ionic groups of the adsorbents. This chemical reaction establishes the basis for the other techniques such as ionic exchange, coagulation-flocculation and membrane filtration as well (Herrera-González, Peláez-Cid and Caldera-Villalobos, 2017[98]).

- **Activated sludge process** is a biological oxidation technique used for treating wastewater with dissolved solids, colloids and coarse solid organic matter. In this process, the wastewater is aerated in a reaction tank with some suspended microbial floc. The aerobic bacterial flora leads to biological degradation of the pollutants into CO_2 and water molecule, while consuming the organic matter for synthesizing bacteria. This bacteria flora proliferates and remains suspended in the form of a floc, which is called Activated Sludge. The effluent from the reaction tank is separated from the sludge by settling and get discharged (Das, 2006[99]).

Water consumption in textile production has high environmental impacts, especially where the freshwater resources are limited (IFC, 2007[47]). Therefore, water efficiency techniques are essential for determining and identifying BAT in this sector, such as controls of water consumption and releases to water.

Textile manufacturing utilises potentially harmful chemicals in its processes (e.g. spent liquors from sizing, dyeing and finishing) to deliver ideal products. Given that nearly all processes are carried out in water baths (or use water in some way), resulting wastewater may contain pollutants that are toxic or poorly biodegradable (EIPPCB, 2022[40]).

Specific BAT Approaches to KEIs Control

The textile sector has many technical approaches used in its manufacturing processes. Considering the comparability, pre-treatment and its three sub-processes, and dyeing are targeted in this study. Table 22 summarises whether the BREFs supplied include the specification of technical approaches according to these processes and sub-processes.

Table 22. Pre-treatment with its sub-processes and Dyeing processes in the BREFs submitted – Textiles manufacture

BAT Reference Document	KEI-specific BAT			
	Pretreatment			Dyeing
	Desizing	Bleaching	Mercerizing	
European Union	Y	Y	Y	Y
VITO	No- technical details on the BAT.	No- technical details on the BAT.	No- technical details on the BAT.	No- technical details on the BAT.
India	Y	N	Y	Y
Korea	N	Y	Y	Y
United States[22]	N	N	N	N
World Bank	Y	Y	Y	Y

[22] *For textiles sector in the US, the process itself is not regulated. These processes are all discussed in the development documents since they are all basic to the textile industry. The decision was made during the development process to regulate the product, not the procedure used to produce the product. For a rule that is applied nation-wide, this is much more practical that trying to regulate based on processes. It is noted that the approach used for each rule may differ based on sector.

Pre-treatment process

Different BAT are specified for the three sub-processes of pre-treatment process, i.e., the desizing, bleaching and mercerizing, in the BREFs submitted.

The desizing sub-process is used to remove sizing compounds from woven fabric/warp which results in high wastewater loads (EIPPCB, 2022[40]). Current bleaching methods use hydrogen peroxide (H_2O_2) and sodium hypochlorite (NaClO, also known as bleach), to whiten fabric but also result in its damage, along with the formation of toxic by-products and large amounts of water and energy to remove these chemicals (EC CORDIS, 2019[100]). Mercerisation is a common industrial process involving sodium hydroxide for cotton yarns or fabrics to increase their lustre and dyeability for later processes (Kalaoglu and Paul, 2015[101]). The country-specific information about three sub-processes identified the BREFs submitted are summarised in Table 23:

Table 23. Pre-treatment related BAT specified in textiles manufacturing

BAT Reference Document	KEI-specific BAT for Pretreatment		
	Desizing	**Bleaching**	**Mercerizing**
European Union	• Selection of sizing chemicals • Pre-wetting of the cotton yarns • Compact spinning • Combined pre-treatment of cotton textiles • Cold pad-batch treatment of cotton textiles • Single or limited number of desizing liquors • **Recovery and reuse of water-soluble sizing chemicals**	• **Chlorine-free bleaching** • Optimised **hydrogen peroxide bleaching**	• **Recovery of caustic soda** used for mercerisation (alkalisation)
VITO	There are no distinctions made regarding the sub-processes of pre-treatment in the VITO-BREF.		
India	Replacing chemical-based process with enzymatic-based oxidation.		Use the highest temperature of water
Korea	See **Information Box 1 K-BREF : Pre-treatment process** below.		
United States	Control technology are not specified in the US regulations. Best available technology used as the basis for standards in regulation are noted in supporting decision documents found in the document. Other guidance documents and resources describe available technology and mitigation approaches. One example is the 1996 best management practices for pollution prevention in the textile industry (US EPA, 1996[102])[23].		
World Bank	• Selection of raw material with low add-on techniques	• Use of **hydrogen peroxide bleaching agent**	• Recovery and reuse of alkali

[23] https://www.epa.gov/sites/production/files/2020-04/documents/best-management-practices-textile-industry-manual.pdf

BAT Reference Document	KEI-specific BAT for Pretreatment		
	Desizing	**Bleaching**	**Mercerizing**
	• Selection of more biodegradable/bioeliminable sizing agents • Application of enzymatic or oxidative desizing with starch • Integration of desizing / scouring and bleaching • **Recovery and reuse of specific water-soluble synthetic sizing agents**	• Reduce the use of **sodium hypochlorite** • Control of stabilizers employed	

Information Box 1 K-BREF : Pre-treatment process

In the Korean BREFs (K-BREF), the pre-treatment processes are categorised according to the textiles type. Some of which are:

6.2.1 Cotton and cellulose

BAT 16. The technique is to reduce water use and energy consumption by integrating and optimizing individual processes of pre-treatment applied to cotton materials.

- Application of an integrated process of pre-treatment for cotton textile (see Section 5.1.6)
- Optimisation of cotton warp yarn pre-treatment (see Section 5.1.11)

BAT 17. The technique is to reduce the discharge of water pollutants by using enzymes in the scouring process applied to cotton materials (see Section 5.1.7).

BAT 18. The technique is to **minimise the use of chlorine bleach by using alternatives such as hydrogen peroxide, oxygen bleach**, etc. in the bleaching process (see Section 5.1.8).

BAT 19. The technique is to inhibit the generation of or minimise the release of harmful by-products by minimising the use of auxiliaries in the bleaching process (see Section 5.1.9).

BAT 20. The technique is to improve the efficiency of effluent treatment by recovering alkali from the mercerizing process (see Section 5.1.10).

6.2.2 Wool

BAT 21. In order to manage wastewater generated in wool scouring facilities, the techniques given below are used.

- Treatment of wastewater from wool scouring facilities (see Section 5.1.12)
- Treatment of wastewater using equipment for removing total suspended solids and recovering wax (see Section 5.1.1)

BAT 22. In order to minimise energy consumed in wool scouring facilities, the techniques given below are used (see Section 5.1.12).

- Installing covers over scouring bowls
- Minimising water content in wool before it goes into a dryer
- Increasing temperatures in scouring bowls
- Retrofitting heat recovery units to dryers

BAT 23. In order to prevent any possible contamination of groundwater arising from diffuse pollution and accidents and minimise fugitive losses during the wool scouring process, the technique is to use organic solvent (not miscible with water) (see Section 5.1.3).

6.2.3 Others

BAT 24. The technique is to recover thickening agents used in the weaving process for recycling (see Section 5.1.4).

BAT 25. The technique is to remove thickening agents using the oxidative route (see Section 5.1.5).

BAT 26. The technique is to reduce the use of water and energy by using fully closed loop facilities when washing textile with organic solvent during pre-treatment (see Section 5.1.13).

6.2.4 ETP

BAT for pre-treatments in plants include **activated sludge** using low F/M ratios (applied to operations discharging recalcitrant substances), combined biological, physical and chemical treatments of mixed wastewater, anaerobic treatment of residual dye (applied to printing operations), and the use of Fenton oxidation.

Dyeing process

In the dyeing process, techniques are used to reduce the release of pollutants by improving dyeing techniques and, in some cases, categorised according to the unprocessed material of textiles. The country specific information about specific BAT on dyeing process provided in the BREFs is listed in Table 24:

Table 24. Dyeing process-related BAT specified in textiles manufacturing

BAT Reference Document	KEI-specific BAT for Dyeing
European Union	The revised EU-BREF categories the dyeing techniques according to general BAT practices and to the type of the base material of the textile. These BAT are: • **Generic dyeing techniques:** o Selection of vat dyes o pH-controlled batch dyeing o Optimised removal of unfixed dyestuff in reactive dyeing o Dyeing with levelling agents made from recycled vegetable oil o Minimisation of dye liquor losses in pad dyeing techniques o Optimisation of batch dyeing o Reuse/recycling of spent baths in batch dyeing processes o Spray dyeing o Recovery and reuse of brines and/or salts from dyeing • **Cellulose:** o Minimised use of sulphur-based reducing agents o Selection of vat dyes o Use of high-fixation polyfunctional reactive dyes o Cationisation of cotton o Cold pad-batch dyeing o Optimised rinsing of cotton dyed with reactive dyes o Use of concentrated alkali solution in cold pad-batch reactive dyeing o Steam fixation of reactive dyes • **Wool:** o Chromium-free dyeing o Optimised metal-complex dyeing o Minimised use of chromates o Optimised reactive dyeing

BAT Reference Document	KEI-specific BAT for Dyeing
	○ Use of liposomes in acid dyeing of wool • **Polyester:** ○ Match dyeing without dyestuff carriers ○ Optimised use of dyestuff carriers in batch dyeing ○ **Optimised desorption of unfixed dye in batch dyeing** ○ Supercritical CO_2 dyeing
VITO	There are no distinctions made regarding the dyeing process in the VITO-BREF.
India	• Reuse of dye bath
Korea	The K-BREF discusses a number of BAT on *dip dyeing* which are grouped according to the base material of the textiles under production. • **Cotton and cellulose** ○ The technique is to save energy, water, chemicals, etc. by shortening the processes of dyeing with vat dyes ○ The technique is to reduce the release of pollutants by replacing sulphur dyes during the cotton dyeing process ○ The technique is to reduce the release of pollutants by improving cleaning techniques during the dyeing process. – In reactive dyeing, after-soaping with enzymes following dyeing – Improvement in the after-cleaning process of cotton dyeing using reactive dyes ○ The technique is to reduce the release of pollutants by improving dyeing techniques. – Application of alternatives to continuous and semi-continuous processes of **reactive dyeing for cellulose fibers** – Application **of pH-controlled dyeing techniques** ○ The technique is to reduce the release of pollutants by applying alternatives to dyes, chemicals, etc. used in dyeing. – Change in fixation methods for cold pad batch (CPB) dyeing – Reactive dyeing of cellulose fibers using high-fixation dyes – Dip dyeing using low-salt reactive dyes – Application of neutral reactive dyes (thermo-reactive dyes) ○ The technique is to reduce the use of chemicals by stabilizing pH in the bath where dyeing reaction occurs, thereby lowering the rate of faulty dyeing and improving reproducibility • **Polyester** ○ The technique is to reduce the release of chemicals by removing unpenetrated dyes on the textile surface in the after-treatment process for polyester textile dyeing using disperse dyes • **Wool**

BAT Reference Document	KEI-specific BAT for Dyeing
	○ The technique is to reduce pollutants (metals) released to the water environment by improving processes among wool dyeing techniques. – Use of ultra-low-chrome and after-chrome methods for wool – Application of chromium-free dyeing of wool ○ The technique is to increase energy efficiency and reduce the release of pollutants by using liposome as an auxiliary during wool dyeing • **Others** ○ The technique is to choose and use environmentally-friendly chemicals at the stage of dye formulation ○ The technique is to minimise losses of dye liquid and reduce the release of pollutants by improving pad dyeing techniques ○ **The technique is to reduce the release of pollutants through the optimisation, of dyeing equipment or introduction of more efficient dyeing equipment.** – Optimisation of equipment in batch dyeing – Application of improved winch dyeing machines – Introduction of airflow dyeing machines – Introduction of soft-flow dyeing machines – Introduction of single-rope dyeing machines – Application of low-liquor-ratio dyeing machines – Application of atmospheric- and high-pressure dyeing machines – Introduction of water setting machines ○ The technique is to decrease the generation of pollutants and wastewater and reduce the use of energy by applying the cold pad batch method to knitted fabric dyeing.
United States	Control technologies are not specified in the US regulations. Best available technology used as the basis for standards in regulation are noted in supporting decision documents referenced in the US-technology based performance standards. Other guidance documents and resources describe available technology and mitigation approaches.
World Bank	The EHS Guideline provided a list of BAT related to the dyeing process, that are: • Use of automatic systems for dosing and dispensing dyes • Use of continuous and semi-continuous dyeing processes • Use of machinery with automatic controllers of temperature • Optimisation of machine size • Implementation of mechanical liquor extraction • Adoption of optimized process cycles • Substitution of conventional dye carriers and finishing agents with less toxic compounds • Use of non–carrier dye-able polyester fibres • Conduct dyeing in **high temperature conditions**

BAT Reference Document	KEI-specific BAT for Dyeing
	• Replacement of sodium dithionite • Replacement of conventional powder and liquid sulphur dyes • Use of disperse dyes • Substitution of chrome dyes with reactive dyes • Adoption of low-salt dyeing techniques • Adoption of a pH-controlled drying process

Releases to water

In addition to the processes used in the textiles production, the KEIs related to concerns about water were included in this comparative analysis of BREFs submitted. There are various BAT identified by each BREF to reduce and control releases of pollutants into water. The country specific information is summarised in Table 25:

Table 25. BAT used for the releases to water in textiles manufacturing

BAT Reference Document	KEI-specific BAT
European Union	The EU-BREF mentions the following BAT for releases to water, and the document also includes information on their applicability as another BAT (BAT 19) and the integrated strategy for waste water management and treatment (BAT 18) • Pretreat (separately collected) waste water streams and pastes (e.g. printing and coating) containing high loads of pollutants that cannot be treated adequately by biological treatment (BAT 19) • Equalisation • Neutralisation • Physical separation • **Adsorption** • Precipitation • Chemical oxidation • **Chemical reduction** • Evaporation • **Activated sludge process** • Membrane bioreactor • Anaerobic pre-treatment • Nitrification/denitrification • **Coagulation and flocculation** • Sedimentation • **Filtration** • Flotation
VITO	The VITO-BREF includes the following BAT:

BAT Reference Document	KEI-specific BAT
	• Characterise released wastewater or liquid waste flows in the interest of re-use, treatment and/or disposal • Collect exhausted process baths and dispose via a qualified processing company • Recuperate maximum amount of chemical surpluses • Wherever possible, remove solid residues dry • Dispose of rinse waters from process baths via a qualified processing company • **Appropriately treat industrial wastewater by implementing a combination of suitable waste purification techniques** • Use environment-friendly alternative chemicals The VITO-BREF also provided descriptions of primary, secondary and tertiary purifications of wastewater. The aim of primary purification is to physically remove solids and sedimentary matter from the wastewater. Secondary purification primarily involves the removal of organic substances and nutrients (e.g. nitrogen and phosphorous. The aim of tertiary purification is to thoroughly purify the wastewater (e.g. phosphorous) or to remove components from the wastewater that are difficult to break down. Tertiary purification techniques are not only implemented as effluent polishing after main biological purification, but are also used for pre-treating (concentrated) partial flows.
India	The COINDs included the following BAT: • Screening • Oil & Grease Removal • Equalisation-cum-Neutralisation Tanks • Coagulant Dosing • **Clarifloculation** • Aerated Lagoon • Aeration Tank • Secondary Clarifier • Sludge Thickener • Vacuum Filter or Sludge Drying Beds

Korea	The K-BREF includes the BAT below:
	• Treatment of mixed wastewater for water recycling
	• Wastewater recycling using membrane filtration
	• In order to reduce the concentration of water pollutants before discharging wastewater generated from textile dyeing and finishing processes, the techniques given below can be applied alone or in combination.
	    ○ Settlement
	    ○ Air flotation
	    ○ **Filtration**
	    ○ **Adsorption**

BAT Reference Document	KEI-specific BAT
	○ **Aerobic treatment** • In order to reduce the discharge of water pollutants by recycling wastewater generated, the wastewater treatment techniques given below can be applied. ○ Treatment of mixed wastewater for water recycling ○ Wastewater recycling using membrane filtration ○ Treatment and recovery of wastewater containing pigment printing pastes (applied to printing operations)
United States	The development document for Textile Mill Effluent Guidelines describes a number of in-plant process controls and end-of-pipe treatment techniques commonly used in textile mills, as well as the selection of techniques used to set discharge limits. Discharge limits for textile mills are derived from pollution control attainable through a combination of **biological treatment**, multi-media **filtration**, and **chemical coagulation/clarification.**
World Bank	The EHS Guideline listed the following three BAT: • Selection of water soluble and biodegradable lubricants • Use of organic solvent washing for non-water soluble lubricants • Minimising residual liquor

Water Consumption

In addition to the processes used in the textile manufacturing, the KEIs related to water consumption were included in this comparative analysis of BREFs submitted. The country specific information is listed in Table 26:

Table 26. BAT used in the optimisation of water consumption specified in textiles manufacturing

BAT Reference Document	KEI-specific BAT
European Union	• Water management plan and water audits • Production optimisation • Processes using little or no water • Optimisation of the amount of process liquor used • Optimised cleaning of the equipment • Optimised batch processing, washing and rinsing of textile material • Optimised continuous processing, washing and rinsing of textile materials • Water reuse and/or recycling • Reuse of processed liquor • Segregation of polluted and unpolluted water streams
VITO	• Optimise production planning • Empty chemical packaging properly dry, do not rinse with water, store in an appropriate manner and dispose via a qualified processing company or via the chemicals supplier • Use dry cleaning method on process baths before rinsing them with water

BAT Reference Document	KEI-specific BAT
	• Rinse process baths with a minimum amount of water • Keep the amount of rinse water in cleaning activities to a minimum • Wherever possible, re-use rinse waters from process baths in the production process
India	-

Korea	The K-BREF provides a list of BAT used in the control of water consumption, which are:
	• In order to optimize water consumption in textile operations by controlling and reducing or recycling water consumption, the techniques given below can be applied.
	  ○ Optimisation of water consumption in textile operations
	  ○ Integration of processes
	  ○ Adjustment of inputs
	  ○ Ensuring storage capacity prepared for malfunction
	• The technique is to reduce the amount of discharged wastewater by reusing or recycling water in batch dyeing processes. Use of flow control devices
	  ○ **Reuse of dye solutions**
	• The technique is to reduce the use of water and energy by improving textile cleaning techniques in dyeing processes
	  ○ Water and energy conservation in batch washing and rinsing
	  ○ Water and energy conservation in continuous cleaning and rinsing
	  ○ Application of automated rinsing programs

United States	The BREF document indicates that discharge limits are linked to mass of textile produced. Water conservation practices make it easier to achieve discharge limits. Practices for conserving water are described in guidance documents (US EPA, 1984[103]).
World Bank	The EHS Guideline listed the following BAT: • **Reuse of dyebaths;** • Adoption of continuous horizontal washers and vertical spray washers or vertical, double-laced washers; • Adoption of countercurrent washing (e.g. reuse the least contaminated water from the final wash for the next-to-last wash); • Use of water flow–control devices to ensure that water only flows to a process when needed; • Reuse of preparation and finishing water

Chemicals substitution

In addition to the processes used in the textiles manufacturing, this KEI was targeted to collect information on alternative solutions to the chemicals used in the textiles that are considered harmful.

