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

Activity 5: Value chain approaches to determining BAT for industrial installations

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BETTER POLICIES FOR BETTER LIVES

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Best Available Techniques (BAT) for Preventing and Controlling Industrial Pollution

Activity 5: Value chain approaches to determining BAT for industrial installations

Foreword

In most countries, Best Available Techniques (BAT) are understood to mean the most effective and advanced stage in the development of industrial activities and their methods of operation, designed to prevent and, where that is not practicable, to reduce emissions and the impact on the environment as a whole (OECD, 2017[1]). BAT concepts may be referred to by different terms in some countries. Typically, BAT are determined for processes within a sector, in isolation of the larger value chain. There may be opportunities to further reduce industrial emissions by considering the place of an installation within a larger value chain when making BAT determinations. In November 2018, the 58th Joint Meeting of the Chemicals Committee and the Working Party on Chemicals, Pesticides and Biotechnology agreed to conduct a study mapping the opportunities and challenges associated with value chain approaches to determining BAT for industrial installations.

The study thus aims to examine existing BAT frameworks (such as Best Available Techniques Reference documents or BREFs) to identify and assess gaps, such as in coverage of environmental impacts, production processes, effectiveness as well as efficiency in mitigating industrial emissions and whether those could be addressed through the application of value chain approaches. More specifically, the study explores how a value chain perspective can be reflected when determining BAT, whilst taking into account that BAT-based permitting applies at the level of industrial installations. Benefits of considering value chain aspects when determining BAT are highlighted while also accounting for challenges including that BAT determination within defined Sector / Installation boundaries is an already resource-intensive activity. To the extent possible, the study considered ways to systematically consider value chain concepts, and notes that further work to understand and develop such approaches would be beneficial.

The development of this document was led by the United States Environmental Protection Agency (EPA) and the OECD secretariat. An initial draft was presented at the 4th Meeting of the OECD’s Expert Group on BAT, in October 2019, followed by revisions based on reviews by the Expert Group.

This report is published under the responsibility of the Chemicals and Biotechnology Committee of the OECD.

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Acronyms

B2B	Business-to-Business
BAT	Best Available Techniques
BAT-AEL	BAT-Associated Emission Levels
BAT-AEPL	BAT-Associated Environmental Performance Levels
BAT-EA	Best Available Techniques Economically Achievable
BREF	BAT Reference Document
CAA	Clean Air Act
CELIS	Circular Economy Labelling and Information Schemes
CLP	Classification Labelling Packaging
DG	Directorate-General
EC	European Commission
ECHA	European Chemicals Agency
EMAS	Eco-Management and Audit Scheme
EPA	Environmental Protection Agency
ETS	Emissions Trading Systems
EU	European Union
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
FDM	Food, Drink and Milk
GHG	Greenhouse gas
HCS	Hazard Communication Standard
HAZBREF	Hazardous industrial chemicals in the IED BREFs
IED	Industrial Emissions Directive
LCP	Large Combustion Plant
LEED	Leadership in Energy and Environmental Design
MACT	Maximum Achievable Control Technology
NESHAP	National Emission Standards for Hazardous Air Pollutants
OECD	Organisation for Economic Co-Operation and Development
OSHA	Occupational Safety and Health Administration
POTWS	Publicly Owned Treatment Works
PPA	Pollution Prevention Act
PRTR	Pollutant Release and Transfer Register
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
SCIP	Substances of Concern In articles as such or in complex objects (Products)
SIPs	State Implementation Plans
SOx	Sulphur Oxides
SRD	Sectoral Reference Document
STS	Surface Treatment using Organic Solvents
TRI	Toxics Release Inventory
TSCA	Toxic Substances Control Act
UK	United Kingdom
UN	United Nations
UNECE	United Nations Economic Commission for Europe
US	United States
VITO	Vlaamse Instelling voor Technologisch Onderzoek – Flemish Institute for Technological Research
VOC	Volatile Organic Compound
VECAP	Voluntary Emissions Control Action Programme
WET	Whole effluent toxicity
WRI	World Resources Institute
WWTP	Wastewater treatment plant
ZDHC	Zero Discharge of Hazardous Chemicals Foundation

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Boxes

Executive summary

In the transition towards a non-polluting, resource efficient industry, greater consideration of value chains shows potential to deliver greater overall environmental benefit than less integrated approaches that focus on individual stages, such as installation or sectoral emissions. Actions taken at the design and manufacturing, or other product life phases, can influence environmental impacts at other stages such as material processing, and waste recycling. The overall life-cycle impacts need to be accounted for at the outset.

Reflecting its origins in sectoral and installation level emissions control, BAT policy does not generally mandate a systematic approach to considering factors beyond the defined industrial manufacturing activities, although it can and often does rely on ad hoc wider systems thinking. As a result, BAT determinations often take into account industry trends and environmental understanding such as innovations to enhance the environmental performance of products and services, although they are not specifically designed to take account of value chains.

Value chain refers to the process of adding incremental value to products and services as they are generated and transformed at each step along the production cycle. The benefit of taking more holistic value chain approaches to BAT determinations is the opportunity to consider broader sustainability goals, where the focus is not on “less emissions” or “reduced environmental impacts” from the *installation*, but rather upon finding overall solutions that reduce negative environmental impacts on a whole-system basis, whilst still providing local emissions control and the intended output, and hence benefits of the value chain as a whole (i.e. including the service or product output of the industrial activity).

This study assesses how value chain approaches are/should be incorporated in BAT determinations and related environmental regulatory and policy concepts to accelerate progress toward identifying practices that more effectively consider an industry’s entire value chain to reduce overall environmental impacts as well as individual manufacturing sites within a given sector *(Chapter 1).*

Four concepts for expanding BAT determination through a value chain perspective were considered *(Chapter 2)*:

- Green chemistry
- Resource efficiency
- Circular economy
- Decarbonisation

Using the commonalities among these four concepts as a lens, overarching BAT policy and three sector examples were then assessed, namely the Textiles, Paints and Coatings, and Food Industries. Environmental issues associated with their value chains were then considered including the upstream and downstream impacts from each sector. Some impacts arising from a lack of value chain consideration were also noted.

Some regulatory bodies have already responded to address value chain gaps appearing from a sectoral/installation BAT approach by overlaying them with cross-cutting initiatives including the application of other chemical safety legislation, voluntary programs such as the EU Eco-Management and Audit Scheme (EMAS), or specific BAT or other regulatory updates that address certain issues *(Chapter 3).*

Whilst the potential benefits of value chain thinking are noted, so are challenges. The challenges discussed in this report from an installation-level perspective include: the degree of control beyond facility boundaries, the availability of information about products including broad versus narrow product use, and how to account for internalized costs and externalized benefits of value chain thinking. Administrative complexity and resource challenges are also noted when incorporating value chain approaches into the existing BREF development processes, which are already complex and time-consuming *(Chapter 4).*

Further, ideas/recommendations are included on how to leverage existing resources and encourage the development of criteria/screening approaches that could be applied towards BAT development or implementation. Such screening approaches have the potential to overcome these “complexity and resource” challenges when including “cross-sector effects” or producing “value chain BAT”, by allowing existing processes to be maintained, and the variant “value chain BREF” to be produced following such “screening”. Further work is recommended to assess the approach and criteria that may be applied *(Chapter 5.1)*.

With many environmental issues being global as well as local, this work also identifies the importance of continued and enhanced utilisation of existing schemes or programmes that focus on management across value production/supply chains. Those schemes/programmes, including information-sharing platforms, environmental footprint labels, life-cycle assessments, and environmental performance indicators, could facilitate a value chain approach in BAT determination *(Chapter 5.2)*.

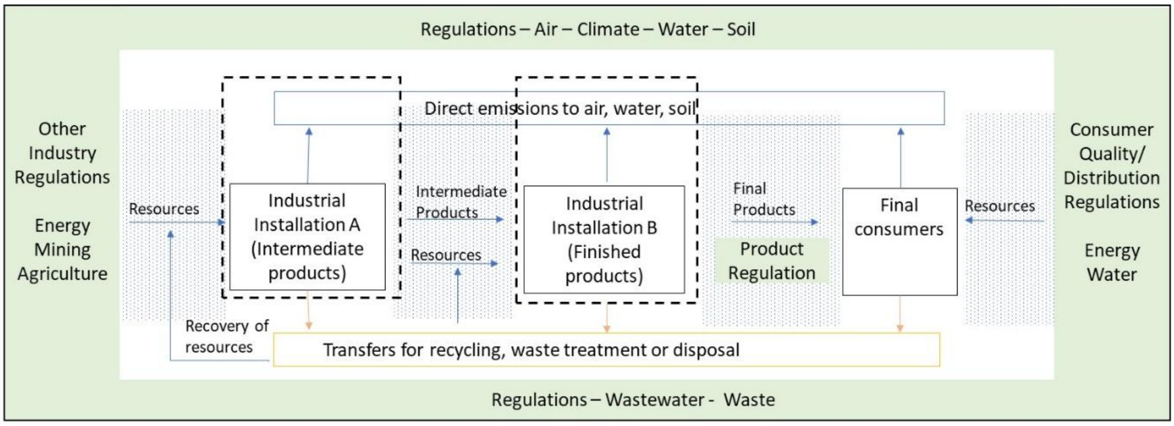
Towards the end of this study, we concluded that further research is needed to reduce overall environmental impacts throughout industry’s entire value chains. Possible topics to be explored include the extension of BAT to non-industrial sectors such as the development of city planning, energy, or waste/resources strategy development and broader environmental concepts *(Chapter 5.3)*.

1 What's the issue?

Role of BAT in a regulatory /market framework

Best Available Techniques (BAT) are usually established at the level of each industrial sector or activity to prevent or reduce emissions and the impact on the environment as a whole. Regulatory authorities typically set requirements for installation operations to prevent or reduce emissions to air, water, soil, energy and water consumption, and waste management through treatment or disposal. As shown in Figure 1, regulatory authorities tend to focus on installation activities that produce intermediate products or finished products depending on the size of the installation.

Figure 1. Illustration of BAT Regulatory Framework



Notes:
1. Dashed lines represent the industrial installation/activity regulated by BAT. Certain activities may supply materials to other regulated industries.
2. Grey dotted sections represent market interactions that may influence use of resources and products at each stage.
3. Framing the illustration are multiple regulations that protect natural resources, environment, and human health.