There are various alternative approaches provided to the use of hazardous chemicals in the textile manufacturing processes. The country specific information is listed in Table 27.

Table 27. BAT used for Chemicals substitution specified in textiles manufacturing

BAT Reference Document	KEI-specific BAT
European Union	• Implementation of a chemicals management system • Implementation of a chemical inventory • Reduction of the need for process chemicals • Treatment of textile materials with enzymes • Automatic systems for preparation and dosing of process chemicals and process liquors • Optimisation of the quantity of process chemicals used • Reuse of process liquor • **Recovery and use of leftover process chemicals** • Substitution of poorly biodegradable substances • Reduction of the use of complexing agents
VITO	• Make agreements with suppliers of purchased tissues and yarns concerning the chemicals used, and their quantities, on the tissues and yarns • Make agreements with suppliers of formulations concerning the composition of chemicals • **Make agreements with suppliers of formulations concerning the return of left-over chemical** • Use environment-friendly alternative chemicals for finishing activities wherever possible to replace Deca-BDE, HBCD, PFOS and PFOA, NP/NPE, PAH • Modify and/or optimise the production process • Store waste residues containing Deca-BDE, HBCD, Sb2O3 and/or PFOS/PFOA in an appropriate manner and dispose via a qualified processing company.
India	--
Korea	• Alternatives to use of harmful surfactant • Use of biodegradable sequestering agents • The use of antifoaming agents with improved environmental performance • Careful selection and control of raw materials • Minimising the leakage of chemicals • Monitoring the movement of chemical materials • Automation of solution preparation systems • The choice of fuel assemblies used in production • The technique is to avoid or minimise the occurrence of any surplus chemical liquor by automatically mixing and supplying chemicals used for processes (see Section 4.1.3).

	• The technique is to predict substances potentially emitted to the air during processes by introducing the concept of emission factors, and minimise their emissions (see Section 4.3.1). • The technique is to substitute and use chemical products developed with environmentally favourable components. o Use of alternatives to hazardous surfactants o Use of biodegradable sequestering agents • Use of antifoaming agents with better environmental performance
United States	As noted in previous KEIs, techniques are not specified in the effluent guideline rule. Supporting documents and resources describe alternative chemicals to reduce pollution (US EPA, 2015[104]). Alternate chemical solutions are described as potential pollution prevention methods.
World Bank	• Use of non-biodegradable and bio-eliminable tensides as a BAT for chemicals substitution.

Sub-Chapter Conclusion

The textiles manufacturing industry uses multiple processes in the production of fabrics. The BAT adopted for the two processes of the textiles manufacture, namely, pre-treatment with three sub-processes (desizing, bleaching and mercerizing) and dyeing were selected as the main KEIs for the European Union (EU), Flanders (Belgium), India, South Korea, United States and World bank group. The fundamental aim of this chapter was to gather the BAT practices employed by several countries for the two processes, along with BAT used to prevent or control releases to water, water consumption and chemicals substitution given their importance in the functioning of the sector. Summaries of two processes and common BAT identified for the selected KEIs are provided in the section 0.

The general BAT conditions are existing general practices carried out by the regulatory institutions that can be considered as good environmental practices for all industrial sectors. The EU-BREF, VITO-BREF, K-BREF, Effluence Guidance from the US and EHS Guideline included sections on the general BAT practices for the textile manufacturing sector. The COINDs only informed about the technical information regarding the BAT used in the sector. In each BREF, there were a mixture of approaches considered; if the BREF included technical approaches, generally, both pre-treatment and dyeing processes were also covered.

Proper pre-treatment of textiles is essential for quality and reproducible results in all subsequent processes, such as dyeing. There are different BAT specified for each sub-process of pre-treatment included for removing impurities from raw materials (e.g. fibres, yarn, cotton) in the BREFs submitted. The BAT reported for each sub-process from the BREFs submitted showed mostly different practices, which made the comparative analyses to identify commonalities difficult. The desizing process had a higher number of different BAT noted compared to bleaching and mercerizing. Regardless, the recovery and reuse of water-soluble sizing chemicals used in the sub-process was a common BAT identified. For bleaching sub-process, two common BAT noted were from the EU-BREF and EHS Guideline which were the use of chlorine-free bleaching or reduced use of it, and the use of hydrogen peroxide as bleaching agent. Use of chlorine-based bleaches may produce organic halogens and lead to significant concentrations of absorbable organic halogens (AOX), such as trichloromethane (chloroform), in the wastewater. For mercerisation, the recovery of caustic soda used for the process itself was the commonly reported BAT.

Dyeing processes lead to the discharge of many chemicals, prominently metals and pigments, and residual pollutants remaining on the fibre (e.g. pesticides residues on wool) (Cobbing and Ruffinengo, 2013[105]). Among the BREFs analysed, there were similarities in BAT used and two BREFs (i.e. EU-BREF and K-BREF) categorised their BAT approaches according to the base material, such as cotton and cellulose.

Chemicals used in the early stages of production are more likely to be consumed and washed away into wastewater effluents than the chemicals used in the following processes of treating the textiles, such as dyeing and finishing processes (KEMI, 2013[106]). Therefore, prevention and control of releases of chemicals to wastewater was another KEI assessed in this report. Among the BREFs, broadly similar BAT on releases to water were specified, such as coagulation /flocculation, adsorption and filtration of the wastewater.

The textiles manufacturing sector is highly dependent on using water at many stages of production and heavily relies on the chemicals, such as dyes, to deliver the intended textile products. Water consumption was also included as a KEI for this report. There were various BAT identified in each BREF to reduce and control water consumption during the textile manufacturing. All BREFs targeted the optimisation of water consumption by effective planning and reuse of water, for example, by reusing the bathwater or dyewater. However, reusing water or dyebath is limited by the build-up of impurities from several sources, such as the textile material itself or chemical components used in the processes. Also, there were different BAT used in the treatment of wastewater in the BREFs that depended on the pollutant itself, such as the use of filtration for solids removal.

In addition to the removal of the chemicals from wastewater effluents, all BREFs (except the COINDs) included BAT on substituting harmful chemicals with more environmentally-friendly or biodegradable alternatives as well as learning more information about the chemicals used in the processes from providers as common BAT in the textile production.

In general, textiles manufacturing is a complex industry involving various production processes and many practices employed by the installations. Therefore, the nature of the sector itself made this comparative analysis and identification of similar or same BAT a major challenge in the BREFs submitted. It may also be assumed that, due to the various approaches used within the sector, developing a comprehensive sectoral BREF with BAT addressing all KEIs possible would be a challenge for the responsible regulatory bodies as well.

4 Quantitative BAT

Section introduction

This section compares the *emission standards* and *other quantitative performance standards* that are specified as BAT-associated for the selected key environmental issues (KEIs) in the BREFs submitted for the three focus sectors studied in this project. The emission and/or performance levels of the following KEIs agreed for each sector were collected:

- Thermal power plants: BREFs were categorised according to installation fuel types; coal and gas-fired installations. Air emissions (or performance) levels of *Particulate matter (PM- without distinguishing the size of the PM), oxides of sulphur (SO_x) and nitrogen (NO_x), mercury (Hg) and carbon dioxide (CO_2)* for the coal-fired plants, and, the *oxides of nitrogen (NO_x)* and *carbon dioxide (CO_2)* were extracted from the eight BREFs submitted on TPP sector. In addition to these emissions, the *energy efficiency* performance levels were collected to remark the practices carried out in those countries.
- Cement production: Air emissions (or performance) levels of *Particulate matter (PM- without distinguishing the size of the PM), oxides of sulphur (SO_x) and nitrogen (NO_x), mercury (Hg) and carbon dioxide (CO_2)* were gathered for this sector
- Textile manufacturing: BREFs were considered for the two *processes* used in the production of textiles: pre-treatment and dyeing. Additional KEIs agreed were *releases to water (pH, AOX, BOD, COD and metals)* and *water consumption*. The OECD Secretariat was not able to include finishing process in this report however, noted that finishing process has a significant effect on the emissions and overall pollution due to the variety and high amount of chemical additives used in the process[24].

Each sector is dealt with in turn, presenting and considering the following:

- Emission and performance levels specified for the identified KEIs
- Operational conditions, whether there are specific allowances made for the standard and non-standard operating conditions, such as during their start-up or shut down phases
- Associated conditions, definitions, and qualifying comments, e.g. averaging periods[25]

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[24] EU-BAT conclusions include these emissions as long as they are directly associated and technically connected with the main activity pre-treatment and dying and carried out at the same site.

[25] US EPA defines averaging time as the period over which data are averaged and used to verify proper operation of the pollution control approach (or compliance) with the emissions limitation or standard (US EPA, 2021[115]).

Thermal Power Plant

This section compares the emission limits and other quantitative performance standards for the selected KEIs from the BREFs submitted on the TPP sector.

Emission standards for KEIs Control

When referring to the quantitative emission standards or values of selected KEIs collected for the TPP sector, there are significant differences in terms of the measurements conditions, such as the averaging period of the continuous measurements (i.e. daily, monthly, yearly, hourly, half-hourly, etc.), the sampling or analysis methods, the correction factor for the reference oxygen level (vol.%), the standardization for the humidity, temperature and pressure, the consideration of measurement uncertainties, the calibration and control of the functionality of measurement devices, etc. The various measurement conditions result in substantial differences in the emission values. For example, by using the formula of the correction factor for the reference oxygen content (O_2) in the EU, for coal-fired combustion plants using 6 vol.% O_2 as reference oxygen level and assume a measured oxygen level of 9 vol.% O_2, a measured dust concentration of 30 mg/m³ at 9% O_2 would be adjusted to 37.5 mg/m³ at the 6% reference O_2-level. Some of the above measurement conditions were included in the tables indicating emission values for the selected KEIs, however not all were available in the BREFs submitted. The varying approaches of dealing with measurement uncertainties for continuous monitoring may result to up to 25% difference between the recorded values. The country-specific information is listed below:

People's Republic of China

Techniques and emission levels were specified in the GATPPC, however, there were other relevant supporting standards to the GATPPC for TPP sector, some of which are:

- Emission Standard of Air Pollutants for Thermal Power Plants (GB 13223)
- Technical specification for flue gas de-nitration engineering of thermal power plant selective catalytic reduction method (HJ 562)
- Selective non-catalytic reduction method (HJ 563)
- Technical specifications for operation and management of flue gas treatment facilities in thermal power plants (HJ 2040)
- Electric bag composite dust collector for coal-fired power plant (JB/T 11829)

The Emission Standard of Air Pollutants for TPPs was the key document providing the emission levels to the BAT used, which stipulated the emission limit of the pollutants and monitoring requirements in the sector. The other four supporting documents were the technical specifications on specific flue gas treatment techniques or facilities, which explained the technical requirements in design, construction, acceptance, operation and maintenance process. The HJ 562, HJ 563 and JB / T11829 documents provided the technical requirements of SCR, SNCR, and electrostatic-fabric integrated precipitator, respectively. On the other hand, the HJ 2040 document included the operation and maintenance management requirements of all the flue gas governance facilities in the TPP.

European Union

The EU-BAT conclusions defined legally binding BAT associated emission levels (BAT-AELs) for all environmental media, including the BAT-AELs for air emissions that have to be complied together with requirements of Chapter III "Special Provisions for Combustion Plants" of the IED and its associated Annex V "Technical provisions relating to combustion plants" setting binding minimum emission standards and including compliance rules and provisions for monitoring (EU, 2010[107]). Until the environmental permits are updated in line with the EU-BAT conclusions (EIPPCB, 2017[7]), the emission limit values are set out in Annex V to the IED. The applicable values are determined in relation to the total rated thermal input of the entire combustion plant.

India

The MINAS document specified the emission standards.

Japan

The BAT table set out efficiency target requirements only.

Korea

The K-BREF document included BAT-AELs for PM, SO_x and NO_x.

United States

The national legislation specified the emission standards.

World Bank

The EHS Guidelines for any sector are considered as guidance for the World Bank members.

Operational Conditions

Different BAT for installations may be set according to the installation operating regime and to make allowances for standard and non-standard operating conditions, such as during their start-up or shut down phases. Load factors differentiation takes account of the lower mass emissions from plants with lower operating hours, and BREFs may also set out the operating hour constraints applicable. In the cases where non-standard operational standards are applied, some interpretation is required to define these conditions as they will vary from sector to sector.

The country-specific information on operating regimes of installations covered in the BREFs submitted is provided below.

European Union

The BAT-AELs for emissions to air and BAT-AEELs apply to all operation regimes[26], but vary

- for power plants operating above 1500 h/y, they are fully applicable,
- for power plants operating below 1500 h/y, some of BAT-AELs are slightly higher or have indicative (not binding) character
- for power plants operating below 500 h/y, most of BAT-AELs have indicative character.

Generally, the emission limit values set in permits by the competent authorities refer to normal operating conditions (IED Art. 15.3). IED Art 14.1(f) also stated that measures relating to conditions other than normal operating conditions such as start-up and shut-down operations, leaks, malfunctions, momentary stoppages and definitive cessation of operations shall be included in the permits.

26 Decision 2012/249/EU concerning the determination of start-up and shut-down periods: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32012D0249&from=EN

In the EU BREF for LCP, the issue of emissions during “non-standard operating periods” is addressed through the introduction of provisions for “Other than normal operating conditions” (OTNOC) in BAT 10 and BAT 11. The IED (in Chapter III and Annex V) contains minimum requirements for combustion plants that fall under the scope of Chapter III of the IED.

United States

The emission standards must be achieved during all periods of operation unless there is a separate defined standard in the permit. For the rule limiting HAP emissions, there are “work practice standards” during periods of start-up and shutdown. As for the work practices, in this final rule, the EPA requires sources to operate using either natural gas or distillate oil for ignition during start-up. The EPA also requires sources to vent emissions to the main stack(s) and operate all control devices necessary to meet the normal operating standards under this final rule (with the exception of dry scrubbers and SCRs) when coal, solid oil-derived fuel, or residual oil is fired in the boiler during start-up or shutdown. It is the responsibility of the operators of EGUs to start their dry scrubber and SCR systems appropriately to comply with relevant standards applicable during normal operation.

The EPA carefully considered fuels and potential operational constraints of air pollution control devices (APCDs) when designing its work practices for periods of start-up and shutdown. The EPA notes that there is no technical barrier to burning natural gas or distillate oil for longer portions of start-up or shutdown periods, if needed, at a boiler, and the HAP emission reduction benefits warrant additional utilization of such fuels until the temperature and stack emissions pressure is sufficient to engage the APCDs. The EPA is aware that SCR systems with ammonia injection need to be operated within a prescribed and relatively narrow temperature window to provide NO_X reductions. Further, the EPA is aware that dry scrubbers also need to be operated close to flue gas saturation temperature. Because these devices have specific temperature requirements for proper operation, the EPA notes in its work practices that it is the responsibility of the operators of EGUs to start their SCR and dry scrubber systems appropriately to comply with relevant standards applicable during normal operation.

World Bank

The EHS Guideline indicated that emissions limits reported are achievable under normal operating conditions.

Coal-fired power production

The tables below provide a summary of the quantitative emission standards/values set out in the BREFs submitted on TPP for the selected KEIs:

Particulate Matter

Table 28 shows the significant AEL variations between different BREFs, even for new plant standards. Comparing the values in a BREF, new plant standards are often, but not always, (exceptions: China and to some extent also the EU BAT conclusions) dramatically lower than for the older/existing plants. It is also observed that there was some degree of reduction in AELs at larger capacity installations, which reflected the usual economy of scale economics.

Table 28. BAT-AEL specified for PM for new and/or existing coal-fired TPP

BREF	BAT AEL specified		Averaging periods	Further details
	New Plant	Existing Plant		
China	30 mg/m³ 20 mg/m³ (Special AELs) 5 mg/m³ (Ultra low emission limit)			No new / existing plants distinction was made in the GATPPC,. Since January 2012, new enterprises implemented *Emission standard of air pollutants for thermal power plants (GB 13223-2011)*, from July 2014, existing enterprises implemented GB 13223-2011. • All sizes > 100 MW • When the concentration is less than or equal to 20 mg/m³, the HJ 836-2017 is applied. The standard specifies that the sample should be ensured that the weight gain of each sample is not less than 1 mg, or the sample volume is not less than 1 m³. All values are presented under standard conditions: dry gas at a temperature of 273,15 K, and a pressure of 101,3 kPa and a reference oxygen level of 6 Vol.% O_2 (coal boiler), 3 Vol.% O_2 (fuel boiler and gas boiler).
European Union	2-5 mg/m³ all sizes	2 – 18 mg/m³ (ranges for different size plant)		Larger existing plant lower ranges e.g. 2 – 10 > 600 MW AELs given left are yearly averages Daily average ranges set according to plant size within overall range of 4 – 22 mg/m³ Up to 14 - 28 mg/m³ yearly average for plants operating before 7 Jan 2014 (size dependent) All values are presented under standard conditions: dry gas at a temperature of 273,15 K, and a pressure of 101,3 kPa and a reference oxygen level of 6 vol.% O_2.
India	30 mg/m³	2003 to 2016: 50 mg/Nm³ < 2003: 100 mg/Nm³	No averaging period is specified as the standards have to be complied all the time.	New plants from 1 Jan 2017 PM values corrected to 6 % vol.O_2 on a dry basis
Japan				Only efficiency levels in supplied BAT tables

BREF	BAT AEL specified		Averaging periods	Further details
	New Plant	Existing Plant		
Korea	(50-100 MW) 3 – 15 mg/m³ (100 MW) 2- 15 mg/m³		3 years	
United States	15 mg/m³	50 mg/m³	Filterable PM, 30 operating day rolling average; quarterly stack testing or PM CEMS or PM CPMS	Steam-generating thermal power plants that are > 25 MW and that supply greater than one-third of their potential electrical output to the national grid.
World bank	(<1000MW) 30 – 50 mg/m³ (>1000MW) 25 – 40 mg/m³			New plants only

Oxides of Sulphur (SO_x)

Table 29 summarises BAT-AELs specified for SO_x for new and/or existing TPP:

Table 29. BAT-AEL specified for SOx for new and/or existing coal-fired TPP

BREF	BAT AEL specified		Averaging periods	Further details
	New Plant	Existing Plant		
China	200 mg/m³ (coal boiler in Guangxi, Chongqing, Sichuan and Guizhou province) 100 mg/m³ (coal boiler in addition to Guangxi, Chongqing, Sichuan Province and Guizhou Province)	200 mg/m³		• No new / existing plants distinction was made in the GATPPC. Since January 2012, new enterprises implemented *Emission standard of air pollutants for thermal power plants (GB 13223-2011)*, from July 2014, existing enterprises implemented GB 13223-2011. • All sizes > 100 MW

	50 mg/m³（Special AELs） 35 mg/m³ (Ultra low emission limit)			• All values are presented under standard conditions: dry gas at a temperature of 273,15 K, and a pressure of 101,3 kPa and a reference oxygen level of 6 Vol.% O_2 (coal boiler), 3 Vol.% O_2 (oil boiler and gas boiler).
European Union	(50 – 100 MW): 150 - 200 mg/m³	(50 – 100 MW): 100 - 360 mg/m³		AELs left are annual averages Daily average AEL ranges also specified Some higher AELs also noted for plants with lower operating hours (max 500h or 1500h), in operation before 2014 and for FBC.
	(100 – 300 MW): 80 – 150 mg/m³	(100 – 300 MW): 95 – 200 mg/m³		
	>300 MW: 10 – 75 mg/m³	>300 MW: 10 - 130 mg/m³		
India	100 mg/m³	(<500 MW) 600 mg/Nm³ (>500 MW) 200 mg/Nm³	No averaging period is specified as the standards have to be complied all the time.	New plants are considered from 1 Jan 2017. SO_2 values corrected to 6 % vol. O_2 on dry basis.
Japan			Only efficiency levels in supplied BAT tables	
Korea	(50 - 100 MW): 8 – 80 mg/m³ (>100 MW): 10 – 80 mg/m³		3 years	
United States	155 mg/m³	325 mg/m³	30-day rolling average basis; SO_2 CEMS	Existing limit is in lieu of meeting a hydrochloric acid (HCl) standard
World bank	(<600 MW) 400 – 1000 mg/m³ (>600 MW) 200 – 600 mg/m³			

Oxides of Nitrogen (NO_x)

Table 30 summarises BAT-AELs specified for NO_x for new and/or existing TPP:

Table 30. BAT-AEL specified for NOx for new and/or existing coal-fired TPP

BREF	BAT AEL specified		Averaging periods	Further details
	New Plant	Existing Plant		
China	100 mg/m³			• No new / existing plants distinction was made in the GATPPC.Since January 2012, new enterprises

	100 mg/m^3 (Special AELs) 50 mg/m^3 (Ultra low emission limit)			implemented *Emission standard of air pollutants for thermal power plants (GB 13223-2011*), from July 2014, existing enterprises implemented GB 13223-2011. • All sizes > 100 MW • All values are presented under standard conditions: dry gas at a temperature of 273,15 K and a pressure of 101,3 kPa, and a reference oxygen level of 6 Vol.% O_2 (coal boiler), 3 Vol.% O_2 (oil boiler and gas boiler).
European Union	50 – 100 MW 100 - 150 mg/m^3 100 – 300 MW 50 - 100 mg/m^3 >300 MW 65 – 85 mg/m^3	50 – 100 MW 100 - 270 mg/m^3 100 – 300 MW 100 - 180 mg/m^3 >300 MW 65 - 150 mg/m^3		AELs left are annual averages Daily average AEL ranges also specified Some higher AELs also noted for plants with certain lower operating hours, in operation before 2014 and for certain fuel and technology variants e.g. lignite, coal, FBC, PC, SCR, SNCR use
India	100 mg/Nm^3	Before 31 Dec 2003: 600 mg/Nm^3 2004 – 31 Dec 2016: 450 mg/Nm^3 -- Revised to 450 mg/Nm^3	No averaging period is specified as the standards have to be complied all the time.	New plants are considered from 1 Jan 2017 NO_x values corrected to 6 % vol. O_2 on dry basis
Japan				Only efficiency levels in supplied BAT tables
Korea	12 – 70 mg/m^3		3 years	
United States	98 mg/m^3	No uniform national standard for NO_x; Plant specific	30-boiler operating day rolling average basis.	New - 77 Fed Reg 9304 and 40 CFR 60.44Da [27]
World bank	200 – 500 mg/m^3			

[27] US Federal Code of Regulations, Subpart Da - Standards of Performance for Electric Utility Steam Generating Units

Mercury (Hg)

Table 31 summarises the BAT-AEL specified for Hg for new and/or existing TPP:

Table 31. BAT-AEL specified for Hg for new and/or existing coal-fired TPP

BREF	BAT AEL specified (µg/m³)		Averaging periods	Further details/Comments
	New Plant	***Existing Plant***		
China	30 µg/m³			• No new / existing plants distinction are made in the GATPPC. Since January 2012, new enterprises implemented *Emission standard of air pollutants for thermal power plants (GB 13223-2011)*, from July 2014, existing enterprises implemented GB 13223-2011. • All sizes > 100 MW • Coal-fired power plant dust removal, desulphurisation and denitration and other environmental protection facilities are obvious to mercury removal effect, and most power plants can meet the standard. For individual burning high mercury coals, mercury emissions exceeds the standard power plant, single-necked technology can be used. • All values are presented under standard conditions: dry gas at a temperature of 273,15 K, and a pressure of 101,3 kPa and a reference oxygen level of 6 Vol.% O_2 (coal boiler), 3 Vol.% O_2 (oil boiler and gas boiler).
European Union[28]	<300 MW: Coal 1-3 µg/m³ Lignite 1-5 µg/m³ >300 MW: Coal 1-2 µg/m³	<300 MW: Coal 1-9 µg/m³ Lignite 1-10 µg/m³ >300 MW: Coal 1-4 µg/m³ Lignite 1-7 µg/m³		Existing plants are pre-2014

[28] Yearly average or average of samples obtained during one year.

BREF	BAT AEL specified (µg/m³)		Averaging periods	Further details/Comments
	New Plant	*Existing Plant*		
	Lignite 1-4 µg/m³			
India	30 µg/Nm³	> 500 MW 30 µg/Nm³	No averaging period is specified as the standards have to be complied all the time.	New plants include all plant sizes Existing plants are only those installed before 2003 and capacity >500 MW.
Japan			Only efficiency levels in supplied BAT tables	
Korea			--	
United States	0.5 µg/m³	2.0 µg/m³, non-lignite 6.5 µg/m³, lignite	30- boiler operating day rolling average	40 CFR 63 UUUUU [29]Table 1 and 78 Fed Reg 24073 Conversion from lb/MMBtu (pounds per million Btu) to u/m³ (micrograms per cubic meter), and therefore, may not reflect an exact conversion.
World bank			--.	

Carbon Dioxide (CO_2)

Table 32 below describes the BAT-AELs specified for CO_2 for new and/or existing TPP. The EHS Guideline provided a table of "typical" CO_2 emissions and efficiency performance for new thermal power plants, including coal, oil and gas-fired plants at a variety of sizes – see Information Box 2.

Table 32. BAT-AEL specified for CO_2 for new and/or existing coal-fired TPP

BREF	BAT AEL specified		Further details
	New Plant	Existing Plant	
China			--
European Union			CO_2 emissions are noted in the BREF
India			--

[29] National Emission Standards for Hazardous Air Pollutants: Coal- and Oil-Fired Electric Utility Steam Generating Units

Japan			--
Korea			CO_2 emissions are noted throughout the K-BREF, but the available translation does not presently allow a full review.
United States			--
World bank	676 – 934 g/KWh (various fuel types and technologies)		Table 4 set out comprehensive emission data for a variety of situations for new installations performances

Energy Efficiency

Table 33 below summarises the BAT-AEL specified for energy efficiency for new and/or existing TPP. The Information Box 2 presents the CO_2 emissions and efficiency performance levels for new installations from the EHS Guideline.

Table 33. BAT-AEL specified for Energy Efficiency for new and/or existing coal-fired TPP

BREF	BAT AEL specified		Comments
	New Plant	Existing Plant	
China			--
European Union	<1000 MW: 36.5 – 41.5 Coal* 36.5 – 40 Lignite** >1000 MW: 45-46 coal 42-44 lignite ***	<1000 MW: 32.5-41.5 (coal) 31.5-39.5 (lignite) >1000 MW: 32.5-41.5	* up to 46 % in the case of units of ≥ 600 MWth using supercritical or ultra-supercritical steam conditions **up to 44 % in the case of units of ≥ 600 MWth using supercritical or ultra-supercritical steam conditions *** For units burning lignite with a lower heating value below 6 MJ/kg, the lower end of the BAT-AEEL range is 41.5 % [30]
India			Heat Rate has been specified for Power Plants depending upon their unit rating (MW) by the Central Electricity Authority of the country.
Japan	41 – 45 %		Higher levels for larger installations and where SC or USC steam conditions used Sub-C steam 41-43 % GCC 46-48%

[30] (*)(**)(***) An incremental improvement of +3% is possible for all plants.

Korea	<300 MW: 35-36 electrical 75-85 cogeneration >300 MW: 34-40 electrical	No new/existing plant differentiation was made.
United States		--
World bank	41 – 50	Table 4 in the EHS guideline sets out comprehensive emission data for a variety of situations – see Information Box 2. The focus is on new installation performances.

Information Box 2 World Bank Table 4 – Typical CO_2 emissions performance of new thermal power plants (coal gas and oil)

Simple cycle	34 (12)	36 (12)	Based on 150MWe unit / 300MWe unit	780-820 (11,C2)	NDA	Based on 150MWe unit / NDA
Reciprocating Engine	42-48 (10)	NDA	None given / NDA	556-663 (C2)	NDA	Fuel type (LFO-HFO) / NDA
Boiler	NDA	41 (12)	NDA / Based on 300MWe unit.	NDA	651-680 (12,C2)	NDA / Fuel type (LFO-HFO)

Sources:

1. US EPA (2006)
2. World Bank (2006a)
3. European Commission (2016)
4. IEA (2012)
5. European Commission (2013)
6. Parsons Brinckerhoff (2009)
7. US DOE/NETL (2013)
8. Wartsila product guides
9. Gas Turbine World (2015)
10. Review of manufacturer data (Wartsila and MAN)
11. ESMAP (2007)
12. World Energy Council (2013)
13. US EPA (2010)
14. Gas Turbine Association (2014)
15. Review of manufacturer data (Foster Wheeler)
16. Inter-American Development Bank (2012)
17. World Bank (2008)
18. DUKES (2016)
19. IPPC (2006)

PC = pulverized coal-fired
LFO = Light fuel-oil
HFO = Heavy fuel-oil

Notes:

a) C1 = Calculated values. Where there is a reference for plant efficiency for a certain fuel and technology type on an HHV basis, a conversion has been calculated to ensure that the reference is replicated on the corresponding LHV basis. The following equation has been used in the conversion:
   LHV efficiency = HHV efficiency / (100 – ((HHV of the fuel – LHV of the fuel) / HHV of the fuel) x 100) x 100
   HHV efficiency = LHV efficiency x (100 – ((HHV of the fuel – LHV of the fuel) / HHV of the fuel) x 100) / 100
   For example, the efficiency expressed in HHV terms of an oil fired simple cycle plant of 32% on a LHV basis is as follows:
   HHV efficiency = 32 x (100 - ((43.4GJ/t-40.8 GJ/t)/43.4 GJ/t) x 100) / 100 = 30%
   Calorific values were sourced from the DUKES (18) report.

b) C2 = Calculated values. For categories of plant where it was not possible to obtain specific gCO_2/kWh values from the same sources as the efficiency, the gCO_2/kWh values have been calculated based on the efficiency range of the plant, using standard IPCC (source 19) factors for CO_2 emissions and the following equation:
   gCO_2/kWh = (3.6/Efficiency as decimal)/1000*fuel factor (in $kgCO_2/TJ$).
   For example, the gCO_2/kWh for a 33% efficiency boiler firing lignite is calculated as follows:
   gCO_2/kWh = 3.6/0.33/1000*101000$kgCO_2/TJ$ = 1102gCO_2/kWh.

c) Ranges presented for coal are predominantly due to variation in coal type (where stated); coals with a higher moisture content and lower volatile matter content will typically emit more CO_2 per unit energy generated i.e., plant operating with lower quality coals such as lignite/brown coal will typically have lower efficiencies and higher CO_2 emissions than a like-for-like plant firing better quality bituminous coals.

d) Where there are more than two references for a range of values, the references for the highest and lowest values in the range have been presented in **bold**. Where the range is a result of a C1 or C2 calculation this is also presented in **bold.**

e) Ultra-supercritical, supercritical and subcritical technologies are defined by their pressure and temperature. Refer to Table A-1, Annex A for a summary.

f) NDA = No data available, i.e., at the time of writing no publicly available, referenceable literature was found for that specific category of plant technology, fuel, size or efficiency basis. This is not intended to preclude consideration of these options and simply indicates where robust source information was not available.

g) It is important to note that the values in this table have been obtained from a range of sources and it may not be appropriate to compare between them, e.g., comparing gross values with net values for the same technology/fuel. Additionally, in some cases professional judgement has been has been employed when selecting sources. This underlines the fact that this table includes 'typical' values, not benchmarks, as individual values are dependent on a number of project-specific factors that may not be directly comparable. Users of this table are encouraged to refer directly to the sources for further information on the specific values presented and to undertake their own assessments.

Information Box 2 World Bank Table 4 – Typical CO2 emissions performance of new thermal power plants (coal gas and oil)

Table 4 – Typical CO_2 emissions performance of new thermal power plants

Thermal power plant efficiency and CO_2 emissions performance are dependent on a number of factors including, but not limited to, fuel type, technology, unit size, local climatic conditions, altitude and cooling technology. Values presented in this table are indicative and, due to the degree of variation in power plant characteristics, may not be directly comparable to actual new facilities. For this reason, values should not be interpreted as a benchmark or limit value and are for guidance only.

Fuel	Technology	Efficiency (%) (source no. in brackets) <300MWe	≥300MWe	Details and reason for range of values <300MWe / ≥300MWe	CO_2 (g/kWh) (source no. in brackets) <300MWe	≥300MWe	Details and reason for range of values <300MWe / ≥300MWe
Efficiency: %Net, LHV							
Coal	Ultra-Supercritical	NDA	39-48 (1,2,4,5,**13**,**C1**)	NDA / Fuel type (lignite-bituminous)	NDA	676-934 (**1**,2,4,**C2**)	NDA / Fuel type (bituminous-lignite)
Coal	Supercritical	NDA	40-46 (**2**,4,**5**,7,12,15,C1)	NDA / Fuel type (lignite-bituminous)	NDA	748-938 (1,**2**,4,7,12,**C2**)	NDA / Fuel type (bituminous-lignite)
Coal	Subcritical	37-39 (2,**5**,**17**,**C1**)	38-43 (**2**,4,5,7,**12**,17,C1)	Unit size, fuel type / Fuel type, region	951-1362 (2,C2)	796-970 (1,2,4,7,**12**,**C2**)	Unit size, region, fuel type / Fuel type, region
Coal	IGCC	NDA	41-50 (**1**,2,**4**,5,7,12,**C1**)	NDA / Fuel type, region	NDA	654-856 (**1**,2,4,7,12,**C2**)	NDA / Efficiency, fuel type (bituminous-lignite)
Gas	CCGT	41-56 (9)	46-62 (**5**,7,**9**,14,16,C1)	Unit size	361-488 (C2)	325-439 (7,14,16,**C2**)	Unit size / Unit size
Gas	Simple Cycle	30-45 (**5**,6,**9**,C1)	36-42 (**9**,**16**,C1)	Unit size / Unit size	448-673 (6,C2)	483-645 (14,C2)	Unit size / Unit size
Gas	Boiler	NDA	40-42 (3)	NDA / None given	NDA	481-505 (C2)	NDA / Plant efficiency
Gas	Reciprocating Engine	38-49 (**3**,**5**,10,C1)	NDA	Unit size and configuration / NDA	412-531 (C2)	NDA	Plant efficiency / NDA
Oil	CCGT	NDA	47-60 (16)	NDA / None given	NDA	445-568 (16)	NDA / None given
Oil	Simple cycle	32 (6,C1)	36 (16)	Based on 50MWe turbine / None given	823 (6)	741 (16)	50MWe turbine, diesel fuel / None given
Oil	Reciprocating Engine	38-47 (3,**10**,**16**,C1)	NDA	Unit size, configuration / NDA	579-702 (16,C2)	NDA	Plant efficiency / NDA
Efficiency: %Gross, LHV							
	Ultra-Supercritical	NDA	47 (11)	NDA / Based on 500MWe PC plant	NDA	728-777 (C2)	NDA / Fuel type (other coal-lignite)
	Simple cycle	34 (12)	36 (12)	Based on 150MWe unit / 300MWe unit	780-820 (11,C2)	NDA	Based on 150MWe unit / NDA
	Reciprocating Engine	42-48 (10)	NDA	None given / NDA	556-663 (C2)	NDA	Fuel type (LFO-HFO) / NDA
	Boiler	NDA	41 (12)	NDA / Based on 300MWe unit.	NDA	651-680 (12,C2)	NDA / Fuel type (LFO-HFO)

Sources:

1. US EPA (2006)
2. World Bank (2006a)
3. European Commission (2016)
4. IEA (2012)
5. European Commission (2013)
6. Parsons Brinckerhoff (2009)
7. US DOE/NETL (2013)
8. Wartsila product guides
9. Gas Turbine World (2015)
10. Review of manufacturer data (Wartsila and MAN)
11. ESMAP (2007)
12. World Energy Council (2013)
13. US EPA (2010)
14. Gas Turbine Association (2014)
15. Review of manufacturer data (Foster Wheeler)
16. Inter-American Development Bank (2012)
17. World Bank (2008)
18. DUKES (2016)
19. IPPC (2006)

PC = pulverized coal-fired
LFO = Light fuel-oil
HFO = Heavy fuel-oil

Notes:

a) C1 = Calculated values. Where there is a reference for plant efficiency for a certain fuel and technology type on an HHV basis, a conversion has been calculated to ensure that the reference is replicated on the corresponding LHV basis. The following equation has been used in the conversion:

LHV efficiency = HHV efficiency / (100 – ((HHV of the fuel – LHV of the fuel) / HHV of the fuel) x 100) x 100

HHV efficiency = LHV efficiency x (100 – ((HHV of the fuel – LHV of the fuel) / HHV of the fuel) x 100) / 100

For example, the efficiency expressed in HHV terms of an oil fired simple cycle plant of 32% on a LHV basis is as follows:

HHV efficiency = 32 x (100 - ((43.4GJ/t-40.8 GJ/t)/43.4 GJ/t) x 100) / 100 = 30%

Calorific values were sourced from the DUKES (18) report.

b) C2 = Calculated values. For categories of plant where it was not possible to obtain specific gCO_2/kWh values from the same sources as the efficiency, the gCO_2/kWh values have been calculated based on the efficiency range of the plant, using standard IPCC (source 19) factors for CO_2 emissions and the following equation:

gCO_2/kWh = (3.6/Efficiency as decimal)/1000*fuel factor (in $kgCO_2/TJ$).