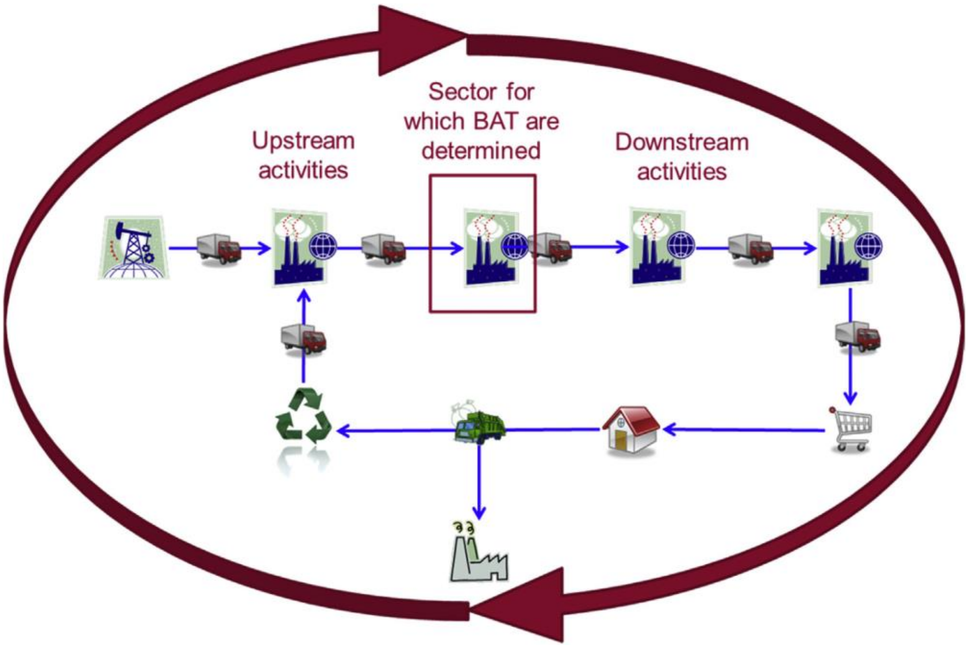
While procedures for establishing BAT aim to consider the most effective technologies and methods available considering the cost and the required site-specific environmental protection benefits, broad accounting of upstream and downstream interactions can be difficult. The extent to which particular countries and BAT policies consider the interactions within the value chain systematically or for specific sectors is unclear.

In general, establishing BAT takes 2 to 4 years with periodic review between 8 to 12 years, requiring resources and time for adequate consideration. When determining BAT for sector-specific activities, consideration of up- or downstream interactions of the sector's value chain may be limited. That is, a sector-specific activity may be impacted by upstream suppliers and affect downstream activities including further processing or consumer use that are not necessarily considered in BAT determinations. Additionally, the sector of focus could impose requirements upon upstream markets or be affected by downstream regulatory or market requirements.

Environmental regulation along with other regulatory requirements and market decisions define the framework within which an industrial installation operates. Sector activities, including essential inputs, are increasingly fragmented across the globe with installations carrying out a variety of different industrial processes. The different processes and installations from an individual production chain may be located in different countries (VITO, 2014[2]).

These production chain complexities and the broad array of factors, affecting a given industrial activity are not fully understood. In general, the establishment of BAT is focused upon dealing with industrial activities individually, in isolation. As such, there is the possibility that the BAT approaches identified do not adequately consider interactions with other industries and actors as shown in Figure 2.

Figure 2. Current Application of BAT



Source: (Huybrechts, D *et al*, 2018[3])

In the illustration above, the box is representative of established BAT requirements or guidance for a given sector. Global assessment across the value chain (*significant up-stream and/or connected operations, and relevant earlier steps of associated activities with a technical connection*) may indicate that the prescribed BAT-associated emission levels optimise environmental performance in one industrial process while at the same time have negative environmental implications on, influence the costs of, or the need for new techniques in, other parts of the value chain (VITO, 2014[2]).

While the multi-stakeholder groups in charge of establishing BAT – known as Technical Working Groups in some countries – may consider value chain effects in the development of some BREFs, this is usually not done systematically (VITO, 2014[2]). Industrial symbiosis and circular economy are described in Chapter 2 and Chapter 3, respectively. This lack of systematic methodology for value chain consideration may result in regulatory gaps, deficiencies or no net gain in pollution prevention or reduction. Thus, researchers have called for more explicit and methodical approaches to ensure that BAT form a consistent driver to greening global value chains and sustainable supply chain management (Huybrechts, D *et al*, 2018[3]).

Definitions and rationale

For a common understanding, key terms and concepts related to BAT and value chains are defined.

- **Best Available Techniques (BAT)** are understood to mean the most effective and advanced stage in the development of industrial activities and their methods of operation, designed to prevent and, where that is not practicable, to reduce emissions and the impact on the environment as a whole (OECD, 2017[1]).
- **Supply Chains** are used internationally to encompass every logistical and procedural activity involved in producing and delivering a final product or service, "from the supplier's supplier to the customer's customer" (Feller, Shunk and Callarman, 2006[3])".
- **Value Chains** represent all processes that generate or add incremental value necessary to bring goods and services to market. Value chains differ from, and are broader than, supply chains in that they encompass more than direct supplier-customer relationships (Reddy Amarender, 2013[4]). See Chapter 2 for a more extensive discussion.

Industrial installations and activities are interlinked through value chains. A value chain typically includes processes such as raw material production, manufacturing of primary materials, intermediate materials and end-products, distribution, use, waste collection, material recuperation or waste treatment and management processes. Due to interconnected industrial activities, research is needed to assess the extent to which conventional BAT determination delivers wider value chain considerations.

Project objectives and next steps

To set the context for evaluating the application of value chain approaches to BAT determinations, Chapter 2 of this document briefly describes four value chain approaches and discusses their commonalities, helping define the value chain lens used in this study.

Chapters 3 to 5 of this document aim to:

- examine the extent to which industrial value chains have been considered when establishing BAT or similar regulatory concepts and, if there is a lack of value chain consideration, to assess their impact;
- evaluate gaps in existing frameworks to assess if the application of value chain approaches could improve BAT determination;
- discuss challenges associated with the use of value chain approaches in the BAT determination process; and
- develop recommendations on if, and how, value chain approaches could be more widely incorporated in establishing BAT.

This study will hopefully lead to the systematic integration of value chain approaches into BAT determination, resulting in overall reductions of environmental impacts at the industrial sector level and at the installation level.

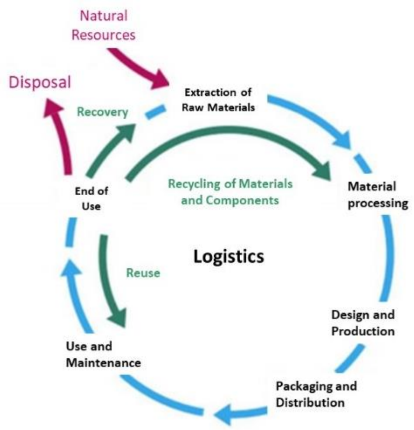
2 Expanding view of BAT determination through a value chain perspective

Value chains

Value chains describe the full range of value-adding activities required to bring a product or service through the different phases of its production, including procurement of raw materials and other inputs, assembly, physical transformation, acquisition of required services such as transport or cooling, and ultimately response to consumer demand (Kaplinsky and Morris, 2002[5]). As such, value chains include all vertically linked, interdependent processes that generate value (or something useful) for the consumer, as well as horizontal linkages to similar processes that provide goods and services serving the same customer.

The model depicted in Figure 3 (below) illustrates a sustainable value chain as the "full life-cycle of a product or process, including material sourcing, production, consumption and disposal/recycling processes." Value chains focus on value creation – typically via innovation in products or processes, as well as marketing – and also on the allocation of the incremental value (Webber and Labaste, 2010[6]). It is called a value chain because value is being added to the product or service as it is being transformed (Montalbano, Nenci and Salvatici, 2015[10]). As shown in Figure 3 and , at each transfer point in the chain there is an opportunity to add value, with examples for textile sector described in Table 1. Manufacturing is only one of many value-added links, and each link represents a range of activities that may feed into many other value chains. Manufacturers, for example, create value by acquiring processed materials and using them to produce something useful. Where the unsustainable model is often a straight line ending in disposal, the sustainable value chain focuses on closing and optimizing material loops.

Figure 3. Sustainable Value Chain Model



Source: Adapted from (WBCSD, 2011[7])

Table 1. Example Textile Sector Value Added

Example Textile Sector Value Added	
Extraction of Raw Materials	Harvest cotton; separate secondary materials for other streams
Material Processing	Refine material; produce cloth, add dyes
Design and Production	Consider impacts from material and chemical inputs; produce products (e.g., cotton clothing)
Packaging and Distribution	Minimal packaging; Clear labels for distributers and markets; Advertise value chain practices (manufacturing company and sustainable processing/extraction)
Use and Maintenance	Extend utility – reuse, donate, resend clothing to retailer
End of use	Recover valuable material; limit quantitites disposed; transform to other value goods.

Source: Adapted from (WBCSD, 2011[7])

The study of value chains expands traditional supply chain analysis by taking a broader look at primary and support activities to deliver maximum value to the end user for the least possible total cost (Topazio, 2014[8]). (Lysons and Farrington, 2006[9]). As such, supply chain management is a subset of the value-chain analysis. Analyses of value chains are also increasingly complex, as processes are fragmented across the globe (OECD, 2019[10]) with raw materials obtained from distant countries or intermediate products supplied to manufacturing installations in other geographical locations, creating a wide network of interdependencies.

Relevant to this study are the vertical interactions or *temporal* value chains, i.e. a series of industrial processes adding value to a product at each stage. Activities that are upstream and downstream of the focus manufacturing installation type will be considered, particularly those immediate linkages to production operations where external actors may directly or indirectly exert influence. Regarding other scope factors:

- Spatial clusters of similar or interrelated industries are critical to consider during BAT determination. However, the physical environment, local availability of resources, and demand are very specific to individual countries. To ensure the findings of this study are broadly applicable, it will not assess the geographic distribution of specific sectors.
- While the degree of control or influence by other actors engaged in the same value chain is an important consideration to understanding interactions, this study does not assess the levels of influence but rather draws awareness to likely forces be they market driven, regulatory mandates, or other incentives and/or barriers.

The following examples in Box 1 illustrate how industrial installations and activities are interlinked through value chains.

Box 1. Examples of industrial process linkages and impacts on the value chain

- Purchase or production of materials: The consideration of transport emissions is an essential element of a value chain approach to determining BAT. For example, installations in the ceramics industry could reduce SOX emissions by substituting raw materials that have a high sulphur (S) content with raw materials with lower S content. If the original raw materials are supplied locally, replacing them may require additional transport, leading to increased energy use and emissions in the value chain. On the other hand, some measures such as on-site production of auxiliaries may increase energy consumption at the installation level, but lower the energy use and associated emissions associated with transport, and therefore reduce the overall environmental impact of the value chain (VITO, 2014[2]).

- Consumer interests driving upstream changes: Coal-fired power plants generate fly ash as waste. This fly ash can be used to replace a portion of the cement, which is very energy intensive to produce, in concrete. However, fly ash from coal burning sometimes has high concentrations of mercury in the form of mercury oxides. Environmental certifications such as Leadership in Energy and Environmental Design (LEED) certification encourage the use of fly ash but limit its mercury content (USGBC, 2009[9]), incentivizing concrete manufacturers to source low-mercury fly ash. This in turn incentivises coal power plants to take measures to reduce the mercury in the fly ash, so they can sell it instead of disposing of it. Coal burning plants may reduce the mercury content in fly ash by using coal with lower mercury content, or they may apply controls which decrease air emissions of mercury from coal combustion. Mercury captured by pollution control devices is not destroyed but can be managed more safely than direct releases.

Value chain approaches

Whilst BAT are designed for implementation at the level of industrial installations to prevent and control direct industrial emissions, the question posed is whether more could be done at the installation level to consider value chains more broadly and uniformly under the varying authorities that determine BAT for a particular sector.

Existing BAT policies and efforts encourage more holistic accounting of potential environmental impacts, seeking to study upstream and downstream interactions when establishing sector BATs. However, to date, broader assessments systematically considering industrial sector interactions have not been conducted uniformly across BAT policies and in an efficient manner.

Various concepts can be described as value chain approaches designed to holistically minimize and prevent impacts to the environment and human health. Such concepts include green chemistry, resource efficiency, circular economy, and decarbonisation and could be applied as a lens by which to assess sector interactions during the BAT determination process. Brief descriptions are provided below.

Green chemistry

Green chemistry is the design of chemical products and processes that reduce or eliminate the use or generation of hazardous substances by looking across the life cycle of a chemical product, including its design, manufacture, use, and ultimate disposal (US EPA, n.d.[11]). Twelve principles demonstrate the breadth of green chemistry as focused on the prevention of waste and reduction of hazard in the inputs and products of chemical synthesis (see Annex 5.B).

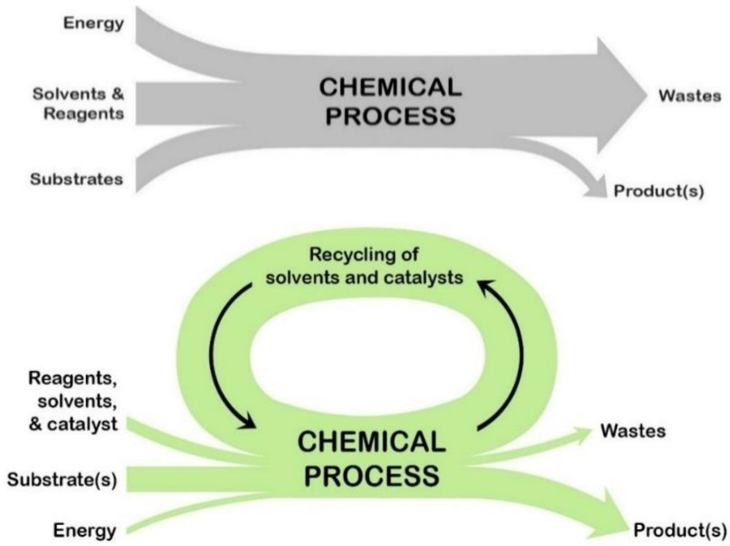
Even prior to the 'establishment' of green chemistry as a concept in the 1990s, industry has successfully applied these principles to a variety of syntheses and chemical processes to reduce their environmental impacts, resource intensity, and associated operating costs and continues to do so.

The concept of green chemistry is closely related to sustainable chemistry, which is defined by the OECD as a scientific concept that seeks to improve the efficiency with which natural resources are used to meet human needs for chemical products and services (OECD, n.d.[12]). Sustainable chemistry is sometimes slightly broader in scope, seeking to minimize environmental impact and stimulate innovation across all sectors through design of new chemicals, production processes, and product stewardship practices. Nine golden rules summarize the most important principles of sustainable chemistry (see Annex 5.C) (Reihlen, A *et al*, 2016[15]).

Certain principles of green chemistry may impact value chains in a variety of ways. For instance, substitutions of input materials with renewable or safer alternatives occur through changes in upstream material supply and may impact downstream activities such as waste management or product use. It is key to carefully evaluate these downstream impacts to avoid regrettable substitutions. Principles such as designing for waste prevention and resource efficiency may also impact downstream activities; the quantity and characteristics of waste can have a dramatic impact on the efficiency of treatment operations. Similarly, designing for degradation may affect the types of materials available for downstream reclamation, reuse, and recycling.

Considering BAT determination through a green chemistry lens might result in identification of alternative chemicals and technologies that are economically competitive and offer advantages for industry and consumers, and (of course) are environmentally advantageous. Figure 4 illustrates how chemical use can be optimized through a green chemistry approach. In a 'typical' conventional chemicals process (in grey), a large amount of waste is produced relative to the amount of product. Implementation of green chemistry principles (in green) can lead to greater resource and energy efficiency, waste minimization, and recycling and regeneration of certain inputs.

Figure 4. Green Chemistry Example



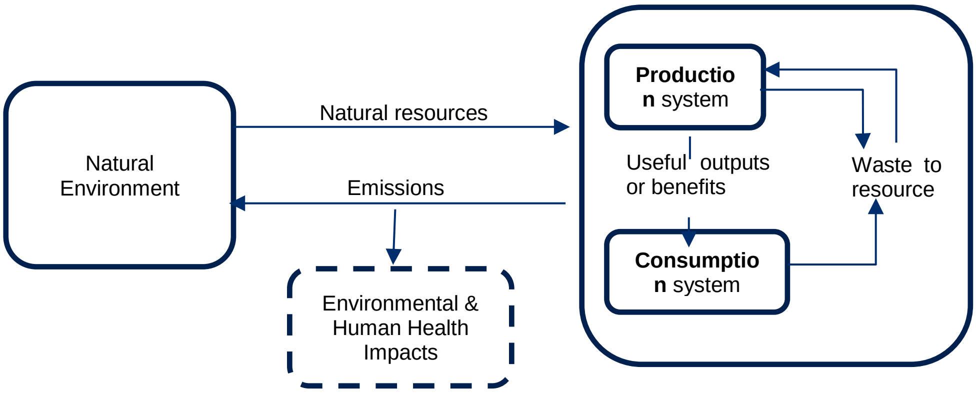
Source: Adapted from: Green Chemistry (Organic Chemistry, n.d.[13])

Resource efficiency

While definitions of resource efficiency may vary greatly depending on scope and scale, the European Commission notes that the goal of resource efficiency is to "deliver greater value with less input" (EC, 2020[14]). As such, resource efficiency can be considered as the ratio of the benefits derived from a process (generally as value added) to quantity of resources used and/or the environmental impact associated with resource use (Huysman, Sofie *et al*, 2015[18]). In common terms, resource efficiency can be defined as a unit of resource input per unit of product output (EC, 2016[15]), e.g., kilogram clay (input) per kilogram ceramic tiles (output), and cubic meter water (input) per ton meat produced (output). Therefore, maximizing for resource efficiency can achieve cost savings and reduce emissions. The concept of resource efficiency is illustrated below, in Figure 5.

At the scale of the individual installation, resources include natural and processed natural resources (industrial resources). These resources generally include some combination of the following: raw materials, water, chemical agents, process residues, packaging, and equipment. Additionally, energy efficiency is often considered a component of resource efficiency.

Figure 5. Illustration of the Resource Efficiency Concept



Source: Modified illustration of (Huysman, Sofie *et al*, 2015[18])

The concept of using and re-using resources more efficiently is also addressed through similar approaches including EPA's and OECD's Sustainable Materials Management, which considers the impacts of materials throughout the entire life cycle to reduce environmental impacts at each stage and throughout (OECD, 2008[16]) (US EPA, 2019[17]). Other concepts in place include Japan's Sound Material-Cycle Society (MOEJ, 2018[18]), UNEP's Sustainable Production and Consumption (UNEP, 2015[19]), and Zero Waste (ZWIA, 2021[20]).

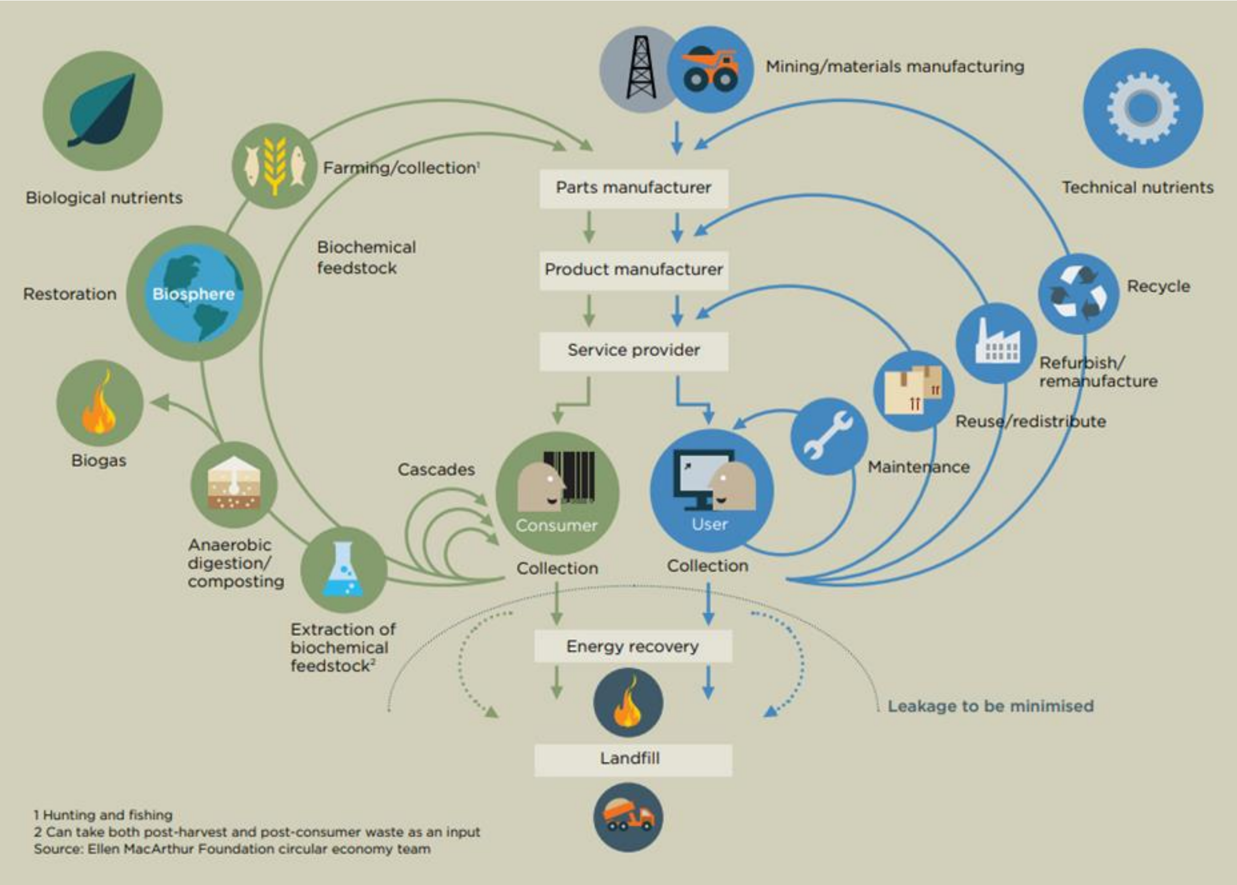
Considering BAT determination through a resource efficiency lens (including through the use of BAT environmental performance levels) might result in efficiencies throughout the product's life cycle such as process or technology adjustments to reduce water and energy consumption, and the use of toxic substances. Moreover, consideration of resource efficiency may facilitate identification of renewable feedstocks and raw materials for product manufacturing, resulting in the extraction of more sustainable materials upstream and detoxification of the overall materials used, reducing toxic or hazardous properties as it continues through product use and eventual reclamation or final disposition.