For example, the gCO_2/kWh for a 33% efficiency boiler firing lignite is calculated as follows:

gCO_2/kWh = 3.6/0.33/1000*101000$kgCO_2/TJ$ = 1102gCO_2/kWh.

c) Ranges presented for coal are predominantly due to variation in coal type (where stated); coals with a higher moisture content and lower volatile matter content will typically emit more CO_2 per unit energy generated i.e., plant operating with lower quality coals such as lignite/brown coal will typically have lower efficiencies and higher CO_2 emissions than a like-for-like plant firing better quality bituminous coals.

d) Where there are more than two references for a range of values, the references for the highest and lowest values in the range have been presented in **bold**. Where the range is a result of a C1 or C2 calculation this is also presented in **bold.**

e) Ultra-supercritical, supercritical and subcritical technologies are defined by their pressure and temperature. Refer to Table A-1, Annex A for a summary.

f) NDA = No data available, i.e., at the time of writing no publicly available, referenceable literature was found for that specific category of plant technology, fuel, size or efficiency basis. This is not intended to preclude consideration of these options and simply indicates where robust source information was not available.

g) It is important to note that the values in this table have been obtained from a range of sources and it may not be appropriate to compare between them, e.g., comparing gross values with net values for the same technology/fuel. Additionally, in some cases professional judgement has been has been employed when selecting sources. This underlines the fact that this table includes 'typical' values, not benchmarks, as individual values are dependent on a number of project-specific factors that may not be directly comparable. Users of this table are encouraged to refer directly to the sources for further information on the specific values presented and to undertake their own assessments.

(*Source:* (IFC, 2017[30]))

Gas-fired power production

This section includes a series of tables that provides an overview of the techniques specified in the BREFs submitted for the selected KEIs emissions at gas fired power plants:

Oxides of Nitrogen (NO_x)

Table 34 summarises BAT-AELs specified for NO_x for new and/or existing TPP.

Table 34. BAT-AEL specified for NO_x for new and/or existing natural gas-fuelled TPP

BREF	BAT AEL specified		Averaging periods	Further details
	New Plant	Existing Plant		
China	100 mg/m³ (Natural gas boiler) 200 mg/m³ (Other gas fuel boiler) 120 mg/m³ (Gas turbine group of other gas fuel boiler) 50 mg/m³ (Gas turbine group of natural gas boiler) The PM special emission limit in the key area is: 100 mg/m³（gas boiler） 50 mg/m³ (Gas turbine group of gas boiler) Ultra low emission limit: 50 mg/m³			• No new / existing distinction in GATPPC, but GB 13223 is the key document to provide the BAT AELs, which stipulates the emission limit of the pollutants and monitoring requirements in thermal power plant sector. Since January 2012, new enterprises implemented *Emission standard of air pollutants for thermal power plants (GB 13223-2011)*, from July 2014, existing enterprises implemented GB 13223-2011. • All sizes > 100 MW • All values are presented under standard conditions: dry gas at a temperature of 273,15 K, and a pressure of 101,3 kPa and a reference oxygen level of 6 Vol.% O_2 (coal boiler), 3 Vol.% O_2 (oil boiler and gas boiler).
European Union	NG turbine 10 – 30 mg/m³ NG boiler 10 -60 mg/m³	NG turbine: < 600 MW, 10 – 45(50) mg/m³ >600 MW, 10 - 40(50) mg/m³		AELs left are annual averages – daily averages also set Other AEL variations for low operating hours, OCGT / CCGT, fuel and technology variants

	NG engine 20 -75 mg/m^3	NG boiler: 50 – 100 mg/m^3 NG engine: 20 – 100 mg/m^3		
India	Emissions limit for NO_x • 400 MW and above (i) 50 ppm for the units burning natural gas (ii) 100 ppm for the units burning naphtha • Less than 400 MW but up to 100 MW (i) 75 ppm for the units burning natural gas (ii) 100 ppm for the units burning naphtha • Less than 100 MW- 100 ppm for units burning natural gas or naphtha as fuel. • For the plants burning gas in a conventional boiler- 100 ppm	150 ppm (v/v) at 15 % excess O_2)		For new units w.e.f. 01.06.1999 for existing units-At 15 % excess O_2
Japan				Only efficiency levels in supplied BAT tables
Korea	Gas internal combustion engine(power generation) June 2001, 7~80 (15) mg/m^3` July 2001 to Dec. 2014, 3~50 (15) mg/m^3		3 years	
United States	NG turbine <14 MW, 323 mg/m^3 14 – 249 MW, 168 mg/m^3 >249 MW, 60 mg/m^3	No uniform national standard for existing NO_x units	Hourly average	Continuous monitoring system for water or steam injection or continuous emission monitoring system (CEMS)[31]

[31] Standards of Performance for Stationary Combustion Turbines

World bank	180 – 200 mg/m3		

Carbon Dioxide (CO_2)

Table 35 below summarises BAT-AELs specified for CO_2 for new and/or existing TPP. The EHS Guideline provided a table of "typical" CO_2 emissions and efficiency performance for new thermal power plants, including coal, oil and gas-fired plants at a variety of sizes – see Information Box 2.

Table 35. BAT-AEL specified for CO_2 for new and/or existing natural gas-fuelled TPP

BREF	BAT AEL specified		Further Details
	New Plant	Existing Plant	
China			--
European Union			Data on sector CO_2 emissions noted in the BREF
India			--
Japan			Only efficiency levels in supplied BAT tables
Korea			CO_2 emissions are noted throughout the K-BREF, but the available translation does not presently allow a full review.
United States	450 kg/MWh (output based) for baseload PP (i.e., those that operate approximately > 40% utilization) 50 kg/GJ, non-baseload, heat input	No national standard for existing natural gas units	Sources that modify EGUs resulting in 10% increase in CO_2 emissions are evaluated based on historicalannual emission rate (from 2002 to the date of the modification).
World bank	<300MW 361 - 488 g/KWh >300 MW 325 – 439 g/KWh		Table 4 sets out comprehensive emission data for a variety of situations – see Information Box 2 WB focus is new installation performance

Energy Efficiency

Table 36 below summarises the BAT-AEL specified for Energy Efficiency for new and/or existing TPP. For further information on efficiency performances for new thermal power plants, including coal, see the Information Box 2 World Bank Table 4 – Typical CO2 emissions performance of new thermal power plants (coal gas and oil).

Table 36. BAT-AEL specified for Energy Efficiency for new and/or existing natural gas-fuelled TPP

BREF	BAT AEEL specified		Further Details
	New Plant	Existing Plant	
China	-	-	--
European Union	NG CCGT: <600 MW 53 – 58.5 >600 MW 57 – 60.5 NG OCGT: >50 MW, 36 – 41.5 NG boiler: 39 – 42.5 NG engine: 39.5 - 44	NG CCGT: <600 MW 46 - 54 >600 MW 50 - 60 NG OCGT: >50 MW, 33 – 41.5 NG boiler: 38 - 40 NG engine: 35 - 44	AELs left are yearly averages The BAT-AEELs do not apply to units operated < 1 500 h/yr
India			--
Japan	Various ranges between 51 - 63		Efficiency AEL higher in range at larger plant Highest AEL range 56.5 – 63% for 1650 CC Gas Turbines > 600 MW Lowest AEL range 51.5 - 57% for 200 MW CCGT (1200)
Korea	--		
United States	--		

World bank	<300 MW 41 – 56 >300 MW 46 - 62	Table 4 sets out comprehensive emission data for a variety of situations – see Information Box 2 EHS Guideline is focused on new installation performances

Sub-Chapter Conclusion

The BAT-associated emission levels (BAT-AELs) set for a number of selected KEIs in China, the European Union, India, Japan, South Korea, the United States, and World bank group for TPP were extracted from their relevant BREFs. This collective information aimed to indicate the BAT-AELs determined by several countries to prevent or control emissions to air based on the two selected fuel-type used by the new and/or existing TPP plants. In addition to the air emissions, BAT used to ensure energy efficiency of coal-fired and gas-fuelled power plants were collected from the BREFs included in this study.

According to the IED's Article 3(13), the BAT–AELs are the range of emission levels obtained under normal operating conditions using a BAT or a combination of BAT. The BAT-AELs are described in BAT conclusions (BAT-C) and expressed as an average over a given period of time, under specified reference conditions. The main purpose of determining BAT-AELs is to guide environment permitters to set emission limits within those ranges. The BREFs are developed to establish emission and other relevant performance levels for installations in a sector, although, they are often also supported by or linked to other specific emission regulations. For example, in the case of the EU, the BAT-AELs are reported within the BAT-Conclusions of the EU-BREFs.

The differences in the operational conditions of installations, such as their start-up or shutdown phases, may influence BAT determined for standard and non-standard operations. These conditions may require some interpretation or having allowances to the BAT set in the BREFs. The BREFs from the EU indicated differences under these conditions. The US-technology based performance standards reported for normal operating conditions of the installations. There was no information available on the non-standard operations in the BREFs submitted by China, Japan, South Korea, and India.

Particulate matter (PM), oxides of sulphur (SO_x) and nitrogen (NO_x), mercury (Hg), carbon dioxide (CO_2) emissions and energy efficiency from coal-fired power plants were selected to compile BAT-AELs from the seven BREFs submitted for this report. Among all BAT-AELs included in this report, there was some degree of reduction in the AELs at larger capacity installations observed between the countries, which may be reflected on the economic status of the countries.

For PM emissions, there were significant AEL variations between different BREFs, even for the new plant standards. Comparing the values in a BREF, new plant standards are often but not always (exceptions: China and to some extent also the EU-BAT conclusions) dramatically lower than for older existing plants.

The BAT-AELs specified for SO_x and NO_x for new and/or existing TPP showed large AEL variations, even for the new plant standards as well. This may be due to the fuel type selected and policy differences regarding the application of flue gas desulphurisation (FGD) technology. The BAT-AELs set for NO_x, South Korea, China and the EU had the lowest levels. In general, the values set for the new plant standards are often dramatically lower than for the older/existing plants, which may be due to the more recent and general application of FGD. Notably, in the EU, fuel type and technology influences are considered for the AELs set.

In the Minamata Convention on Mercury's Guidance on Best Available Techniques and Best Environmental Practices (BAT/BEP) for mercury emissions to air, a BAT for mercury is set at 1µg/Nm³ for hard coal and 0.5µg/Nm³ for lignite (UNEP, 2019[8]). The BAT-AEL set in the US-technology based performance standards (for new plants) were aligned with the values indicated in the Convention's guidance.

For the gas-fuelled plants, the overall BAT-AELs specified for NO_x in the new and/or existing installations range vary from 10 to 400 mg/m³. As documented for the coal-fired plants, the larger installations generally set lower AELs, and these ranges often differ according to the generation technology of the plant.

As indicated in the previous chapters, the CO_2 emissions control is regulated under international agreements, however, its BAT-AELs set for both fuel types were collected to reflect on the available information within the BREFs submitted. The US-technology based performance standards and the EHS Guideline included the AELs set for CO_2 and, the AEL for new installations in the US is below the low end of the range given by the level of the EHS Guidelines

The energy efficiency levels for new and/or existing plants with both fuel types were indicated to have higher BAT-AELs set for new and larger installations. The design steam conditions may lead to allowing higher efficiencies.

Cement Production

This section compares the emission limits and other quantitative performance standards for the selected KEIs in the BREFs submitted for the cement production industry.

Emission standards for KEIs Control

There were significant differences between the emission standards/values collected for this study, in terms of the measurements conditions such as the averaging period of the continuous measurements (i.e. daily, monthly, yearly, hourly, half-hourly, etc.), the sampling/analysis methods, the correction factor for the reference oxygen level (vol.%), the standardization for the humidity, temperature and pressure, the consideration of measurement uncertainties, the calibration and control of the functionality of measurement devices, etc. The various measurement conditions result to substantial differences in the emission values. For example by using the formula of the correction factor for the reference oxygen content (O_2) in the EU, when a measurement emission is 400 mg/Nm³ at 12% O_2, this is adjusted to 488 mg/Nm³ at 10% reference O_2 (EIPPCB, 2017[7]). Some of the above measurement conditions were included in the tables indicating emission values for the selected KEIs, however not all were available in the BREFs submitted The tables below provide a summary of the quantitative emission standards/values set out in the BREFs submitted for cement production sector for each of the selected focus KEIs:

Particulate matter (PM)

Table 37 summarises the BAT-AEL specified for the PM for cement production installations:

Table 37. BAT-AEL specified for PM for cement production installations

BREF	BAT-AEL specified (with notes on relevance i.e. which process stream?)		Averaging periods	Units
	Existing plants	New Plants		
China	20			mg/m³
(Further detail)	• No new / existing installation distinction was made in GATPPC, but GB 4915 and GB 30485 are the key document to provide the BAT AELs, which stipulated the emission limit of the pollutants and monitoring requirements in cement production industry. Since March 2014, new enterprises implemented *Emission standard of air pollutants for cement industry (GB 4915-2013*), from July 2015, existing enterprises implemented *GB 4915-2013.* Since March 2014, all co-processing of solid wastes in cement kiln implemented GB 30485-2013 *(Standard for pollution control on co-processing of solid wastes in Cement kiln).* • For averaging periods the following definitions apply: ○ Daily average value: Average value over a period of 24 hours measured by the continuous monitoring of emissions ○ All values were presented under standard conditions: dry gas at a temperature of 273,15 K, and a pressure of 101,3 kPa and a reference oxygen level of 10 vol.% O_2 (cement kiln and kiln tail heat utilization system)， 8vol.% O_2 (Drying equipment with independent heat sources)			
European Union	A) < 10 (dusty operations) B) < 10 – 20 (kiln firing, cooling and milling)		Daily average value: Average value over a period of 24 hours measured by the continuous monitoring of emissions Average over the sampling period: Average value of spot measurements (periodic) of at least 30 minutes each, unless otherwise stated Reference conditions for air emissions: Kiln activities: 10 % oxygen by volume Non-kiln activities: all processes: No correction for oxygen	mg/Nm³
(Further detail)	A): channelled dust emissions from *dusty operations* (other than those from kiln firing, cooling and the main milling processes), (as the average over the sampling period (spot measurement, for at least half an hour). B): channelled dust emissions from *kiln firing* (as daily average value) & *Cooling and milling* (as the daily average value or average over the sampling period (spot measurements for at least half an hour))			

BREF	BAT-AEL specified (with notes on relevance i.e. which process stream?)		Averaging periods	Units
	Existing plants	**New Plants**		
	For both BAT-AELs ((A) and B)) the lower level is achieved when applying fabric filters or new or upgraded electrostatic precipitators (ESPs).			
India	30 (for all Rotary Kilns) 75 (for vertical kilns installed before 01.06.2016 in critically polluted area or urban centres with population above 100,000 or within its periphery of 5 km radius) 150 (for vertical kilns installed before 01.06.2016 in other than critically polluted area or urban centres)	50 (for vertical kilns installed after 01.06.2016)	No averaging period is specified as the standards have to be complied all the time.	mg/Nm^3
(Further detail)	The standards refers that all cement plants located in critically polluted areas and urban centres with population above 1.0 lakh[32] or within its periphery of 5.0 km radius shall meets the norms of 50 mg/Nm3 with effect from 01.06.2015 and after meet the norms of 30 mg/Nm3 with effect from 01.06.2016 to bring them at par with emissions from cement plants established after the notification (i.e. 25.08.2014)			
United States	0.07 (about 12.6) Upper limit of 0.30 for existing between 1971-2008	0.02[33] (about 3.6)	30 day rolling average using CPMS	lb/ton clinker (mg/m^3 estimate for a preheater/pre calciner kiln)
(Further detail)	Kiln/clinker cooler New and existing limits also apply for combined exhaust with clinker cooler and/or alkali bypass and/or inline coal mill in one stream Limits apply to all cement kilns regardless of facility size or level of hazardous air pollutant emissions.			