Circular economy

Although there is no single commonly accepted definition for the term "circular economy", (Kirchherr, Reike and Hekkert, 2017[21]), the three main features of circular economy are often highlighted as: *closing* the loops of material flow by recycling and remanufacturing; *slowing* loops by increasing the working life of goods and products; and *narrowing* loops by using natural resources and goods more efficiently within linear systems (e.g. buildings and cars) (McCarthy, Dellink and Bibas, 2018[22]) (OECD, 2020[23]).

Circularity can also be described as two parts: biological and technical cycles. A circular biological cycle involves the consumption and movement of bio-based materials, ultimately feeding back into the system through processes such as composting and anaerobic digestion, serving to regenerate natural systems such as soil. Circular technical systems keep materials and products in use longer through strategies such as reuse, repair, and remanufacturing, focusing on recovery of materials through recycling (Ellen Macarthur Foundation, 2013[24]). Figure 6 illustrates the conceptual basis of circular economy along with biological and technical cycles within it.

Figure 6. Illustration of the Circular Economy Concept



Source: (Ellen Macarthur Foundation, 2013[24])

Considering BAT determination through a circular economy lens might result in identification of alternative materials and technologies that can contribute to waste reduction and recycle, the use of secondary and reusable materials and energy efficiency throughout the whole value chain.

Decarbonisation

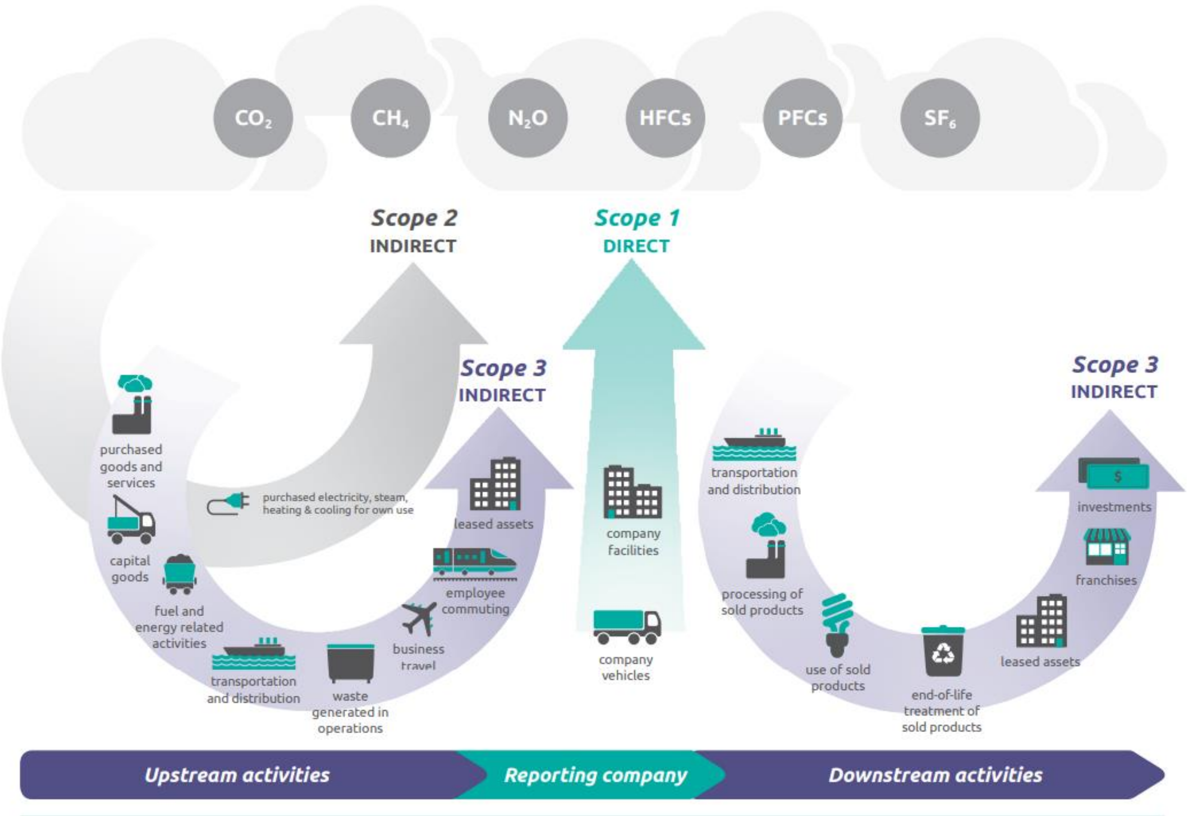
Climate change mitigation is a crucial global environmental issue. The Paris agreement sets the target to limit global warming to well below 2, preferably to 1.5 degrees Celsius, compared to pre-industrial levels (UNFCCC, 2015[25]). To achieve global reduction targets of greenhouse gas (GHG) emissions, there is a need for mitigation actions from all industrial sectors.

The term "decarbonisation" is generally used in the context of power supply. Here, the main strategies for reducing GHG emissions are use of renewable energy resources in place of fossil carbon-containing fuels, and implementation of carbon capture and storage (Luderer, Pehl and Arvesen, 2019[26]). These strategies apply to any sector which requires power generation; the main strategy for decarbonizing manufacturing sectors is to meet their energy needs through decarbonized power supplies, be they on or off site.

Other important strategies for decarbonisation include use of hydrogen as a fuel such as in transportation and electrification of industrial processes which traditionally rely on fossil fuels for power. For full decarbonisation of such processes, the energy requirements to generate hydrogen or electricity must be met with decarbonised power sources. (Thomaßen, Kavvadias *et al*, 2021[30]) (Koch Blank and Molly, 2020[27]).

The GHG Protocol is widely used across the world for accounting and reporting of carbon dioxide (CO_2) and other GHGs emissions. It classifies GHG emissions into three categories: Scope 1 (all direct GHG emissions); Scope 2 (indirect GHG emissions from consumption of purchased electricity, heat or steam); and Scope 3 (other indirect emissions not covered by Scope 2). Examples include the extraction and production of purchased materials and fuels, transport-related activities in vehicles not owned or controlled by the reporting entity, electricity-related activities (e.g. transmission and distribution losses) not covered in Scope 2, outsourced activities, waste disposal, etc. These scopes thus try to cover the whole GHG emissions through the value chain (Figure 7) (GHGProtocol, 2013[28]).

Figure 7. Overview of GHG Protocol Scopes and Emissions Across the Value Chain



Source: (GHGProtocol, 2013[28])

Considering BAT through decarbonisation and GHG reduction lens might result in the identification of further potential for the reduction of GHG emissions, not only at the industrial installation, but also throughout the value chain, e.g. through consistent application of BAT-associated environmental performance levels for energy efficiency. Moreover, measuring the GHG emissions of an entire value chain could help determine which raw materials or techniques should (and should not) be used in a given industrial activity in terms of GHG emission reduction through the whole process including material production, transportation, product use, and waste disposal. Such approaches also allow consideration of product benefits. For example, the production of isocyanates to produce insultation is energy consuming, but then saves energy when used. Similarly, certain plastic packaging, although itself fossil fuel derived can lead to wider overall environmental benefits by preserving food and this avoiding food waste impacts.

Common themes among value chain approaches

While value chain approaches described here vary significantly, all are guided by the ultimate goals of environmental sustainability. Some of the approaches focus on specific resources; green chemistry pertains to the production and use of chemicals, whereas decarbonisation focuses on fossil fuel resources. Compared to these more targeted frameworks, resource efficiency and circularity are much broader in scope. Circularity, in particular, seeks to reframe current patterns of consumption, use, and disposal. Regardless of differences in target and scope, common themes underlie many of these value chain approaches. These themes are described in Box 2.

Box 2. Common themes of value chain approaches and examples

Pollution prevention and waste minimisation - The first principle of green chemistry is "Prevent waste: design chemical syntheses to prevent waste. Leave no waste to treat or clean up." Similarly, "designing out waste" is a principle of circularity. Much of decarbonisation is aimed at designing fossil fuel combustion out of energy production.

Resource efficiency - The green chemistry principle "maximizing atom economy" is guided by resource efficiency to ensure that more of the starting materials in a chemical process are incorporated into the product. Similarly, catalysis is a strategy to avoid the inefficient use of stoichiometric reagents during synthesis, often with reaction conditions closer to ambient conditions. The reframing of waste as a resource in resource efficiency is one of the main principles of a circular economy, where the waste from any process may serve as an input for another use, displacing other raw material usage.

Use of renewable feedstocks and raw materials - All approaches highlight the importance of renewable feedstocks and raw materials. Decarbonisation seeks to eliminate the use of fossil fuels and petroleum-based resources through use of renewable feedstocks and resources. The concept of a circular economy relies on the use of renewables as a key link in the biological cycle (e.g., composting and anaerobic digestion of consumer waste for production of renewable chemical and energy resources).

Recycling and material recovery - Reframing waste as a resource is a common theme in the approaches. A goal of resource efficiency is to decouple production from consumption of natural resources with recycling and material recovery necessary to achieve this end. In the concept of a circular economy, these strategies ensure minimal leakage of resources from the system. In biological cycles, waste collection is key in the production of biochemical feedstocks and the restoration of biological systems for renewable feedstock production. In technical cycles, the recovery and recycling of metallic and mineral resources is necessary to maintain circularity for part and product manufacturing.

Hazard reduction - Green chemistry focuses heavily on hazard reduction in terms of chemical inputs as well as products. Similar themes appear in resource efficiency and circularity, where minimizing the hazard associated with inputs may be a strategy to minimize use of resources dedicated to risk management at the installation level. Minimizing hazard associated with products is also key in ensuring that materials may be recycled and reused at other links in the value chain. Material substitution is a key strategy for hazard reduction, but usually requires a priori knowledge of any potential impacts on other links in the value chain and during product use to avoid regrettable substitutions.

Note:

Many systems and process changes that will deliver environmental benefits require more energy which makes the supply of sufficient decarbonised energy is critical and can be considered as a pre-requisite for a change to other production processes.

Together, these value chain approaches aim to consider relevant industrial interactions, be they upstream of the installation as an input, downstream of the installation as a product to another producer or consumer, or mutually beneficial operations that enable greater capture and reuse of resources, and post-consumer recapture and re-integration in the production. These approaches share a common goal of helping industry achieve greater sustainability through pollution prevention, waste minimization, resource efficiency, recycling and material recovery, and hazard reduction.

Implementation of value chain concepts

At an installation level, these concepts could be implemented in various ways to help find sustainable solutions and designing for e.g. waste prevention and resource efficiency. Collectively, these individual design objectives inform policy and BAT determinations, and applying the value chain lens may aid in:

- identifying safer chemical alternatives for hazardous raw materials and auxiliaries;
- prioritizing the use of renewable feedstocks which may effectively incorporate agricultural products or recycled materials;
- highlighting more efficient processes to optimize the conservation of water, energy and other resources through synergistic activities promoting manufacturing processes or technologies that reduce net global impact;
- reducing impacts from pollutants of special concern;
- designing products for downstream applications and requirements that limit impact to consumers and enable waste prevention and reclamation.

When determining BAT and operating requirements for specific industries, taking a broader value chain perspective may shed light on movement towards more sustainable practices in related or connected industries These forces could be regulatory, or market driven as society aims to respond to sustainability goals and reduce our footprint.

The next section considers existing BAT and whether they are efficient from a value chain perspective.

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3 Analysis of BAT effectiveness from a value chain perspective

Value chain principles in BAT regulatory frameworks

Many current regulatory frameworks for BAT determination imply consideration of value chain concepts, particularly the common themes previously outlined. Specifically, guidance documents, legislation, and statutes point to pollution prevention, hazard reduction, and resource efficiency as guiding principles for these decisions. Additionally, these frameworks may be designed to favour low waste technologies or those which reduce the consumption of virgin materials. Directives highlighted below point towards systems thinking of installation operations.

European Union

The Industrial Emissions Directive (IED (EU, 2010[29]), which is currently under review provides the framework for the determination of BAT in the European Union (EU) and requires techniques to "reduce emissions and the impact on the environment as a whole." One main goal of the IED is "to prevent, where that is not practicable, to reduce and as far as possible eliminate pollution arising from industrial activities" (EU, 2010[29]). Under its revision, IED targets to enhance the value chain perspective, promoting decarbonisation and circular economy which are more prominently addressed in the more recent BREFs.

Several principles in the EU's BREF Guidance Document (EU, 2012[30]) and the parent directive IED correspond to value chain concepts:

- Art. 1 of the IED reads "and to prevent the generation of waste".
- Techniques will "reduce the use of raw materials, water and energy" and "prevent or limit the environmental consequences of accidents and incidents"
- "Techniques will cover both pollution prevention and control measures, *recognizing that emission prevention, where practicable, is preferred over emissions reduction* (EU, 2010[29])".

Further, the Technical Working Groups are instructed to consider the following criteria for the determination of BAT as outlined in Annex III of the IED:

- The use of low-waste technology for production processes
- The use of less hazardous substances
- The furthering of recovery and recycling of substances generated and used in the process and of waste
- The extent of consumption and nature of raw materials and energy
- The need to prevent or reduce the overall impacts of emissions on the environment
- The need to prevent accidents and to minimise the consequences for the environment (EU, 2010[29]).

The European Commission (EC) through its chemical strategy, including through the application of the "sustainable by design" strategy, encourages facilities to use chemicals more safely and sustainably, and considers the chronic effects of chemicals on human health and the environment to ultimately minimize and substitute substances of concern and phase out the most harmful substances used in consumer products (EC, 2020[31]).

United States

Central to US environmental laws is the Pollution Prevention Act (PPA) of 1990, which established prevention of pollution as the preferred paradigm to replace the traditional "end-of-pipe" paradigm, which focused on controlling pollution after it had been created. The law states that "pollution should be prevented or reduced at the source wherever possible" and hazard to public health and the environment health should be reduced where feasible (US EPA, 2017[32]). It establishes a hierarchy for waste management that prioritizes prevention over control measures, regardless of the media to which waste would be released. Related examples include:

- A US EPA memorandum (Habicht, 1992[33]), clarifying the definition of 'pollution prevention' in the PPA, states that pollution prevention may be achieved through process or equipment modifications; product reformulation; substitution of raw materials for safer alternatives; staff education; and inventory control. All of these techniques are directly related to value chain concepts.
- To implement this preventative approach, the EPA reviewed, developed, and promulgated rules specific to air quality, water quality, and hazardous waste that consider pollution prevention at every stage, as well as prevention options equally with pollution control measures. This collaborative effort was referred to as the Source Reduction Review Project.

To aid in determining best available control techniques, EPA or local authorities with delegated rights to implement federal regulations have developed media- or program-specific guidelines for industrial sectors or processes (e.g. Greenhouse Gas Control Measures, Texas Air BACT, and San Francisco Air BACT) (US EPA, 2017[34]; TCEQ, 2018[35]; Bay Area Air Quality Management District, 2015[36]).

To what extent has the value chain been considered in BAT policy?

A number of studies have analysed the extent to which value chain concepts are integrated into BREF documents, sectoral guidance, and regulations. For instance, studies assessing how the EU Industrial Emissions Directive (IED) (EU, 2010[29]) considers value chain approaches to determining BAT, e.g. contributes to circular economy objectives, facilitates resource efficiency, and otherwise considers value chains, are discussed below along with other research.

On behalf of the Directorate-General (DG) for Environment, Ricardo and VITO conducted a study on the contributions of the IED to circular economy (Anderson, Natalia *et al*, 2019[41]), using – amongst others – the EU's Circular Economy Monitoring Framework (EC, 2018[37]). The report reviews the BAT Conclusions for 17 industrial sectors, and considers the following topics related to circular economy: use of energy and materials, generation of waste and the reduction of the use of hazardous chemicals. The report findings include:

- Energy usage is the most covered topic area of BAT Conclusions and represents the highest proportion of quantitative BATs (concentrated in the Large Combustion Plants and Food, Drink and Milk sectors) while BAT conclusions were generally of a qualitative nature, and not quantitative.
- Waste generation is the second most covered topic (concentrated in the Large Volume Organic Chemical, Non-ferrous Metals (NFM) and Iron and Steel sectors). Along with recycling rates, demand of recycled materials as raw material inputs, and innovative waste management practices most directly supported circular economy objectives.

- Related to value chain impacts, industrial symbiosis, that is the application of waste or by-products of one industry to become inputs for another is visible in the NFM sector. For instance, the EU BREF[1] encourages slag (stony waste matter separated from metals during the smelting or refining of ore) to be reused in construction applications, sandblasting grit, or as a raw material for the production of silico-manganese or other metallurgical applications (EIPPCB, 2017[43]). Techniques that promote industrial symbiosis are also explored in the Ceramic sector (JRC, 2021[38]).

Waste prevention is mentioned in the BREFs but only in generic terms, not connected to a specific BAT-AE(P)L which would drive for measurable impact on the ground. It is rare to find qualitative waste prevention targets for specific sectors. Some examples include:

- The Food, Drink, and Milk (FDM) BREF BAT 10[2] states "*to use residues*" but adds the applicability restriction: "*may not be applicable due to legal requirements*". Phosphorous recovery is also mentioned (BAT 10), but not from a quantitative perspective. (Santonja, German Giner *et al*, 2019[45]).
- The Iron and Steel (I&S) BREF3 includes reference to some very specific techniques for residue recycling (e.g. iron-rich residues recycling include specialised techniques such as the OxyCup® shaft furnace, the DK process, smelting reduction processes or cold bonded pelletting/briquetting) and also mentions in more general terms how waste can be prevented (e.g. BAT 8 and 9), using rather more vague language such as: "wherever this is possible and in line with waste regulation" or "the recycling may not be within the control of the operator of the iron and steel plant, and therefore may not be within the scope of the permit" (EIPPCB, 2013[46]). The Waste Treatment BREF4 mentions in general terms the "substitute of materials with waste" to use materials efficiently (BAT 22) and "reuse of packaging" to reduce quantities sent for disposal (BAT 27). Other than general guidance to set up an environmental management system (BAT 2), there are no conditions on the outputs of certain waste treatment as it is not in the scope of the BREF (EIPPCB, 2018[47]).

As part of the HAZBREF[5] project, the Finnish Environment Institute SYKE reviewed how circular economy considerations are taken into account in the IED framework (Dahlbo et al., 2021[39]), concluding that:

- Circular economy considerations appear in the IED framework in multiple places. According to IED Article 11 d-e, waste generated in industrial processes should be prepared for re-use, recycling, or recovery, or – where not possible – disposal. In line with IED Articles 12(1) b and h, applications for integrated environmental permits should include a description of raw and auxiliary materials as well as other substances used by an industrial installation, in addition to a description of measures for prevention, preparation for re-use, recycling and recovery of waste generated by the installation.
- Circular economy considerations within the IED framework can be strengthened. For instance, in IED Articles 12(1) b and h, the directive does not explicitly link waste management to the avoidance of hazardous substances. Additionally, while article 14 of the IED requires that permits define limit values for polluting substances that are likely to be emitted, the directive provides no specific requirements – only general ones – regarding permit conditions on waste generation. It also makes no explicit mention of measures for the use of raw materials or auxiliaries.

BAT is not usually used to directly address greenhouse gas (GHG) emissions. This is partly due to policy decisions to use market-based approaches, such as the emissions trading system (ETS) in the European Union. Provisions in the IED framework and EU-ETS Directive prohibit the setting of emission limits for GHG in permits, for the installations covered by the ETS. While this approach may limit the potential for 'double-regulation', it is possible that it can lead to certain sectors not taking into full account available options for the control of GHGs when determining BAT for sectors and installations.

Most BREFs aim for decarbonisation and GHG emission reduction as a co-benefit through BAT on energy use and efficiency. Fuel choice is a fundamental BAT, discussed in many BREFs. Further, some BAT

Conclusions aim to replace the use of refrigerants that harm the ozone layer or have global warming potential, supporting prevention of climate change.