[32] one hundred thousand

BREF	BAT-AEL specified (with notes on relevance i.e. which process stream?)		Averaging periods	Units
	Existing plants	**New Plants**		
United States	10% Opacity		6-minute averages observed over a period of 3 hours.	%, percent
(Further detail)	All kilns have a requirement to have a CPMS so the 20 percent opacity limit is no longer necessary. Opacity applies to new and existing raw mills, finish mills, bulk unloading systems, raw material dryers, conveying system transfer points, and finished product storage bins that are major sources for hazardous air pollutants; represents about 75% of the Portland cement facilities in the U.S.			
World Bank	25			mg/Nm^3

Oxides of sulphur (SO_x)

Table 38 summarises the BAT-AEL specified for SO_x for cement production installations:

Table 38. BAT-AEL specified for SO_x for cement production installations

BREF	BAT AEL specified		Averaging Periods	Units
	Existing plants	New Plants		
China	100			mg/Nm³
(Comments)	• No new / existing installation distinction was made in GATPPC, but GB 4915 and GB 30485 are the key document to provide the BAT AELs, which stipulates the emission limit of the pollutants and monitoring requirements in cement industry. Since March 2014, new enterprises implemented *Emission standard of air pollutants for cement industry (GB 4915-2013*), from July 2015, existing enterprises implemented *GB 4915-2013*. Since March 2014, all co-processing of solid wastes in cement kiln implemented GB 30485-2013 *(Standard for pollution control on co-processing of solid wastes in Cement kiln).* • For averaging periods the following definitions apply: ○ Daily average value: Average value over a period of 24 hours measured by the continuous monitoring of emissions ○ All values were presented under standard conditions: dry gas at a temperature of 273,15 K, and a pressure of 101,3 kPa and a reference oxygen level of 10 vol.% O_2 (cement kiln and kiln tail heat utilization system), 8 vol.% O_2 (Drying equipment with independent heat sources)			
European Union	<50-400 (as daily average value)		For averaging periods the following definitions apply: Daily average value: Average value over a period of 24 hours measured by the continuous monitoring of emissions Reference conditions for air emissions: Kiln activities: 10 % oxygen by volume Non-kiln activities: all processes: No correction for oxygen	mg/Nm³
(Comments)	SO_x expressed as SO_2 *The range takes into account the sulphur content in the raw material.*			
India	Rotary Kilns 100 (when pyritic sulphur in the limestone is less than 0.25 %,) 700 (when pyritic sulphur in the limestone is 0.25 % to 0.5%) 1000 (when pyritic sulphur in the limestone is more than 0.5 %)		No averaging period is specified as the standards have to be complied all the time.	mg/Nm³

BREF	BAT AEL specified		Averaging Periods	Units
	Existing plants	New Plants		
	200 (vertical kiln w.e.f. 01.01.2016)			
(Comments)	Applicable to existing and new plants Irrespective of data of commissioning. SO_2 values corrected to 10 % oxygen on dry basis.			
United States		0.4 (about 72)	30 day rolling average.	lb/ton clinker (estimate mg/m³)
(Comments)	Applies to new kilns			
World Bank	50 - 400			mg/Nm³

Oxides of nitrogen (NO_x)

Table 39 summarises BAT-AELs specified for NO_x for cement production installations.

Table 39. BAT-AEL specified for NOx for cement production installations

BREF	BAT AEL specified		Averaging Periods	Units
	Existing plants	New plants		
China	320			mg/m³
(Comments)	• No new / existing distinction in GATPPC, but GB 4915 and GB 30485 are the key document to provide the BAT-AELs, which stipulates the emission limit of the pollutants and monitoring requirements in cement industry. Since March 2014, new enterprises implemented *Emission standard of air pollutants for cement industry (GB 4915-2013*), from July 2015, existing enterprises implemented *GB 4915-2013*. Since March 2014, all co-processing of solid wastes in cement kiln implemented GB 30485-2013 *(Standard for pollution control on co-processing of solid wastes in Cement kiln).* • For averaging periods the following definitions apply: ○ Daily average value: Average value over a period of 24 hours measured by the continuous monitoring of emissions ○ All values are presented under standard conditions: dry gas at a temperature of 273,15 K, and a pressure of 101,3 kPa and a reference oxygen level of 10 vol.% O2 (cement kiln and kiln tail heat utilization system), 8 vol.% O2 (Drying equipment with independent heat sources) .			
European Union	A) <200-450 (as daily average value) (Preheater kilns) B) 400-800 (as daily average value) (Lepol and long rotary kilns)		For averaging periods the following definitions apply: Daily average value: Average value over a period of 24 hours measured	mg/Nm³

BREF	BAT AEL specified		Averaging Periods	Units
	Existing plants	New plants		
			by the continuous monitoring of emissions Reference conditions for air emissions: Kiln activities: 10 % oxygen by volume Non-kiln activities: all processes: No correction for oxygen	
(Comments)	A): *Preheater kilns*; Additional for A): The upper level of the BAT-AEL range is 500 mg/Nm^3, if the initial NOx level after primary techniques is >1 000 mg/Nm^3. B*): Lepol and long rotary kilns*; Additional for B) Depending on initial levels and NH_3 slip.			
India	800 (rotary kiln plans installed before 25.08.2014 with In Line Calciner (ILC) technology) 1000 (rotary kiln plans installed before 25.08.2014 using mixed stream of ILC. Separate Line Calciner (SLC) and suspension pre-heater technology or SLC technology alone or without calciner) 500 (for vertical kiln w.e.f. 01.01.2016)	600 (for rotary kiln plants installed after 25.08.2014)	No averaging period is specified as the standards have to be complied all the time.	mg/Nm^3
(Comments)	NO_x values corrected to 10 % O_2 on dry basis.			
United States		1.5 (about 270)	30 day rolling average.	lb/ton clinker (estimate mg/m^3)
(Comments)	Applies to *new* kilns Does not apply to alkali bypass installed on kiln			

BREF	BAT AEL specified		Averaging Periods	Units
	Existing plants	New plants		
World Bank	600			mg/Nm^3

Carbon dioxide (CO_2)

Table 40 summarises BAT-AELs specified for CO_2 for cement production installations. Although several BREFs made notes of CO_2 emissions as an important issue, there were no limit values specified for CO_2 in the BREFs submitted.

Table 40. BAT-AEL specified for CO_2 for cement production installations

BREF	BAT-AEL specified	Comments
China	-	--
European Union	-	The EU BREF itself contains general information on CO_2 emissions from cement activity, Section 1.3.4.4.1 CO_2; also referring to the corresponding EU Directives regulating CO_2 emissions resulting from industrial activities. Cross-reference is given.
India	-	--
United States	-	There is no CO_2 limit, but US cement facilities are required to report to the Greenhouse Gas Reporting Program.
World Bank	-	--

Operational Conditions

Different BAT for installations may be set according to the installation operating regime and to make allowances for standard and non-standard operating conditions, such as during their start-up or shut down phases of cement production plants. Load factors differentiation takes account of the lower mass emissions from plants with lower operating hours, and BREFs may also set out the operating hour constraints applicable. In the cases where non-standard operational standards are applied, some interpretation is required to define these conditions as they may vary from sector to sector. The country-specific information on operating regimes of installations covered in the BREFs submitted is provided below:

European Union

The CLM BREF refers to the normal operating conditions. This is because the IED's Article 3(13) defines BAT-AELs as 'the range of emission levels obtained under normal operating conditions using a best available technique or a combination of best available techniques, as described in BAT conclusions, expressed as an average over a given period of time, under specified reference conditions. However, there are start-up and/or shutdown conditions specified for the use of waste at the cement production installations, and such information is included in CLM BREF as:

- Under section 1.2.4 Use of waste - 1.2.4.2 Waste feeding into the kiln (techniques/measures to control the feed into the kiln); in this section, there is a technique included for co-incineration of waste for start-ups and/or shutdowns[34]:
- Also, BAT 12 (f) indicated that the delay or stop co-incineration of waste for operations such as start-ups and/or shutdowns when appropriate temperatures and residence times cannot be reached.

India

The minimum emission standards (MINAS) specified that the emission standards are expected to be achieved at all operations involving cement production.

United States

The emission standards must be achieved during all periods of operation unless there is a separate defined standard in the permit. For the NESHAP rule limiting HAP emissions, there are “work practice standards” during periods of start-up and shutdown for kilns, clinker coolers, and raw material.

World Bank

The EHS Guideline indicated that the emissions limits reported are achievable under normal operating conditions.

Sub-Chapter Conclusion

The BAT-associated emission levels (BAT-AELs) set for the cement manufacturing installations for a number of selected key environmental issues (KEIs) in BREFs from China, the European Union, India, the United States, and the World Bank group were collected. This information aims to present the BAT-AELs determined by several countries to prevent or control emissions to air for the new and/or existing installations.

Cement production installations are major sources of particulates polluting the environment, especially with emissions of particulate matter (PM), nitrogen oxides (NO_x), sulphur dioxide (SO_2), carbon monoxide (CO), heavy metals, and volatile organic compounds into the environment (Aleksei Kholodov, 2020[108]). These pollutants are also formed during industrial dumping of overburdened rock formed at the extraction of raw materials, storage, crushing, and transporting of raw materials as well as during packing and loading of the cement (Aleksei Kholodov, 2020[108]).

Deriving conclusions based on the BAT-AELs collected from the BREFs was challenging due to the differences noted between the AELs and the specificities associated with these values. The BAT-AEL specified for PM in the BREFs submitted showed that the new plant standards were in the 10% O_2 range of 10-30 mg/Nm_3. For the SO_x emission values, the AELs were set between 50 mg/Nm_3 up to 400 mg/Nm_3 in the EU-BREF and EHS Guideline, with the exception noted for the MINAS with 1000 mg/Nm_3 set for plants using higher sulphur limestone. The overall range of AELs set for NO_x emissions varied from 200 (low end of EU range 200-450) to 1000 mg/Nm^3. Also, it was noted that these AELs set differed according to the type of kiln as mentioned in the further notes added to Table 39.

As indicated in the previous chapters, the CO_2 emissions control is regulated under international agreements, however, the availability of its emission limits was explored in the BREFs submitted.

[34] IED provisions of Chapter IV, where waste is co-incinerated the ELV need to be met at effective operating time (EOT) which makes the requirements stricter.

Although several BREFs made notes of CO_2 emissions as an important issue, there were no limit values specified for CO_2 in any of the BREFs submitted.

The differences in the operational conditions of installations, such as their start-up or shutdown phases, may influence BAT determined for standard and non-standard operations. These conditions may require some interpretation or have allowances to the BAT set in the BREFs. The EU-BREF indicated the differences made under standard/non-standard operational conditions only for the uses of waste at the cement production installations. The US-technology based performance standards, the MINAS and the EHS Guideline reported setting BAT-AELs that are achievable under normal operating conditions of the installations.

Textile Manufacturing

This section compares the emission limits (or performance levels) and other quantitative performance standards that are specified as BAT-associated emission (or performance levels) in the BREFs submitted for the textiles manufacturing industry.

Wastewater effluents from the dyeing process during textiles production contain various compounds such as colour pigments, halogens, and **metals** (e.g. chromium, copper, nickel and zinc). These effluents are also known to have high **BOD (biological oxygen demand)** and **COD (chemical oxygen demand)** levels. BOD represents the amount of oxygen consumed by microorganisms while they decompose organic matter by aerobic reactions at a specified temperature (USGS, 2018[91]). COD is the amount of oxygen that can be consumed by reactions under a controlled environment (Li and Liu, 2019[92]) and is used to measure the amount of oxidizable pollutants present in wastewater, or in surface water (Li and Liu, 2019[92]). The BOD/COD ratio indicates the proportion of non-biodegradable organic matter present in the wastewater (Khan, Patel and Khan, 2020[93]). **Absorbable organic halogens (AOX)** are the concentration of organic halogens, which are components containing chlorine, bromine or iodine, in wastewater. They are often introduced or occur as by-products in textile processes, especially during dyeing and bleaching, at steps such as the chlorination shrink proof process of wool, the bleaching process by sodium hypochlorite and chlorite and the dry-cleaning process by chlorinated solvent. However, AOX can be difficult to biodegrade and is a persistent, bioaccumulative toxic substance with high fat solubility (Ding, Y; Cao, L; Zhou, L; Qian, K; Tang, J; Zhou, J; Dong, S, 2022[109]).

Emission standards for KEIs Control

The BAT-AEPL (BAT-associated environmental performance levels) and/or BAT-AELs (BAT-associated emission levels) for water consumption, water release (direct and indirect) and of the pre-treatment and dyeing processes were collected for this report.

Some parameters, such as AOX and COD, apply not only to the processes within the scope of this project, but to additional processes, especially the finishing. This is an essential factor to be considered when assessing the BAT-AELs indicated in the tables below, because these additional processes may cause higher emission levels in the total wastewater stream. Please see Appendices 0 for US-EPA, 0 for additional important parameters with sectoral ELVs in VLAREM II from Flanders BREF and 0 BAT-AEL set for textile dyeing and finishing facility in the K-BREF.

Table 41 provides an overview of whether the BREFs submitted includes the specification of quantitative emission limit or related values.

Table 41. General Emission Standards specified in the BREFs submitted for the textile manufacturing

BREFs	Water consumption	Water release (Direct discharges)	Water release (Indirect discharges)	Processes (Pre-treatment/Dyeing)
European Union	Yes (indicative levels)	Yes	Yes	Yes*
VITO	No	Yes	Yes	No
India	No	Yes	Yes	No
Korea	No	Yes	No	No
United States	No	Yes	No	No
World Bank	Yes	Yes	No	No

*Only for mercerizing sub-process. For mercerisation, there is a BAT-AEPL for the % of caustic soda recovered. The aim is to use resources efficiently and to reduce the amount of alkali discharged to waste water treatment. (BAT 39 of TXT BAT conclusions)

Operational Conditions

Different BAT for installations may be set according to the installation operating regime and to make allowances for standard and non-standard operating conditions, such as during their start-up or shutdown phases. Load factors differentiation takes account of the lower mass emissions from plants with lower operating hours, and BREFs may also set out the operating hour constraints applicable. In the cases where non-standard operational standards are applied, some interpretation is required to define these conditions as they may vary from sector to sector. The country-specific information on the operating regimes of installations included in the BREFs submitted is provided below.

European Union

Generally, the emission limit values set at permits by the competent authorities refer to normal operating conditions (IED Art. 15.3). The IED Art 14.1(f) also stated that measures relating to conditions other than normal operating conditions, such as start-up and shutdown operations, leaks, malfunctions, momentary stoppages and definitive cessation of operations, shall be included in the permits.

Flanders, Belgium

The Flemish BAT studies focus on well-managed enterprises, and BAT conclusions refer to normal operating conditions.

United States

The US-technology based performance standards are production based. If on average, a facility only operates a limited time each day, or month, then they are regulated based on what is produced during that time. If the plant is shut-down or not producing, there should not be any routine or production-related discharges of pollutants.

World Bank

The EHS Guidelines indicated that the emissions limits reported are achievable under normal operating conditions.

Water consumption

Table 42 summarises the BAT-AEPLs[35] set for water consumption at the textile manufacturing installations according to the BREFs submitted.

Table 42. BAT-AE(P)Ls specified for water consumption in the textile manufacturing

Process	Sub-Process		BREF	
			European Union	**World Bank**
			Indicative-levels **m^3/t (treated textile material (e.g. fibre yarn or fabric)**	**m^3/t**
Pre-treatments	Bleaching	Batch	10-32 m^3 /t (*)	
		Continuous	3-8 m^3 /t	
	Scouring of cellulosic materials	Batch	5-15 m^3 /t (*)	
		Continuous	5-12 m^3 /t (*)	
	Desizing of cellulosic materials		5-12 m^3 /t (*)	
	Combined bleaching, scouring and desizing of cellulosic materials		9-20 m^3 /t (*)	
	Mercerisation		2-13 m^3 /t (*)	
	Washing of synthetic material		5-20 m^3 /t (*)	
Dyeing	Batch Dyeing	Fabric	10-150 m^3 /t (*)	
		Yarn	3-140 m^3 /t (*) (**)	15-30 m^3 /t
		Loose fibre	13-60 m^3 /t	4-15 m^3 /t
	Continuous Dyeing		2-16 m^3 /t (*) (***)	

[35] BAT-AEPL: BAT associated environmental performance levels

(*) The lower end of the range may be achieved with a high level of water recycling (e.g. sites with integrated water management for several plants).

(**) The range also applies to combined yarn and loose fibre batch dyeing.

(***) The higher end of the range may be higher and up to 100 m3/t for plants using a combination of continuous and batch processes.

Releases to water

Table 43, Table 44 and Table 45 summarise the BAT-AE(P)Ls for pH, AOX-BOD-COD and a number of metals released to water from the textile production installations. It is highlighted that the quantitative emission standards for wastewater discharge show significant differences in terms of types and number of wastewater sampling (e.g. spot sampling, composite 2 hourly mixed composite sampling, 24-hours sampling with an automatic sampler) and averaging periods (i.e. spot sampling period, daily, monthly, yearly average value) and the analysis methods (self-monitoring by use of rapid test versus standardised methods). Also, it has to be considered whether values are determined in filtered or unfiltered and homogenised samples. The various sampling methods, including the locations of the sampling, the handling of samples and measurement conditions, result in substantial differences in the recorded emission values. The relevance of these aspects may vary depending on the parameter concerned, the corresponding variations of wastewater flow and concentrations of pollutants in the wastewater. All the above measurement conditions are explicitly specified, as far as available, for the reader to have a meaningful comparison of the recorded emission values and the quality and reliability of the data.

The emission limits for the three parameters were separately collected in the form of direct and indirect discharges, wherever it was possible. The direct dischargers release the contaminants in the effluent directly into surface waterways, whereas indirect discharges (or industrial users) release them into municipal sewer systems that compel the municipal waste treatment plants to address the contaminated wastewater (Earnhart, 2013[110]).

BAT-AELs for pH

Table 43 summarises BAT-AELs specified for pH for textile manufacturing installations.