The concept of resource efficiency is promoted in some BAT Conclusions. For example, the Production of Large Volume Organic Chemicals BAT 15 and 16 promotes process optimisation, reuse of organic solvents, and catalyst selection, protection and monitoring techniques.

The concept of safer or more efficient alternatives is promoted to a limited extent in BAT policies. Where possible, EU BREF documents may contain information about available substitutes for certain inputs. In the EU Tanning of Hides and Skins BREF, Section 4.2 details several specific inputs that should be replaced and potential substitutes. The driving force for many of these substitutions is the restriction of chemicals under chemical safety regulations. While specific substitutions and alternative technologies may be promoted in sector specific guidance, other regulatory frameworks and organizations track technological advances more readily and provide drivers and background information required to implement these changes.

Sector examples and extent of value chain consideration in BAT

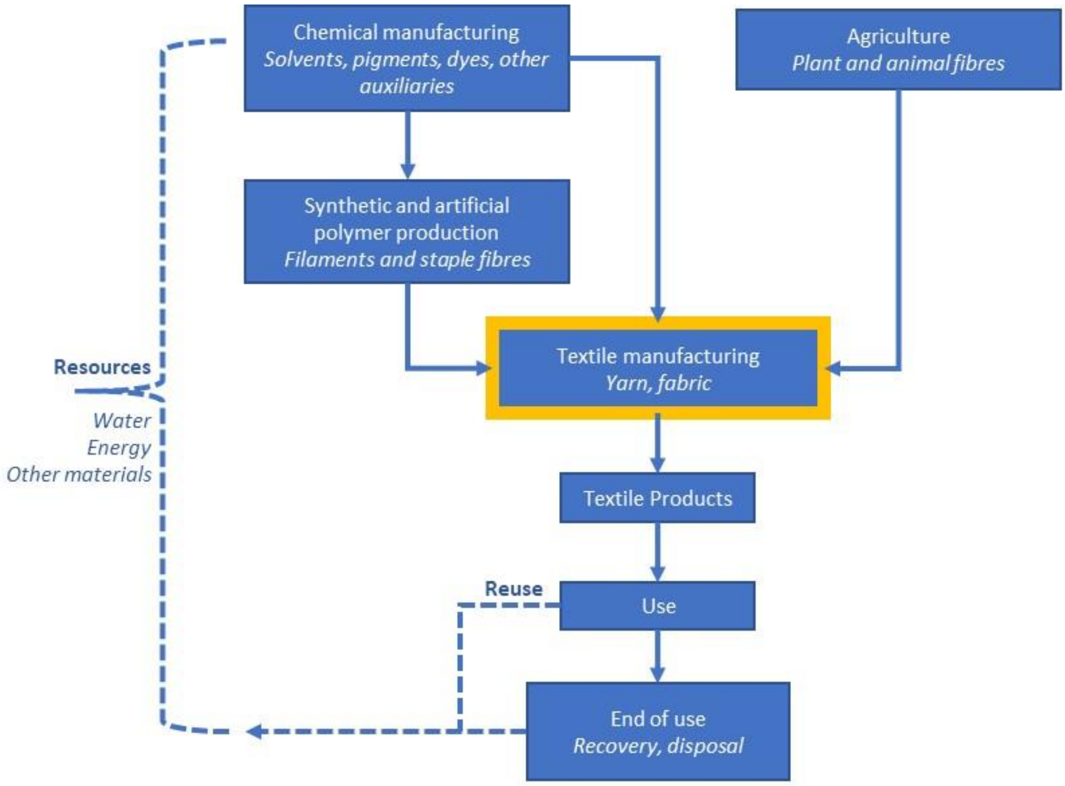
To extend the findings presented above, analysis of selected sectors and pertinent BREFs across multiple countries is described below to determine the extent of value chain considerations.

Textile industry

The textile industry covers a variety of activities, including yarn and fabric production, wet processing (bleaching, dyeing, etc.), finishing, and coating. Upstream chemical manufacturing supplies a number of commodities and fine chemicals to these processes. Polymer production supplies man-made and artificial fibres, whereas agricultural activities supply natural fibres (e.g., cotton) to the industry. Design concept plays a crucial role in the textiles manufacturing (Martinez-Pardo, 2020[40]) as it highly influences the environmental impact of the end products and therefore, all the downstream steps and implications. Downstream activities include apparel, carpet, and automobile manufacturing, among others. Figure 8 gives an overview of textiles manufacturing with some of its components.

Environmental issues stemming from the textiles industry include use of hazardous chemicals, polluted effluent, microplastic releases as well as water, energy, and material consumptions. Additional environmental considerations include land use and degradation for the production of agricultural raw materials, their consumption, and energy used during processing (Manshoven, 2019[41]). Additionally, these activities include use of hazardous chemicals such as fertilizers, pesticides, and chemicals used during processing (e.g. for production of artificial fibres).

Figure 8. Textile Manufacturing Flow Diagram



These issues may be addressed in BAT regulations for the textile manufacturing industry. Relevant regulations include:

- The 2019 draft EU BREF document for the textiles industry[6] scope includes some of the textile value chain, including yarn and fabric production, pre-treatment (washing, mercerizing, bleaching, etc.), dyeing, fabric printing, coating, finishing, and lamination. Additionally, certain aspects of wool textile production are also covered, including wool scouring, carbonizing, and fulling. Selected activities related to waste management are also covered (EIPPCB, 2019[42]).[7]
- The US technology-based standards[8] for air emissions from the textiles sector cover web coating and printing, slashing, and dyeing, and finishing as three separate subcategories. New or reconstructed facilities must also comply with polymeric coating standards to woven, knit, and nonwoven textiles as well as cord and yarn. Standards for discharges to water cover wool scouring and finishing, low water use processing, woven fabric finishing, knit fabric finishing, carpet finishing stock and yarn finishing, nonwoven textile manufacturing, and felted fabric processing.
- The Russian BREF document[9] for the textiles industry focuses on pre-treatment, dyeing, printing, and finishing process while other upstream activities including yarn and fabric productions are briefly described (Rosstandart, 2017[43]).
- The Korean BREF for the textile industry also focuses primarily on pre-treatment, dyeing, and the other finishing process (NIER, 2019[44]).

The above documents and regulations address the textile value chain in various ways. Strategies for addressing the environmental impacts from textile production often include chemical selection and increasing processing efficiency. Assessment of textile-related BREFs show instances where solutions from other links in the value chain were considered in addressing environmental issues from the textiles industry.

Related to upstream considerations,

- The draft EU BREF for the textiles industry specifies use of fibres and filaments with minimal contamination from pesticides, manufacturing residues, mineral oils, and sizing chemicals. In order to verify minimal contamination, BAT is to monitor incoming contaminants through in-house testing, coordination with suppliers, or certification schemes and standards.
- Concerning chemical use and management, the draft EU BREF for the textiles industry specifies that “procurement policy [is] to select process chemicals and their suppliers with the aim to minimise the use of hazardous chemicals. BAT also includes careful charting of movement of chemicals through the facility, from procurement to products, waste, and releases to the environment. Additionally, it is BAT to use textile material with low content of contaminants (pesticides, manufacturing residues) and facilities should establish a system to return unused process chemicals to suppliers (EIPPCB, 2019[42]).
- US BAT regulations consider the substitutions of sulphur dyes and phenolic dye carriers for safer alternatives when establishing discharge limits for sulphide and total phenols.
- The US National Emission Standards for Hazardous Air Pollutants (NESHAP) for printing, coating, and dyeing of fabrics and other textiles allows for a “compliant material option,” where facilities may demonstrate that purchased coatings or printing material has an organic hazardous air pollutant (HAP) content less than or equal to the relevant emission limit. Additionally, cleaning and thinning materials may contain no hazardous organic pollutants. Facilities must demonstrate that materials meet these standards as purchased, encouraging collaboration with upstream suppliers to minimize HAP content in incoming materials.
- Korean BAT 8 focuses on chemical substitutions including the use of less harmful and biodegradable surfactants, sequestering agents, and antifoaming agents. These substitutions can reduce the load of downstream wastewater treatment and may prevent chemical residues in product (NIER, 2019[44]).

Relating to resource efficiency,

- BAT Conclusions also specify use of textile materials with ‘inherent characteristics’ which require less processing in order to maximize resource efficiency and minimise the use of hazardous substances. The draft EU BREF for the textiles industry provides additional details on the cationisation process, including a brief description of potential discharges to water as cross media effects (EIPPCB, 2019[42]).
- While the draft EU BREF for the textiles industry seeks to maintain flexibility by considering wet processes as individual units rather than linked operations, it is useful to note that BAT 9 for water use and waste water generation dictates that production optimization occur to ensure that combined processes (and their scheduling) are considered holistically to minimize water consumption and waste water generation. Additionally, techniques for water reuse and recycling are outlined to ensure maximum resource efficiency (EIPPCB, 2019[42]).
- Korean, EU, and Russian BREFs include recovery of sizing agents in desizing processes or caustic soda in mercerizing processes for later reuse, both of which increase the resource efficiency, i.e., production volume per auxiliary input (NIER, 2019[44]) (EIPPCB, 2019[42]) (Rosstandart, 2017[43]).

Certain environmental issues impacting or resulting from the industry sector may not be sufficiently addressed in guidance. Review of other BREF documents from up- and downstream sectors show instances where environmental issues stemming from the textiles industry were considered.