Table 43. BAT-AEL specified for pH in the textile manufacturing

BREF	BAT AEL specified	
	Direct discharge/unit	Indirect discharge/unit
European Union	See footnote [36]	

[36] EU revised BREF on Textiles has an overall toxicity parameter (BAT 8), monitoring effluent toxicity on three aquatic indicator species (fish eggs, daphnia, luminescent bacteria). BAT 19 describes that the bioeliminability/biodegradability of the waste water streams and pastes before they are sent to the downstream biological treatment is at least:

• 80 % after 7 days (for adapted sludge), when determined according to standard EN ISO 9888 or

• 70% after 28 days when determined according to standard EN ISO 7827.

VITO (VLAREM-II)	6.5 - 9.0	6.5 - 9.5
India	6.5 - 8.5	6.5 - 8.5
Korea		
United States	6.0 - 9.0	
World Bank	6.0 - 9.0	

BAT-AELs for AOX, BOD, COD

Table 44 summarises BAT-AELs specified for BOD (Biochemical Oxygen Demand), COD (COD Chemical Oxygen Demand), and AOX (Absorbable Organic Halogen) for textile manufacturing installations.

Table 44. BAT-AEL specified for AOX, BOD and COD in the textile manufacturing

BREF	BAT AEL specified					
	AOX		BOD		COD	
	Direct discharge/ unit	Indirect discharge/ unit	Direct discharge/ unit	Indirect discharge/ unit	Direct discharge/ unit	Indirect discharge/ unit
European Union	0.1-0.4 mg/L (*)(**)	0.1-0.4 mg/L (*)(**)(***)	No BAT-AEL applies for BOD. As an indication, the yearly average BOD5 level in the effluent from a biological wastewater treatment plant will generally be ≤ 10 mg/L.	--	40-100 mg/L (****)	--
VITO (VLAREM-II)[37]	1 mg/L	1 mg/L	25 mg O_2/L	--	160 (max 250) mg O_2/L	--
India	--	--	30 mg/L	--	100 mg/L	-
Korea	--	--		--	18 – 30 mg/L	-

[37] Daily average: the content or concentration determined on the basis of a 24-hour sampling proportional to the flow rate

BREF	BAT AEL specified					
	AOX		BOD		COD	
	Direct discharge/ unit	Indirect discharge/ unit	Direct discharge/ unit	Indirect discharge/ unit	Direct discharge/ unit	Indirect discharge/ unit
United States	--	--	1.4-35.2 kg/kkg(*****) Daily max 0.7-17.6 kg/kkg 30-day avg New 1.4–16.9 kg/kkg Daily max 0.7-8.7 kg/kkg 30-day avg [38]	--	21.3-256.8 kg/kkg	-
World Bank	1 mg/L	--	30 mg/L	30 mg/L	160 mg/L	125 mg/L

(*) The BAT-AELs only apply when the substance/parameter concerned is identified as relevant in the waste water stream based on the inventory of inputs and outputs mentioned in BAT 2.
(**) The higher end of the BAT-AEL range may be higher and up to 0.8 mg/L when dyeing polyester and/or modacrylic fibres.
(***) The BAT-AELs may not apply if the downstream waste water treatment plant is designed and equipped appropriately to abate the pollutants concerned, provided this does not lead to a higher level of pollution in the environment.
(****) The higher end of the BAT-AEL range may be up to 150 mg/l:
a) when the specific amount of waste water discharged is less than 25 m3/t of treated textile materials as a rolling yearly average;
or b) when the abatement efficiency is ≥ 95 % as a rolling yearly average.
(*****) Kilograms per 1000 Kilograms

BAT-AELs for Metals

Table 45 summarises BAT-AELs specified for Metals (Chromium, Copper, Nickel and Zinc) for textile manufacturing installations.

[38] The range reflects the different limits for the different processes regulated. Wool finishing has the lowest standards while felted fabric processing represents the higher limits.

Table 45. BAT-AEL specified for Chromium, Copper, Nickel and Zinc (Metals) in the textile manufacturing

BREF	BAT AEL specified							
	Chromium		Copper		Nickel		Zinc	
	Direct discharge/ unit	Indirect discharge/ unit	Direct discharge/ unit	Indirect discharge/ unit	Direct discharge/ unit	Indirect discharge/ unit	Direct discharge/ unit	Indirect discharge/ unit
European Union	0.01-0.1 mg/L	0.01-0.1 mg/L(*)	0.03-0.4 mg/L	0.03-0.4 mg/L(*)	0.01-0.1 mg/L	0.01-0.1 mg/L(*)	0.04-0.5 mg/L	0.04-0.5 mg/L(*)
VITO (VLAREM-II) (daily average)	0.5 (Cr-VI 0.05) mg/l	0.5 (Cr-VI 0.05) mg/l	0.2 (max 0.5) mg/l	0.2 (max 0.5) mg/l	0.5 mg/l	0.5mg/l	2 mg/l	2mg/l
India	2 mg/l	2 mg/l	--	--	--	--	--	--
Korea	0.5 mg / l	--	1.0 mg / dm^3	--	0.25 mg / dm^3	--	--	--
United States	*Daily*: 0.023-0.22 kg/kkg *30-day average*: 0.011-0.11 kg/kkg (**)							
World Bank	0.5 mg/L (total)		0.5 mg/L		0.5 mg/L		2 mg/L	

(*) The BAT-AELs may not apply if the downstream waste water treatment plant is designed and equipped appropriately to abate the pollutants concerned, provided this does not lead to a higher level of pollution in the environment.
(**) The range reflects the different limits for the different processes regulated. Carpet finishing represents the lower limit and felted fabric processing the upper limits

Sub-Chapter Conclusion

The BAT-associated emission levels (BAT-AELs) are set for the textile manufacturing installations for pre-treatment with three sub-process and dyeing processes in the European Union, Flanders (Belgium), India, Korea, the United States and the World Bank group. Furthermore, emission levels for water consumption and a number of KEIs (pH, AOX, BOD, COD and four metals) were extracted from the BREFs submitted. This collective information aims to indicate the BAT-AELs determined by several countries to prevent or control releases to water and present quantitative control measures of amount of water used in the production of textile materials.

There are emission values for direct discharges to water found in all BREFs, however, the emission values for the two main processes are noted only in the EU-BREF. The AELs for water consumption are indicated in the EU-BREF and the EHS Guideline (only for dyeing process) for the sector.

The BREFs from India, Korea and the EHS Guideline on textiles manufacturing did not describe any differences in considerations for variations in operating regimes of the installations.

The setting of BAT and BAT-Associated Environmental Performance Levels (BAT-AEPLs) in the EU is generally based on imbalances between plants with high environmental performance to those with less performing levels. The BAT used in the well-performing installations are then used to generalise for the others through BREF development process (for each sector). There is a continuous demand from the market for innovative technologies that provide high performance with low costs. The BAT-AEPLs against the BAT-AELs address the consumption of raw materials, energy or water, as well as waste generation (EC, 2020[111]).

In the textiles manufacturing sector, the water consumption is generally measured in volume of water (m^3) used for per kg of treated textile material, such as fibre yarn or fabric, as indicated by *t*. The water consumption limit was set as indicative values only for the EU-BREF and the EHS Guideline. At the lower end, the EHS Guideline's indicative values were broadly similar with the EU that in general set the lowest levels.

The pH level in nearly all steps of the textiles manufacturing processes, such as pre-treatment, dyeing, as well as printing and finishing, has a great influence on the quality of the product. Therefore, it may also be considered as a key parameter for common BAT considered for all countries. All BREFs gave a pH range of 6.0 (or 6.5) to 9.0 (or 9.5). The MINAS and VLAREM-II reported the same lower pH limit of 6.5 for both direct and indirect discharges to water, however, the MINAS had the lowest high limit of 8.5 compared to all BREFs. The US-technology based performance standards and the EHS Guideline specified the same pH limits.

Among the BREFs submitted, the EU-BREF, VITO (VLAREM-II) and World Bank's EHS guidelines reported to have emission values for Absorbable organic halogens (AOX) of 0.1-0.4 mg/L for the EU and 1.0 mg/L for both VITO and EHS guidelines. AOX is a persistent bioaccumulative toxic substance with high fat solubility and therefore, can be difficult to biodegrade (Ding, Y; Cao, L; Zhou, L; Qian, K; Tang, J; Zhou, J; Dong, S, 2022[109]). The BOD (biological oxygen demand) and COD (chemical oxygen demand) levels are the measures of oxygen consumed by bacteria for the BOD, and dissolved oxygen needed to oxidise soluble organic matters. Both indicators are individually important to show the contents of the effluents after textile processes, as combined in the form of BOD/COD ratio, the value indicates the proportion of non-biodegradable organic matter present in the wastewater (Khan, Patel and Khan, 2020[93]). In the BREFs submitted, the BOD levels are found to be different from each other, except for MINAS and the EHS Guideline that reported the same BOD emission level of 30 mg/L for direct discharge. The EU-BREF reported that there were no BAT-AEL, but an indicative value set for the BOD. The same diversity in AELs was recognised for the COD values, among which, K-BREF indicated a substantially lower AEL of 18 – 30 mg/L compared to the other BREFs. The similar AELs for COD were noted for VITO (VLAREM-II) and the EHS Guidelines. There were no distinctions made between the AELs set for direct and indirect discharges of BOD, COD and AOX, and therefore, no comparative analyses were carried out between the emission values of the two groups.

As there are many prominent pollutants present in the wastewater produced due to the textile manufacturing processes, aside from the BOD-COD-AOX emission levels as indicators, four metals, namely chromium, copper, nickel and zinc releases to water were included in the cross-country comparison of AELs for the textiles sector. It is noted that chromium releases set in the MINAS were higher than the other BREFs, and, the K-BREF, VITO (VLAREM-II) and the EHS guideline have set the same AEL of 0.5 mg/dm^3. In general comparison of the AELs set for metals included, the EU-BREF generally set much lower levels than the other BREFs. The US-technology based performance standards and the EHS Guideline have the same AELs set for copper, nickel and zinc (0.5 mg/L for copper and nickel, and 2.0 mg/L for zinc). Only EU-BREF and VITO (VLAREM-II) reported AELs for indirect discharges of the metals, and the EU-BREF has set the lowest AELs for each indirect discharge of metals. Since no other BREFs have reported separate AELs for direct and indirect discharges for metals (except for India for chromium), no comparative analyses were carried out between the emission values of the two groups.

5 Appendices

NGO BREF document on Thermal Power Plant sector

An Environmental NGO (the European Environmental Bureau) also developed an in-house BREF for electricity generation, with support from the renewable energy industries. The 'Reference Environmental Standards for Energy Techniques (RESET) guidance (EEB, 2021[11]) aims at assessing the impacts of different energy technologies, finding the best techniques to generate energy with lower environmental impact and move towards a cleaner energy mix. It is a tool aimed at supporting civil society and policy makers in their delivery of national and local solutions for better understanding the impacts of energy generation and the move towards a cleaner energy mix.

Table 46. Scope of the EEB BREF - TPP

BREFs	Fuel / technology	Capacity	Boundary	Age
RESET (NGO) guidance	Different techniques for electricity generation, including thermal options	Various options, including thermal combustion >50MWth, exclusion from scope in version 1: fossil oil, municipal waste, nuclear, liquid biofuels, ocean energy, concentrated solar power, ambient heat capture and solar thermal heat	Approach is Life-cycle-assessment (LCA) based but excludes certain options due to lack of data (see page 11 of RESET)	Guidance was developed in January 2021 and (kick off) and finalized on 25 October 2021

The EEB 'RESET guidance' is non-binding and serves as a tool aimed at supporting civil society and policy makers in their delivery of national and local solutions for better understanding the impacts of energy generation and move towards a cleaner energy mix. It has a fuller life-cycle assessment approach compared to the other BREFs covered by this report. The BAT rating was based on several key environmental indicators (KEI) on which basis an environmental score (Escore) – traffic light system - was derived, for most cases the metric is impact per TWh. The following environmental areas were assessed: land use, water pollution, water use, air pollution, climate, material use (where available) energy payback time. For each technique option, a margin of progress was derived.

This guidance derived a metric called 'energy payback time' (EPBT). The energy payback time was defined as the required period in which the energy technology can produce the same amount of energy (most often electricity converted into equivalent primary energy) than the energy consumed over its life cycle. The energy consumed during its life cycle corresponded to the total amount of energy required to procure the fuel or extract the materials, build, operate, and decommission the facility.

BAT-AELs for US-EPA

Within the Textile Mills regulation (US EPA, 1982[45]), the US-EPA sets wastewater discharge limits for nine different subcategories of processes. Any treatment technology may be used provided it meets the massed base discharge requirements (expressed as kilograms of pollutant discharged per thousand kilograms of product produced, kg/kkg). Best Practicable Technology (BPT) is the minimum standard for existing point sources of conventional, toxic, or non-conventional pollutants. If local water quality standards require more treatment, then the permitting authority may require the use of Best Available Technology (BAT) standards for toxic or non-conventional pollutants. The BPT and BAT standards are for existing facilities that directly discharge to Waters of the United States. Existing facilities are those that were established prior to July 01, 1977. For facilities established after July 01, 1977, the New Source Performance Standards (NSPS) are required. Facilities that discharge to a municipal wastewater treatment facility only need to meet the local, municipal discharge requirements since municipal wastewater treatment facilities, by regulation, must have a treatment technology in place to meet or exceed the standards for the Textile Mills regulation.

Table 47. BAT-AELs used in Textiles manufacture sector (US-EPA)

Wool Scouring Subcategory kg/kkg fiber						
	BPT		BAT		NSPS	
	1-day max	30-day avg.	1-day max	30-day avg.	1-day max	30-day avg.
BOD5	10.6	5.3			3.6	1.9
COD	138	69	138	69	52.4	33.7
TSS	32.2	16.1			30.3	13.5
Oil and Grease	7.2	3.6				
Sulfide	0.2	0.1	0.2	0.1	0.2	0.1
Phenol	0.1	0.05	0.1	0.05	0.1	0.05
Total chromium	0.1	0.05	0.1	0.05	0.1	0.05
pH	*	*			*	*

Wool Finishing Subcategory Wool finishers including carbonizing fulling, dyeing, bleaching, rinsing, fireproofing, and other similar processes **kg/kkg fiber**						
	BPT		BAT		NSPS	
	1-day max	30-day avg.	1-day max	30-day avg.	1-day max	30-day avg.
BOD5	22.4	11.2			10.7	5.5
COD	163	81.5	163	81.5	113.8	73.3
TSS	35.2	17.6			32.3	14.4
Sulfide	0.28	0.14	0.28	0.14	0.28	0.14
Phenol	0.14	0.07	0.14	0.07	0.14	0.07
Total chromium	0.14	0.07	0.14	0.07	0.14	0.07
pH	*	*			*	*

Low Water Use Processing Subcategory Yarn manufacture, yarn texturizing, unfinished fabric manufacture, fabric coating, fabric laminating, tire cord, fabric dipping, carpet tufting, carpet backing **kg/kkg product**						
General Processing	BPT		BAT		NSPS	
	1-day max	30-day avg.	1-day max	30-day avg.	1-day max	30-day avg.
BOD5	1.4	0.7			1.4	0.7
COD	2.8	1.4	2.8	1.4	2.8	1.4
TSS	1.4	0.7			1.4	0.7

pH	*	*			*	*
Water Jet Weaving	BPT		BAT		NSPS	
	1-day max	30-day avg.	1-day max	30-day avg.	1-day max	30-day avg.
BOD5	8.9	4.6			8.9	4.6
COD	21.3	13.7	21.3	13.7	21.3	13.7
TSS	5.5	2.5			5.5	2.5
pH	*	*			*	*

Woven Fabric Finishing Subcategory Desizing, bleaching, mercerizing, dyeing, printing, resin treatment, water proofing, flame proofing, soil repellency application, and special finish application **kg/kkg product**						
General	BPT		BAT		NSPS	
	1-day max	30-day avg.	1-day max	30-day avg.	1-day max	30-day avg.
BOD5	6.6	3.3			3.3	1.7
COD	60	30	60	30	41.7	26.9
TSS	17.8	8.9			8.8	3.9
Sulfide	0.2	0.1	0.2	0.1	0.2	0.1
Phenol	0.1	0.05	0.1	0.05	0.1	0.05
Chromium	0.1	0.05	0.1	0.05	0.1	0.05
pH	*	*			*	*
Commission finishing Simple manufacturing with synthetic fiber OR complex manufacturing with natural fiber	BPT		BAT			
	1-day max	30-day avg.	1-day max	30-day avg.		
COD	20	10	20	10		
Commission finishing Simple manufacturing with natural and synthetic fiber blend OR complex manufacturing with synthetic fiber	BPT		BAT			
	1-day max	30-day avg.	1-day max	30-day avg.		
COD	40	20	40	20		
Commission finishing Complex manufacturing with natural and synthetic fiber blend	BPT		BAT			
	1-day max	30-day avg.	1-day max	30-day avg.		
COD	60	30	60	30		
Complex manufacturing operations					NSPS	
					1-day max	30-day avg.
BOD5					3.7	1.9
COD					68.7	44.2
TSS					14.4	6.4
Sulfide					0.2	0.1
Phenol					0.1	0.05
Chromium					0.1	0.05
pH					*	*
Desizing					NSPS	

		1-day max	30-day avg.
BOD5		3.7	2.8
COD		68.7	38.3
TSS		14.4	6.9
Sulfide		0.2	0.1
Phenol		0.1	0.05
Chromium		0.1	0.05
pH		*	*

Knit Fabric Finishing Subcategory
Bleaching, mercerizing, dyeing, printing, resin treatment, water proofing, flame proofing, soil repellency application, and special finish application
kg/kkg product

General	BPT		BAT		NSPS (Simple manuf.)	
	1-day max	30-day avg.	1-day max	30-day avg.	1-day max	30-day avg.
BOD5	5	2.5			3.6	1.9
COD	60	30	60	30	48.1	31
TSS	21.8	10.9			13.2	5.9
Sulfide	0.2	0.1	0.2	0.1	0.2	0.1
Phenol	0.1	0.05	0.1	0.05	0.1	0.05
Chromium	0.1	0.05	0.1	0.05	0.1	0.05
pH	*	*			*	*
Commission finishing Simple manufacturing with natural and synthetic fiber OR complex manufacturing with synthetic fiber	BPT		BAT			
	1-day max	30-day avg.	1-day max	30-day avg.		
COD	20	10	20	10		
Commission finishing Complex manufacturing with natural and synthetic fiber blend	BPT		BAT			
	1-day max	30-day avg.	1-day max	30-day avg.		
COD	40	20	40	20		
Complex manufacturing operations					NSPS	
					1-day max	30-day avg.
BOD5					4.8	2.5
COD					51	32.9
TSS					12.2	5.4
Sulfide					0.2	0.1
Phenol					0.1	0.05
Chromium					0.1	0.05
pH					*	*
Hosiery Products					NSPS	
					1-day max	30-day avg.
BOD5					2.3	1.2
COD					30.7	19.8
TSS					8.4	3.7

	BPT 1-day max	BPT 30-day avg.	BAT 1-day max	BAT 30-day avg.	NSPS 1-day max	NSPS 30-day avg.
Sulfide					0.2	0.1
Phenol					0.1	0.05
Chromium					0.1	0.05
pH					*	*

Carpet Finishing Subcategory

Bleaching, scouring, carbonizing, fulling, dyeing, printing, resin treatment, water proofing, flame proofing, soil repellency application, looping, and backing with foamed and unfoamed latex and jute

kg/kkg product

General	BPT		BAT		NSPS	
	1-day max	30-day avg.	1-day max	30-day avg.	1-day max	30-day avg.
BOD5	7.8	3.9			4.6	2.4
COD	70.2	35.1	70.2	35.1	26.6	17.1
TSS	11	5.5			8.6	3.8
Sulfide	0.08	0.04	0.08	0.04	0.08	0.04
Phenol	0.04	0.02	0.04	0.02	0.04	0.02
Chromium	0.04	0.02	0.04	0.02	0.04	0.02
pH	*	*			*	*
Complex manufacturing	BPT		BAT			
	1-day max	30-day avg.	1-day max	30-day avg.		
COD	20	10	20	10		

Stock and Yarn Finishing Subcategory

Stock or yarn dyeing or finishing including cleaning, souring, bleaching, mercerizing, dyeing, and special finishing

kg/kkg product

General	BPT		BAT		NSPS	
	1-day max	30-day avg.	1-day max	30-day avg.	1-day max	30-day avg.
BOD5	6.8	3.4			3.6	1.9
COD	84.6	42.3	84.6	42.3	33.9	21.9
TSS	17.4	8.7			9.8	4.4
Sulfide	0.24	0.12	0.24	0.12	0.24	0.12
Phenol	0.12	0.06	0.12	0.06	0.12	0.06
Chromium	0.12	0.06	0.12	0.06	0.12	0.06
pH	*	*			*	*

Nonwoven Manufacturing Subcategory

Production of nonwoven textile products from wool, cotton, synthetics, singly or as blends, by mechanical thermal and/or adhesive bonding

kg/kkg product

General	BPT		BAT		NSPS	
	1-day max	30-day avg.	1-day max	30-day avg.	1-day max	30-day avg.
BOD5	4.4	2.2			2.6	1.4
COD	40	20	40	20	15.2	9.8
TSS	6.2	3.1			4.9	2.2
Sulfide	0.046	0.023	0.046	0.023	0.046	0.023
Phenol	0.023	0.011	0.023	0.011	0.023	0.011

Chromium	0.023	0.011	0.023	0.011	0.023	0.011
pH	*	*			*	*

Felted Fabric Processing Subcategory Fulling or felting to achieve fiber bonding **kg/kkg product**						
General	BPT		BAT		NSPS	
	1-day max	30-day avg.	1-day max	30-day avg.	1-day max	30-day avg.
BOD5	35.2	17.6			16.9	8.7
COD	256.8	128.4	256.8	128.4	179.3	115.5
TSS	55.4	27.7			50.9	22.7
Sulfide	0.44	0.22	0.44	0.22	0.44	0.22
Phenol	0.22	0.11	0.22	0.11	0.22	0.11
Chromium	0.22	0.11	0.22	0.11	0.22	0.11
pH	*	*			*	*

Belgium (Flanders) - VLAREM II - ELVs

Besides selecting BAT for preventing and/or minimising the emissions to water of brominated flame retardants (Deca-BDE and HBCD), diantimony trioxide (Sb_2O_3), perfluorooctane sulfonate (PFOS), perfluorooctanoic acid (PFOA), nonylphenols (NP), nonylphenol ethoxylates (NPE) and polycyclic aromatic hydrocarbons (PAH), the Flemish textile BAT study (VITO, 2010[41]) aimed to determine BAT-AELs for these parameters and to propose sectoral ELVs. Table 48 gives a summary of these parameters for which VLAREM II contains ELVs. In column 'Notes', it is indicated which ELVs are based on the BAT-AELs of the BAT study.

Table 48. Additional important parameters with sectoral ELVs in VLAREM II, based on the BAT-AELs of the Flemish BAT study for the textile industry reducing emissions of some micro-pollutants via wastewater (2010) (Flanders, Belgium)

parameter	direct discharge daily averages			indirect discharge (via municipal WWTP) daily averages		
	ELV	Units	Notes	ELV	Units	Notes
Perfluorinated tensides (PFT)						
PFOA (Perfluorooctanoic acid or pentadecafluorooctanoic acid)	0.05	mg/l		0.05	mg/l	
PFOS (Perfluorooctane sulphonate or heptadecafluorooctane sulphonate)	0.01	mg/l		0.01	mg/l	
sum PFT without PFOA and PFOS	0.2	mg/l		0.2	mg/l	
deca-BDE/BDE-209 (Decabromodiphenyl ether)						
used by the textile plant	20	µg/l	based on Flemish TXT BAT study (BAT-AELs: <20 µg/l)	20	µg/l	
not used by the textile plant	10	µg/l	based on Flemish TXT BAT study (BAT-AELs: <10 µg/l)	10	µg/l	based on Flemish TXT BAT study (BAT-AELs: <10 µg/l)
HBCD (Hexabromecyclododecane)						
used by the textile plant	10	µg/l	based on Flemish TXT BAT study (BAT-AELs: <10 µg/l)	10	µg/l	based on Flemish TXT BAT study (BAT-AELs: <10 µg/l)
not used by the textile plant	2	µg/l	based on Flemish TXT BAT study (BAT-AELs: <2 µg/l)	2	µg/l	based on Flemish TXT BAT study (BAT-AELs: <2 µg/l)
Antimony (Sb_2O_3)	1	mg/l	based on Flemish TXT BAT study (BAT-AELs: <1 mg/l)	1	mg/l	based on Flemish TXT BAT study (BAT-AELs: <1 mg/l)

Korea K-BREF BAT-AELs

Table 49. Textile dyeing and finishing processes BAT-AEL set in the K-BREF for air emissions and water releases

- **Emissions to air**

Classification				Pollution	Unit	BAT-AEL
Major	Middle	Minor	Capacity			
Textile dyeing and finishing	Processing	Pre-treatment		Dust	mg/Sm^3	4~24
				HCl	ppm	1~4
				Cd	mg/Sm^3	0~0.1
		Dyeing/ Finishing		HCl	ppm	1~2
				Phenol	ppm	0~2
				Hydrocarbon	ppm	7~34
	Incineration	Wastegas	Less than 2 ton/h	SOx	mg/Sm^3	4~27
				CO	ppm	21~154
				HCl	ppm	2~13
		Wastewater/ waste	Less than 2 ton/h	SOx	ppm	5~27

- **Releases to water**

Pollution	Capacity(Region)	BAT-AEL(mg/L)
COD	2,000ton/day-(Clean)	18 ~ 30
SS	2,000ton/day–(Clean)	2 ~ 17
T-N	(Clean)	12 ~ 30

References

Aleksei Kholodov, A. (2020), "Identification of cement in atmospheric particulate matter using the hybrid method of laser diffraction analysis and Raman spectroscopy", *Heliyon*, Vol. 6/2, https://doi.org/10.1016/j.heliyon.2020.e03299. [108]

Atiofny (n.d.), *Low NOx Burners & Boilers*, https://atiofny.com/low-nox-burners-boilers/. [79]

Belyakov, N. (2019), *Chapter Eight - Efficient and clean combustion of fossil fuels within boiler island*, https://doi.org/10.1016/B978-0-12-817012-0.00019-0. [55]

Cheremisinoff, N. (2012), "2 - Solid Wastes", *Clean Electricity Through Advanced Coal Technologies*, pp. 31-61, https://doi.org/10.1016/B978-1-4377-7815-1.00002-3. [49]

Cheremisinoff, N. and P. Rosenfeld (2010), *Chapter 6 - Sources of air emissions from pulp and paper mills*, https://doi.org/10.1016/B978-0-08-096446-1.10006-1. [53]

Cobbing, M. and E. Ruffinengo (2013), *Textiles: Stop the chemical overdose*, https://wecf-france.org/wp-content/uploads/2019/10/Textiles-report-2013-right-size.pdf. [105]

CPCB (2021), *Pollution Control Acts, Rules and Notifications issued thereunder*, https://cpcb.nic.in/7thEditionPollutionControlLawSeries2021.pdf. [10]

CPCB (2000), *Comprehensive Industry Document on Textile Industries*, Central Pollution Control Board of India, https://cpcb.nic.in/openpdffile.php?id=UHVibGljYXRpb25GaWxlLzE2Ml8xNDU3MDAwNjk3X1B1YmxpY2F0aW9uXzE4N19zZWMzXzU5LnBkZg==. [43]

CPCB (1986), *Minimal National Standards Thermal Power Plants*, Central Board for the Prevention and Control (CBPC) of Water Pollution and the Ministry of Environment, Forest and Climate Change ,India, https://cpcb.nic.in/openpdffile.php?id=UHVibGljYXRpb25GaWxlLzk2XzE0NTY5OTY1MjVfUHVibGljYXRpb25fMjIwX3NlYzNfMjEucGRm. [26]

D.J. Roddy, C. (2012), *5.10 - Biomass Gasification and Pyrolysis*, https://doi.org/10.1016/B978-0-08-087872-0.00514-X. [51]

Das, S. (2006), *Textile Effluent Treatment – A Solution to the Environmental Pollution*, https://www.fibre2fashion.com/industry-article/740/textile-effluent-treatment. [99]

Dijkmans, R. (2000), "Methodology for selection of best available techniques (BAT) at sector level", *Journal of Cleanar Production*, Vol. 8, pp. 11-21. [21]

Ding, Y; Cao, L; Zhou, L; Qian, K; Tang, J; Zhou, J; Dong, S (2022), "Determination of adsorbable organic halogens in textiles by ultrasonic extraction-high temperature combustion absorption-ion chromatography", *Se Pu.*, Vol. 40/1, pp. 74-81, https://doi.org/10.3724/SP.J.1123.2021.03018. [109]

Earnhart, D. (2013), "Water Pollution from Industrial Sources", *Encyclopedia of Energy, Natural Resource, and Environmental Economics*, Vol. 3, pp. 114-120, https://doi.org/10.1016/B978-0-12-375067-9.00091-7. [110]

EC (2020), *COMMISSION STAFF WORKING DOCUMENT EVALUATION of the Industrial Emissions Directive (IED) DIRECTIVE 2010/75/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 24 November 2010 on industrial emissions (integrated pollution prevention and control)*, https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=SWD:2020:0181:FIN:EN:PDF. [111]

EC (2003), *EU Emissions Trading System (EU ETS)*, https://ec.europa.eu/clima/eu-action/eu-emissions-trading-system-eu-ets_en. [31]

EC CORDIS (2019), *Improved Novel Eco-Friendly Bleaching System for Cotton Using Enzyme and Ultrasound Processes*, https://cordis.europa.eu/project/id/243529. [100]

EEA (2018), *Efficiency of conventional thermal electricity and heat production in Europe*, https://www.eea.europa.eu/data-and-maps/indicators/efficiency-of-conventional-thermal-electricity-generation-4/assessment-2. [73]

EEA (2016), *2.A.1 Cement production: EMEP/EEA air pollutant emission inventory guidebook*, https://www.eea.europa.eu/publications/emep-eea-guidebook-2016/part-b-sectoral-guidance-chapters/2-industrial-processes/2-a-mineral-products/2-a-1-cement-production-2016. [82]

EEA (2011), *Emission intensity of public conventional thermal power electricity and heat production*, https://www.eea.europa.eu/data-and-maps/indicators/emissions-co2-so2-nox-intensity-1/assessment-1. [72]

EEA (n.d.), *Pollutant Index*, https://industry.eea.europa.eu/pollutants/pollutant-index. [64]

EEB (2021), *The Reference Environmental Standards for Energy Techniques (RESET) guidance*, https://eeb.org/library/the-reference-environmental-standards-for-energy-techniques-reset-guidance/. [11]

EIPPCB (2022), *Best Available Techniques (BAT) Reference Document for the Textiles Industry - Industrial Emissions Directive 2010/75/EU (Integrated Pollution Prevention and Control) - Final Draft*, Joint Research Centre (JRC), https://eippcb.jrc.ec.europa.eu/sites/default/files/2022-03/TXT_Final_draft_B-W.pdf. [40]

EIPPCB (2017), *Best Available Techniques (BAT) Reference Document for Large Combustion Plants*, https://doi.org/10.2760/949. [7]

EIPPCB (2013), *Best Available Techniques (BAT) Reference Document for the Production of Cement, Lime and Magnesium Oxide*, European IPPC Bureau, https://doi.org/10.2788/12850. [6]

EIPPCB (n.d.), *Sevilla Process*, https://eippcb.jrc.ec.europa.eu/about/sevilla_process. [112]

Enviro BLR (2003), *What Is the Basic Difference Between SCRs and SNCRs? Which Is a Better Method to Reduce NOx?*, https://enviro.blr.com/environmental-faqs/air/CAA-air-regulations/What-Is-the-Basic-Difference-Between-SCRs-and-SNCR. [70]

EP (2021), *The impact of textile production and waste on the environment (infographic)*, https://www.europarl.europa.eu/news/en/headlines/society/20201208STO93327/the-impact-of-textile-production-and-waste-on-the-environment-infographic. [89]

EU (2010), *DIRECTIVE 2010/75/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 24 November 2010 on industrial emissions (integrated pollution prevention and control) (Recast)*, https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32010L0075&rid=1. [107]

Feng, Y. and L. Cui (2018), “Yupeng Feng, Yuzhong Li, Lin Cui”, *Fuel*, Vol. 224, pp. 801-813, https://doi.org/10.1016/j.fuel.2018.03.118. [63]

Gal, P. et al. (2017), “Selective Non-catalytic Reduction (SNCR) and its Efficiency with Respect to Various Combustion Parameters”, *CHEMICAL ENGINEERING TRANSACTIONS*, https://doi.org/10.3303/CET1756320. [71]

Herrera-González, A., A. Peláez-Cid and M. Caldera-Villalobos (2017), “Adsorption of textile dyes present in aqueous solution and wastewater using polyelectrolytes derived from chitosan”, *Journal of Chemical Technology and Biotechnology*, Vol. 92/7, pp. 1488-1495, https://doi.org/10.1002/jctb.5214. [98]

Hotza, D. and B. Maia (2015), “20 - Environmental performance and energy assessment of fired-clay brick masonry”, *Eco-Efficient Masonry Bricks and Blocks*, pp. 447-459, https://doi.org/10.1016/B978-1-78242-305-8.00020-6. [74]

IEA (2021), *Cement*, https://www.iea.org/reports/cement. [81]

IEA (2021), *Coal-Fired Power*, https://www.iea.org/reports/coal-fired-power. [67]

IEA (2019), *The Role of Gas in Today’s Energy Transitions: World Energy Outlook special report*, https://www.iea.org/reports/the-role-of-gas-in-todays-energy-transitions. [68]

IFC (2018), *Environmental, Health, and Safety Guidelines for Cement and Lime Manufacturing DRAFT FOR PUBLIC CONSULTATION—AUGUST 2018*, International Finance Corporation, World Bank Group, https://www.ifc.org/wps/wcm/connect/52592e0e-8475-4231-ba50-aeeb432e8e3c/20180719-Draft+for+2nd+Consultation-Cement+Lime+Mnfg.pdf?MOD=AJPERES&CVID=ml8Xzc7. [37]

IFC (2017), *Environmental, Health, and Safety Guidelines for Thermal Power Plants DRAFT FOR SECOND PUBLIC CONSULTATION—MAY/JUNE 2017*, International Finance Corporation, World Bank Group, https://www.ifc.org/wps/wcm/connect/9ec08f40-9bc9-4c6b-9445-b3aed5c9afad/Thermal+Power+Guideline+2017+clean.pdf?MOD=AJPERES&CVID=lNwcJZX. [30]

IFC (2008), *Environmental, Health, and Safety Guidelines for Termal Power Plant*, International Finance Corporation, World Bank Group, https://www.ifc.org/wps/wcm/connect/f82a5f06-f3f7-4033-8ea6-b767523cda8e/FINAL_Thermal%2BPower.pdf?MOD=AJPERES&CVID=jqeD9Eg&id=1323162579734. [29]

IFC (2007), *Environmental, Health, and Safety (EHS) Guidelines: General EHS Guidelines*, https://www.ifc.org/wps/wcm/connect/29f5137d-6e17-4660-b1f9-02bf561935e5/Final%2B-%2BGeneral%2BEHS%2BGuidelines.pdf?MOD=AJPERES&CVID=nPtguVM. [20]

IFC (2007), *Environmental, Health, and Safety Guidelines for Textile Manufacturing*, International Finance Corporation, World Bank Group, https://www.ifc.org/wps/wcm/connect/711c2479-baf7-461a-aa85-0e483625550a/Final%2B-%2BTextiles%2BManufacturing.pdf?MOD=AJPERES&CVID=jqeIcTk&id=1323162617789. [47]

IPCC (2007), *IPCC Fourth Assessment Report: Climate Change 2007, Section 7.4.5.1 Cement*, https://archive.ipcc.ch/publications_and_data/ar4/wg3/en/ch7s7-4-5.html#7-4-5-1. [86]

Jacobs A., B. (1998), *Best Available Techniques (BAT) for textile finishing*, Academia Press. [17]