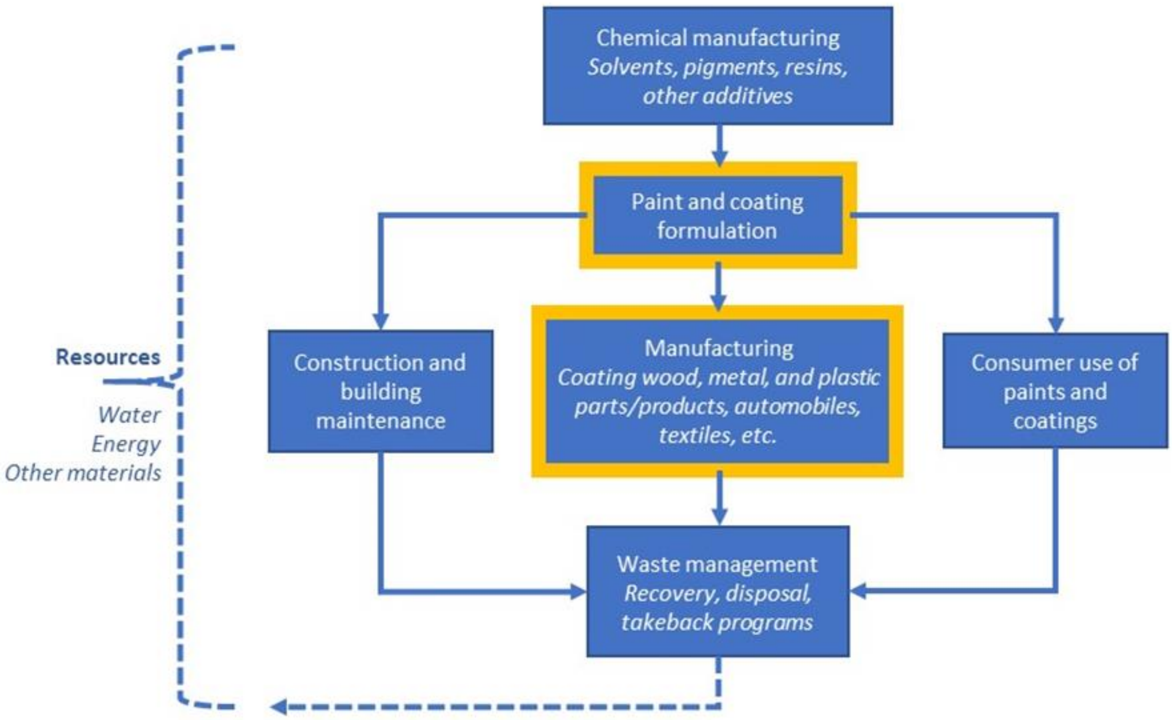
- The fine chemical manufacturing is the upstream supplier of dyes to the textile industry. The draft EU BREF for the textiles industry contains a wealth of information on dyes and dyeing, including information about dye classes, toxicity, and use of auxiliaries. In general, the draft BREF considers use of dyes with minimal toxicity and superior fixation and fastness as BAT. While the EU Organic

Fine Chemicals BREF includes a section on design and synthesis of dyes, the information presented does not align with what is presented in the draft EU BREF for the textiles industry (EIPPCB, 2006[45]). This represents a clear opportunity for increased alignment of guidance and for information from the textiles industry to shape future BREF documents for the Organic Fine Chemicals sector.

Paints and coatings industry

As a subsector of the chemical manufacturing industry, paints and coatings manufacturing generally focuses on mixing formulations of various components (see Figure 9). These components can be roughly grouped into four categories: solvents, binding resins, pigments, and miscellaneous additives. Most components are products of upstream chemical manufacturing, although some may be produced in the installation or at co-located facilities. Roughly 55% of all coatings are used in construction and maintenance of buildings, 35% are used in manufacturing, and the remaining 10% are specialty coatings (IHS Markit, 2019[46]). Environmental issues stemming from the industry include solvent use, emissions of VOCs from application, and use of harmful additives such as certain plasticisers.

Figure 9. Paint and Coating Manufacturing Flow Diagram



While the formulation step of paint and coating manufacture may be covered under some BAT regulations, it is generally the application of paints and coatings in industrial settings that is regulated through these policies.

- The EU BREF on surface treatment using organic solvents[10] covers the activities of surface treatment of substances, objects or products using organic solvents, in particular for dressing, printing, coating, degreasing, waterproofing, sizing, painting, cleaning or impregnating with a solvent consumption capacity above certain thresholds. The main covered activities include coating of new vehicles, aircraft, ships, other metal and plastic surfaces, textiles, wooden surfaces, metal packaging as well as printing processes (EIPPCB, 2020[53]).

- The US technology-based regulations[11] for air emissions from **paint and coating manufacturing** cover mixing binders, solvents, and pigments into paints and other coatings, adhesive manufacturing, and manufacturing other allied coating products. Technology-based standards for discharges to water from paint production cover the manufacturing of oil-based paints where tanks are cleaned with solvents.
- US Technology-based standards[12] for air emissions from the **application of paints and coatings** cover auto and light duty truck surface coating, metal can surface coating, metal coil surface coating, metal furniture surface coating, miscellaneous metal parts and products surface coating, paint stripping and miscellaneous surface coating operations, plastic part surface coating, printing and publishing surface coating, shipbuilding and ship repair surface coating, wood building products surface coating, and wood furniture surface coating. Additional air emission standards apply to new or reconstructed facilities which participate in furniture surface coating, auto and light duty truck surface coating, large appliance surface coating, metal coil surface coating, surface coating plastic parts for business machines, polymeric coating of substrates, coating of flexible vinyl and urethane, and beverage can surface coating. Technology-based standards for discharges to water from paint and coating application apply to coil coating.
- The Russian BREF[13] on surface treatment of objects or products using organic solvents focuses on the processes of surface preparation for painting with the use of organic solvents and dyeing, and the methods to prevent and reduce emissions and waste generation. The main covered activities include coating of: vehicles, trains, aircraft, ships, agricultural machines, industrial machines, electric motors, other metal surfaces, pipelines and other gas and oil installations (Rosstandart, 2017[47]).

The above documents and regulations address environmental issues associated with the paints and coatings value chain in various ways. Strategies for minimizing environmental impacts include resource efficiency and green chemistry approaches. Additionally, upstream or downstream industries may be considered to varying degrees.

Related to upstream considerations,

- In the EU BREF for surface treatment with solvents (STS), BAT 3 requires that facilities select raw materials with minimal hazard.
- Art. 58 of the IED, applying to installations and activities using organic solvents is a more specific provision to substitute substances with certain hazard profiles. The existence of this article means that substitution is not only driven by BREF reviews and mentions of specific substances, but by a much more general and far-reaching legal provision.
- The EU BREF on organic fine chemicals (2006)[14] includes a brief section on synthesis of dyes and pigments. Similarly, the EU BREF on specialty inorganic chemicals (2007)[15] includes information on production of specialty inorganic pigments.
- The Large Volume Inorganic Chemicals BREF covers upstream processes such as titanium dioxide (TiO_2) production. The use of TiO_2 as a pigment in downstream processes is considered in this BREF; certain production processes are avoided because they result in yellowing or yield particle sizes not useful in pigments.
- US NESHAP regulations advise that companies meet VOC emission standards by finding substitutions for organic solvents.
- For many facilities which apply paints and coatings to various substrates, NESHAP regulations include a compliant material option for controlling organic HAPs. Facilities must demonstrate that coating materials meet certain HAP content standards as purchased. For many types of coating

operations, the standard is that materials contain no organic HAPs. This encourages facilities to seek out upstream suppliers which can meet these purchasing requirements.

Relating to resource efficiency,

- The US Development Document for Paint Formulating Effluent Guidelines[16] notes that water consumption can be reduced by using wash water in production of the next batch, provided the next batch is the same colour or darker.
- The EU BREF for surface treatment with solvents also includes a brief section about the automation of paint mixing and advanced coating/chemicals supply systems as strategies to increase resource efficiency through accurate dosing and minimizing cleaning requirements.

Relating to downstream considerations,

- Under US NESHAP, facilities which manufacture coatings may use alternative methods to comply with HAP limits for process vessels, where they demonstrate that the manufactured coating product contains less than 5% HAP content. In addition to controlling HAP emissions at the facility, this alternative may reduce HAP emissions from downstream industrial or consumer use of the coating.
- The EU BREF for surface treatment with solvents (STS) includes limited mentions of the downstream sectors. For instance, certain UV cure technologies were found to have limited applicability due to the potential for migration of residual monomers from ink into food in downstream packaging when over-lacquering is not applied.

While BREFs may consider the overall value chain to minimize the environmental impact of the lifecycle for paints and coatings, certain environmental issues resulting from the sector may not be sufficiently addressed in guidance.

- In the EU Organic Fine Chemicals BREF, there is a brief overview of production of dyes and pigments. The section on dyes contains much more detail on downstream use on different substrates, especially pertaining to the textiles industry. There is much less information on pigments and their downstream uses in paints and coatings.
- In the EU OFC BREF, the section on catalytic reduction notes that in certain cases, iron oxide produced during the reduction process can be used as a pigment. However, there is very little information on what conditions must be met to ensure the iron oxide produced can be used for pigment production.

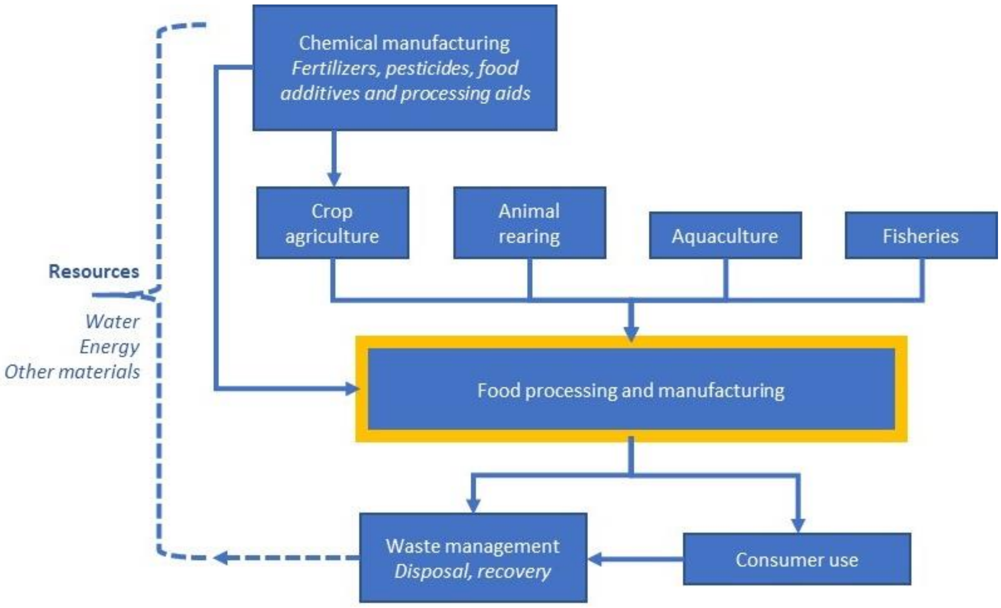
Food Industry

There are various definitions of the food industry, but the scope considered in this study is the ISIC classification "Manufacture of food products". This includes the processing of products from agriculture, forestry, and fishing as food for humans or animals, and includes the production of various intermediate products that are not directly food products. The covered activities are: meat, fish, fruit and vegetables, fats and oils, milk products, grain mill products, animal feeds and other food products (UN, 2008[48]).

As shown in the Figure 10, the upstream activities to the food industry are the production of raw materials including crop and animal productions, fishing, and aquaculture. The manufacture of pesticides, food additives, processing aids, and fertilizers can also be related to the food industry. Processing of food waste into secondary raw material or animal feed, and waste disposal as well as packaging, transportation and storage, and customer use, can be regarded as the downstream activities (UN, 2008[48]).