Johnson, G. and M. Smith (1978), “Emissions of Nitrogen Dioxide from a Large Gas-Turbine Power Station, Combustion Science and Technology”, *Combustion Science and Technology*, pp. 67-70, https://doi.org/10.1080/00102207808946865. [56]

K.J. Ladwig, G. (2017), “3 - Flue-gas desulfurization products and other air emissions controls”, *Coal Combustion Products (CCP’s)*, pp. 67-95, https://doi.org/10.1016/B978-0-08-100945-1.00003-4. [50]

Kalaoglu, F. and R. Paul (2015), *14 - Finishing of jeans and quality control*, Woodhead Publishing, https://doi.org/10.1016/B978-0-85709-843-6.00014-7. [101]

Karam, A., E. Bakhoum and K. Zaher (2021), “Coagulation/flocculation process for textile mill effluent treatment: experimental and numerical perspectives”, *International Journal of Sustainable Engineering*, Vol. 14/5, pp. 983-995, https://doi.org/10.1080/19397038.2020.1842547. [95]

KEMI (2013), *Hazardous chemicals in textiles - report of a government assignment*, https://www.kemi.se/download/18.6df1d3df171c243fb23a98ff/1591454111687/rapport-3-13-textiles.pdf. [106]

Khan, R., V. Patel and Z. Khan (2020), *Chapter 5 - Bioremediation of dyes from textile and dye manufacturing industry effluent*, https://doi.org/10.1016/B978-0-12-818095-2.00005-9. [93]

Kong, Y. and M. Wood (2011), *Dry InjectIon of sodium sorbents for air pollution control*, Period Am Acad Environ Eng. [77]

Kumar, P. and K. Pavithra (2019), *2 - Water and Textiles*, Woodhead Publishing, https://doi.org/10.1016/C2017-0-03774-6. [94]

Li, D. and S. Liu (2019), *Chapter 12 - Water Quality Monitoring in Aquaculture*, https://doi.org/10.1016/B978-0-12-811330-1.00012-0. [92]

Lopez-Ruiz, G., I. Alava and J. Blanco (2021), “Study on the feasibility of the micromix combustion principle in low NOx H2 burners for domestic and industrial boilers: A numerical approach”, *Energy*, Vol. 236, https://doi.org/10.1016/j.energy.2021.121456. [78]

MEE (2017), *Guideline on available technologies of pollution prevention and control (GATPPC) for thermal power plant*, Science and Technology Standards Department of the Ministry of Environmental Protection and Ministry of Ecology and Environment, People's Republic of China, http://www.mee.gov.cn/ywgz/fgbz/bz/bzwb/wrfzjszc/201706/W020170609556701647383.pdf. [25]

MEE (2014), *Guideline on available technologies of pollution prevention and control (GATPPC) for Cement*, Science and Technology Standards Department of the Ministry of Environmental Protection and Ministry of Ecology and Environment, People's Republic of China, http://www.mee.gov.cn/gkml/hbb/bgg/201412/W020141212405767368972.pdf. [13]

MEE (2014), *Management technical specification of the operation of flue gas treatment facilities of thermal power plant*, https://www.mee.gov.cn/ywgz/fgbz/bz/bzwb/other/hjbhgc/201406/W020140619586671940748.pdf. [14]

MEE (2012), *Emission Standard of Air Pollutants for Thermal Power Plants*, http://www.mee.gov.cn/ywgz/fgbz/bz/bzwb/dqhjbh/dqgdwrywrwpfbz/201109/W020130125407916122018.pdf. [12]

MEE (2010), *Engineering technical specification of flue gas selective catalytic reduction denitration for thermal power plant*, https://www.mee.gov.cn/ywgz/fgbz/bz/bzwb/other/hjbhgc/201002/W020130201557706491721.pdf. [15]

MEE (2010), *Engineering technical specification of flue gas selective non-catalytic reduction denitration for thermal power plant*, https://www.mee.gov.cn/ywgz/fgbz/bz/bzwb/other/hjbhgc/201002/W020130201558185530931.pdf. [16]

MEE, C. (2021), *Guideline on available techniques of pollution prevention and control for textile industry*, https://www.mee.gov.cn/ywgz/fgbz/bz/bzwb/kxxjszn/202106/W020210809521494726861.pdf. [113]

MEFCC India (1994), *Comprehensive Evaluation of treatment technology for Cement Industry*, Ministry of Environment, Forest and Climate Change, https://cpcb.nic.in/openpdffile.php?id=UHVibGljYXRpb25GaWxlLzE0Nl8xNDU2OTk5MTUxX1B1YmxpY2F0aW9uXzE5NV9zZWMzXzQ5LnBkZg==. [34]

METI and MOE Japan (2020), *Reference Table on BAT*, Ministry of Economy, Trade and Industry and Ministry of the Environment, Japan, http://assess.env.go.jp/files/0_db/contents/0068_03/200100.pdf. [27]

Miller, B. (2005), *CHAPTER 6 - Emissions Control Strategies for Power Plants*, https://doi.org/10.1016/B978-012497451-7/50006-1. [52]

NETL (n.d.), *8.8. Sullfur oxides (SOx) emissions from coal*, https://netl.doe.gov/research/coal/energy-systems/gasification/gasifipedia/sox-emissions#:~:text=During%20high%2Dtemperature%20gasification%20of,to%20the%20reduced%20oxygen%20environment. [66]

NIER (2020), *Act on the Integrated Control of Pollutant - Dischargeing Facilities*, http://www.law.go.kr/. [18]

NIER (2019), *The Best Available Techniques (BAT) Reference Document for Textile Dyeing (K-BREF for Textiles)*, National Institute of Environmental Research (NIER) of South Korea, https://ieps.nier.go.kr/web/board/5/666/?page=1&pMENUMST_ID=95. [44]

NIER (2016), *Best Available Techniques Reference Document (K-BREF) on Electricity and Steam Production*, National Institute of Environmental Research, Korea, https://ieps.nier.go.kr/web/board/5/146/?page=2&pMENUMST_ID=95. [19]

OECD (2021), *Best Available Techniques (BAT) for Preventing and Controlling Industrial Pollution, Activity 5: Value chain approaches to determining BAT for industrial installations*, https://www.oecd.org/chemicalsafety/risk-management/value-chain-approaches-to-determining-best-available-techniques-industrial-installations.pdf. [5]

OECD (2020), *Best Available Techniques (BAT) for Preventing and Controlling Industrial Pollution, Activity 4: Guidance Document on Determining BAT, BAT-Associated Environmental Performance Levels and BAT-Based Permit Conditions*, Environment, Health and Safety Division, Environment Directorate, https://www.oecd.org/chemicalsafety/risk-management/guidance-document-on-determining-best-available-techniques.pdf. [4]

OECD (2019), *Best Available Techniques (BAT) for Preventing and Controlling Industrial Pollution, Activity 3: Measuring the Effectiveness of BAT Policies*, Environment, Health and Safety Division, Environment Directorate, http://www.oecd.org/chemicalsafety/risk-management/measuring-the-effectiveness-of-best-available-techniques-policies.pdf. [3]

OECD (2018), *Best Available Techniques (BAT) for Preventing and Controlling Industrial Pollution, Activity 2: Approaches to Establishing Best Available Techniques Around the World*, Environment, Health and Safety Division, Environment Directorate, http://www.oecd.org/chemicalsafety/risk-management/approaches-to-establishing-best-available-techniques-around-the-world.pdf. [2]

OECD (2017), *Best Available Techniques (BAT) for Preventing and Controlling Industrial Pollution, Activity 1: Policies on BAT or similar concepts Across the World*, Environment, Health and Safety Division, Environment Directorate, http://www.oecd.org/chemicalsafety/risk-management/policies-on-best-available-techniques-or-similar-concepts-around-the-world.pdf. [1]

Rogoff, M. and F. Screve (2011), *Chapter 8 - Permitting issues*, https://doi.org/10.1016/B978-1-4377-7871-7.10008-5. [69]

Shang, S. (2013), *13 - Process control in dyeing of textiles*, https://doi.org/10.1533/9780857095633.3.300. [90]

Teh, C. (2016), "Recent Advancement of Coagulation–flocculation and Its Application in Wastewater Treatment", *Industrial & Engineering Chemistry Research*, Vol. 55 (16), pp. 4363–4389, https://doi.org/10.1021/acs.iec. [97]

U.K. Environment Agency (2021), *Post-combustion carbon dioxide capture: best available techniques (BAT)*, https://www.gov.uk/guidance/post-combustion-carbon-dioxide-capture-best-available-techniques-bat. [114]

UN (2015), *Paris Agreement*, https://unfccc.int/sites/default/files/english_paris_agreement.pdf. [87]

UNEP (2019), *Guidance on Best Available Techniques (BAT) and Best Environmental Practices (BEP)*, https://www.mercuryconvention.org/en/resources/guidance-best-available-techniques-and-best-environmental-practices. [8]

UNEP (n.d.), *Mercury releases from the cement industry*, https://www.unep.org/globalmercurypartnership/what-we-do/mercury-releases-cement-industry. [9]

US EPA (2021), *Basic Information about Air Emissions Monitoring*, https://www.epa.gov/air-emissions-monitoring-knowledge-base/basic-information-about-air-emissions-monitoring. [115]

US EPA (2021), *Fact-Sheet: Pollutant-Specific Significant Contribution Finding for Greenhouse Gas Emissions from New, Modified, and Reconstructed Stationary Sources: Electric Utility Generating Units, and Process for Determining Significance of Other NSPS Source*, https://www.epa.gov/sites/default/files/2021-01/documents/fs-111bscf-1-12-21.pdf. [59]

US EPA (2021), *Monitoring by Control Technique - Activated Carbon Adsorber*, https://www.epa.gov/air-emissions-monitoring-knowledge-base/monitoring-control-technique-activated-carbon-adsorber. [80]

US EPA (2021), *Monitoring by Control Technique - Electrostatic Precipitators*, https://www.epa.gov/air-emissions-monitoring-knowledge-base/monitoring-control-technique-electrostatic-precipitators. [54]

US EPA (2021), *What is Acid Rain?*, https://www.epa.gov/acidrain/what-acid-rain. [65]

US EPA (2020), *Docket for rulemaking: "National Emission Standards for Hazardous Air Pollutants: Coal- and Oil-Fired Electric Utility Steam Generating Units – Subcategory of Certain Existing Electric Utility Steam Generating Units Firing Eastern Bituminous Coal Refuse*, https://www.epa.gov/sites/default/files/2020-04/documents/mats_coal_refuse_cost-benefit_memo.pdf. [22]

US EPA (2020), *Printing, Coating, and Dyeing of Fabrics and Other Textiles: National Emission Standards for Hazardous Air Pollutants (NESHAP)*, https://www.epa.gov/stationary-sources-air-pollution/printing-coating-and-dyeing-fabrics-and-other-textiles-national. [48]

US EPA (2020), *Steam Electric Power Generating Effluent Guidelines and Standards*, https://www.epa.gov/eg/steam-electric-power-generating-effluent-guidelines. [32]

US EPA (2019), *Affordable Clean Energy Rule*, https://www.epa.gov/stationary-sources-air-pollution/affordable-clean-energy-rule. [62]

US EPA (2019), *Nitrogen Oxides (NOx) Control Regulations*, https://www3.epa.gov/region1/airquality/nox.html#:~:text=Nitrogen%20Oxides%20are%20a%20family,equipment%2C%20boats%2C%20etc.)&text=NOx%20often%20appears%20as%20a%20brownish%20gas. [85]

US EPA (2018), *AP-42: Compilation of Air Emissions Factors: Mineral Products Industry*, https://www3.epa.gov/ttn/chief/ap42/ch11/index.html. [83]

US EPA (2016), *EGU NOX Mitigation Strategies Final Rule TSD*, https://www.epa.gov/sites/default/files/2017-05/documents/egu_nox_mitigation_strategies_final_rule_tsd.pdf. [57]

US EPA (2015), *Disposal of Coal Combustion Residuals from Electric Utilities*, https://www.epa.gov/coalash/coal-ash-rule. [33]

US EPA (2015), *Federal Register : Standards of Performance for Greenhouse Gas Emissions From New, Modified, and Reconstructed Stationary Sources: Electric Utility Generating Units. Final Rule*, https://www.govinfo.gov/content/pkg/FR-2015-10-23/pdf/2015-22837.pdf. [60]

US EPA (2015), *NSPS for GHG Emissions from New, Modified, and Reconstructed Electric Utility Generating Units*, https://www.epa.gov/stationary-sources-air-pollution/nsps-ghg-emissions-new-modified-and-reconstructed-electric-utility#rule-summary. [61]

US EPA (2015), *Textile Manufacturing*, https://www.epa.gov/sites/default/files/2015-01/documents/k02028.pdf. [104]

US EPA (2012), *National Emission Standards for Hazardous Air Pollutants From Coal- and Oil-Fired Electric Utility Steam Generating Units and Standards of Performance for Fossil-Fuel-Fired Electric Utility. Final Rule*, https://www.govinfo.gov/content/pkg/FR-2012-02-16/pdf/2012-806.pdf. [28]

US EPA (2010), *Available and Emerging Technologies for Reducing Greenhouse Gas Emissions from the Portland Cement Industry*, https://www.epa.gov/sites/default/files/2015-12/documents/cement.pdf. [88]

US EPA (2010), *Regulatory Impact Analysis: Amendments to the National Emission Standards for Hazardous Air Pollutants (NESHAP) and New Source Performance Standards (NSPS) for the Portland Cement Manufacturing Industry*, https://www.epa.gov/sites/default/files/2016-04/documents/ria_cement-2010.pdf. [23]

US EPA (2000), *NOx Control Technologies for the Cement industry : Final Report*, https://nepis.epa.gov/Exe/ZyPDF.cgi/P1004PMC.PDF?Dockey=P1004PMC.PDF. [84]

US EPA (1996), *Best management practices for pollution prevention in the Textiles Industry*, https://www.epa.gov/sites/default/files/2020-04/documents/best-management-practices-textile-industry-manual.pdf. [102]

US EPA (1986), *Federal Regulations: Effluent limitations guidelines*, https://www.ecfr.gov/current/title-40/chapter-I/subchapter-N/part-408/subpart-P/section-408.167. [46]

US EPA (1984), *Wastewater Recycle and Reuse Potential for Indirect Discharge Textiles Finishing Mills*, https://nepis.epa.gov/Exe/ZyPDF.cgi/2000THRO.PDF?Dockey=2000THRO.PDF. [103]

US EPA (1982), *Development Document for Effluent Limitations Guidelines and Standards for the Textile Mills Point Source Category*, https://www.epa.gov/sites/default/files/2016-04/documents/textile-mills_dd_1982.pdf. [24]

US EPA (1982), *Textile Mills Point Source Category*, https://www.epa.gov/sites/default/files/2016-04/documents/textile-mills_final_09-02-1982_47-fr-38810.pdf. [45]

US EPA (1978), *Special Wastes*, https://www.epa.gov/hw/special-wastes#mining. [39]

US EPA (1977), *Cement Manufacturing Effluent Guidelines and Standards*, https://www.epa.gov/eg/cement-manufacturing-effluent-guidelines. [38]

US EPA (n.d.), *Air Pollution Technical Reports: Clean Air Technology Center Products*, https://www.epa.gov/catc/clean-air-technology-center-products#reports. [76]

US EPA (n.d.), *Clean Energy Programs*, https://www.epa.gov/energy/clean-energy-programs. [58]

US EPA (n.d.), *What is a Docket?*, https://www.epa.gov/dockets/about-epa-dockets. [116]

US EPA-NESHAP (2018), *National Emission Standards for Hazardous Air Pollutants From the Portland Cement Manufacturing Industry Residual Risk and Technology Review*, https://www.govinfo.gov/content/pkg/FR-2018-07-25/pdf/2018-15718.pdf. [36]

US EPA-NSPS (2015), *National Emission Standards for Hazardous Air Pollutants for the Portland Cement Manufacturing Industry and Standards of Performance for Portland Cement Plants*, https://www.govinfo.gov/content/pkg/FR-2015-07-27/pdf/2015-16811.pdf. [35]

USGS (2018), *Biological Oxygen Demand (BOD) and Water*, https://www.usgs.gov/special-topics/water-science-school/science/biological-oxygen-demand-bod-and-water. [91]

Verma, A., R. Dash and P. Bhunia (2021), “A Review on Chemical Coagulation/flocculation Technologies for Removal of Colour from Textile Wastewaters”, *Journal of Environmental Management*, Vol. 93, pp. 154–168, https://doi.org/10.1016/j.jenvman.2011.09. [96]

VITO (2010), *BAT-study for Textile - Micropollutants - Wastewater*, Vlaams BBT-Kenniscentrum, https://emis.vito.be/sites/emis/files/study/resume/en/BAT_abstract_textile%E2%80%93micropollutants%E2%80%93wastewater.pdf. [41]

VLAREM-II (n.d.), *annex 5.3.2.°44: sectoral ELV’s for Flemish textile installations*, https://navigator.emis.vito.be/mijn-navigator?woId=74932. [42]

Yuan, Q. et al. (2021), *Chapter 2 - Inorganic cementing materials*, https://doi.org/10.1016/B978-0-12-822865-4.00002-7. [75]

Industrial facilities play a major role in environmental consequences as their processes may use large amounts of raw materials and energy, and in return, may release significant amounts of pollutants into the air, water and soil. As part of their operational obligations, industrial facilities are required to meet various regulatory requirements in the form of emission limitations and/or standards of performance and environmental quality objectives at the local level.

This report is a cross-country analysis of BREFs for three selected industrial sectors; thermal power plants (TPP), cement production and textile manufacturing. It examines seven BREFs for TPP, five BREFs for cement production, and six BREFs for textile manufacturing from countries/organisations, including China, India, Japan, South Korea, the US, the EU, Belgium (Flanders), and the World Bank.

The information received from various jurisdictions may encourage and assist countries in their progress towards developing sector-specific BREFs. Beyond that, this comparative analysis may indicate the areas of possible harmonisation between countries, and also highlight the structures or parts of the BREFs that may need expanding or updating for better environmental impact considerations.

This is the sixth in a series of reports developed as part of the OECD's BAT project.

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