The main environmental issues associated with food processing and manufacture activities include high water consumption, the discharge of effluent and the consumption of energy. Significant quantities of organic solid waste including inedible, expired and rejected materials from sorting and grading may also be issues for subsector activities (Massoud, *M et al, 2010*[56]).

Figure 10. Food Processing and Manufacturing Flow Diagram



These issues may be addressed in BAT for the food industry. Relevant documents include:

- The EU BREF for Food, Drink, and Milk Industries[17] covers the treatment and processing of animal and vegetable raw materials, and milk. The independently operated and combined treatment of wastewater originating from these activities is also covered. (Santonja, German Giner *et al*, 2019[45]).
- The US BAT regulations[18] for air emissions from the food industry cover manufacturing nutritional yeast, prepared feed manufacturing, and solvent extraction for vegetable oil production. Additional technology-based air emission standards apply to new or reconstructed grain elevators. BAT regulations for discharges to water from the food industry cover canned and preserved fruits and vegetable processing, canned and preserved seafood processing, diary product processing, grain mills, meat and poultry product processing, and sugar processing.
- The Russian BREF for food production[19] covers activities including processing and preserving of meat and meat food products, of fruits and vegetables, production of vegetable and animal oil and fat, and manufacture of other food product (e.g., sugar production) (Rosstandart, 2017[49]). The Russian BREF for beverages, milk and dairy products[20] covers the production of milk and dairy product, and ice cream production (Rosstandart, 2017[50]).
- China has a BREF for the sugar industry[21] that proposes feasible technologies for the prevention and control of emission gas, wastewater, solid waste and noise from sugar industry installations (MEE, 2019[51]).

The above documents and regulations address environmental issues associated with the food manufacturing value chain in various ways. The reduction of waste and wastewater by recycling and the control of the hazardous substances through the chain are the parts of themes in value chain consideration for food and beverage manufacturing. The integration of value chain considerations in BAT guidance and regulations varies from country to country.

Relating to upstream considerations,

- For facilities in the US which produce vegetable oil, every delivery of extraction solvent must have a HAP content of 1% or less for each HAP. Thus, facilities must find suppliers which can meet these requirements to ensure compliance with NESHAP.
- The Russian BREF states in the section of processing and preserving fruits and vegetables that the residual content of pesticides can be a problem for those pesticides that are difficult to be decomposed in wastewater treatment.

Relating to resource efficiency,

- The US Technical Development Document for Meat and Poultry Product Effluent Guidelines[22] describes in-plant control techniques to decrease water use. "Dry cleaning" processing areas before spraying surfaces with water decreases water use during daily clean-up, with the added benefit of greatly decreasing the BOD in clean-up wastewater. This technique also increases the amount of material recovered for production of inedible rendered products.
- The US development document also describes multiple uses for process water as a method for decreasing water consumption at poultry processing plants. For example, overflow from scalders can be used to remove feathers from mechanical de-feathering equipment. Similarly, chiller overflow is used to wash viscera from screens for recovery prior to rendering.
- To increase the resource efficiency, the EU BREF (BAT 3) requires establishment and regular review of an inventory on water, energy and raw materials consumption as well as wastewater and waste gas streams, and (BAT 10) recommends techniques such as, anaerobic digestion for generating biogas as a fuel, use of residues, and use of waste water for land application.
- The Chinese BREF for sugar industry sets the BAT of resource utilization including use of sludge as a fertilizer and use of molasses as a raw material for fermented products.

Relating to downstream considerations,

- Packaging is essential for complying with the food and drink products' strict hygienic standards and preserving their quality from production to consumption, which also helps to prevent and reduce food waste. It, in turn, may cause environmental issues in downstream stages including packaging waste generation and the adverse effects by chemicals contained in the packages (Santonja, German Giner *et al*, 2019[45]). The Russian BREF for food production recommends environmentally friendly packaging, which may be produced with less hazardous materials or biodegradable materials, and can be recycled or of multi-turn use.
- US BAT for discharges to water from canned and preserved seafood processing use in-plant control techniques as the partial basis for BAT determination. The recovery of secondary products is noted as an important in-plant control technique for reducing pollution. The development document for BAT notes that bones and carcases from fish processing can be made into low protein-high mineral meal used in animal feed. Similarly, chitin in the discarded shells of crustacea can be processed into chitosan, which has several industrial, agricultural, and medical uses.

While these documents consider and leverage the food value chain to minimize its environmental impact, certain environmental issues impacting or resulting from the industry sector may not be sufficiently addressed in guidance.

- The problem of chemical residues in raw materials derived from upstream activities such as use of fertilizers or pesticides is not addressed in the BREFs mentioned above for food processing sector, which is neither the cause nor the recipient of chemical pollution in the value chain.

What is the impact of gaps in value chain consideration in BAT policy?

As shown above, there are several environmental issues associated with the sector specific value chains which may result from instances where BAT-based regulations do not consider the value chain. This scoping limitation of BREFs is exemplified in an observation by the Ministry of Environment and Food of Denmark (2016[52]) which noted that the BREF scope focus on the production site reduces the extent of regulation and assessment of impacts from upstream incoming materials as well as downstream material streams exiting the production site. These gaps and the resulting impacts have been characterized through assessment, review of BREF documents, and feedback from BAT Expert Group members.

Sector case studies

During review of the case-study sectors, gaps in value chain consideration were noted. These gaps may have consequences outside of the industries investigated. Additionally, identified gaps in value chain consideration for the case study sectors may be similar to those in entirely separate sectors.

- The underlying scope of directives and statutes relating to BAT does not include arable farming. Therefore, the onus of addressing pesticide contamination in raw materials from the crop agricultural sector falls on manufacturing facilities which use these materials as inputs. This is also true of the food and drink industry, which relies heavily on agricultural inputs. As a result, numerous certification schemes relating to pesticide use and content in raw materials have arisen to allow for coordination between the agricultural sector and sectors that rely on it.
- The 2019 draft of the updated EU textiles BREF has an expanded scope to ensure more complete coverage of processes within the textiles industry, when compared to the 2003 version of the textile BREF. For instance, most organic matter discharged from desizing operations originates from sizing applied during upstream fabric and yarn production. Under the scope of the 2003 textile BREF, the relationship between sizing and desizing operations could not be considered fully because the 2003 BREF did not cover the application of sizing during yarn and fabric production in its scope. This was changed under the 2019 draft. Approaches to reducing the amount of effluent discharges may now include upstream changes to the quantity and type of sizing material applied.

Cross-cutting legislation reinforcing sectoral BREFs

Boundaries defined in sectoral BAT regulations are often required to narrow the scope of activities assessed and make regulation feasible. These boundaries typically limit the consideration of the value chain out of necessity, but this can result in guidance that does not cover the entirety of industrial activities within a sector. Additionally, guidance may not address important links within or between associated sectors, resulting in incomplete understanding of some activities and their environmental impacts. Other executive directives are necessary to address value chain interactions which fall outside of the purview of BAT regulations.

- Chemical safety legislation and directives may help address certain gaps in the coverage of sectoral BREFs. For instance, activities such as arable farming are outside the focus of BAT regulations but are an upstream source of input materials for many sectors. Where agricultural inputs are treated with pesticides, it falls to the manufacturing facility to manage and treat pesticide residues as waste. Pesticide regulations such as the US Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), as amended by the Food Quality Protection Act (FQPA), play a role in mitigating risks posed by pesticides to human health and the environment by regulating certain uses, setting labelling requirements, and establishing tolerances for pesticide residues remaining on crops.
- BREFs often advocate for use of safer alternatives in the place of hazardous chemicals. Legislation such as the EU's Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) and the US Toxic Substances Control Act (TSCA) are vital in collecting the information on chemical safety and industrial use patterns required to make informed decisions on chemical substitution.

Information requirements under these statutes can help provide toxicological data on chemicals and potential substitutes for hazard reduction.

- Waste minimization, particularly regarding product packaging materials, is often addressed through complementarily executive directives. For example, while the EU Food and Drink Manufacturing BREF does not cover packaging activities, other legal EU frameworks, e.g., Regulation (EC) No 1935/2004, and EU Directive 94/62/EC cover the safety of packaging materials and the reduction of packaging waste.

While not a directive, organizations are taking cross-cutting measures to improve the consideration of hazardous substances in the applications of BREFs by permitting authorities and industries. The Interreg Baltic Sea Region Programme and the EU funded the HAZBREF project which aimed to identify relevant hazardous chemicals, their characteristics, use patterns and potential abatement measures in selected industrial sectors covered by the IED by linking substance-specific information among IED, REACH, and other legal frameworks (HAZBREF, 2020[53]). The objective was thus to take a chemical-centred approach rather than focusing on a specific sector or sectors and apply target chemical information to any sector handling those chemicals (Dahlbo et al., 2021[39]).

Stricter standards by sub-jurisdictions

In order to better protect local environmental conditions, some countries may also impose stricter standards, beyond the BAT approach. For example, the Czech Republic enforces minimal binding energy efficiency standards for certain installations such as Large Combustion Plants (LCP) based on the revised LCP BREF[23] (Thierry Lecomte, 2017[54]). Where ambient conditions are a concern in the United States such as in ozone non-attainment areas, states develop state implementation plans (SIPs) to correct levels of air pollution which often result in stricter permitting standards on industrial facilities (US EPA, 2016[55]; US EPA, 2019[56]).

US states may also approach air pollution control from a health-based perspective resulting in the establishment of ambient air standards for additional chemicals not identified by federal authorities. For instance, North Carolina regulates 92 toxic air pollutants (TAPs), of which 14 are not federal hazardous air pollutants. Sources emitting these pollutants are required to not exceed established health-based acceptable ambient levels (AALs) which may result in additional facility emission limits beyond those specified by applicable federal MACTs (N.C.DEQ, n.d.[57]). This is similar for Louisiana (LDEQ, n.d.[58]) and other states.

To supplement federal regulation on chemical safety, five US states have developed their own laws and programs to broaden frameworks to systematically prioritize chemicals of concern, close data gaps on those chemicals and restrict their uses (NCSL, n.d.[59]). Additionally, many states have laws regulating or banning the use of specific chemicals such as cadmium, BPA, or certain flame retardants in consumer products. For instance, Minnesota requires that products free of PBDE be made available for purchase and use in state agencies.

Stimulating regulatory updates

Outdated regulations may act to stifle broader consideration of value chain implications and the implementation of more sustainable practices. For example, the USEPA's original definition of solid waste made it harder for some facilities to recycle waste. The definition was amended in 2008, after having last been revised in 1984, to alleviate this problem. This may serve as an obstacle: slowing down industry progress and the resulting BAT determinations may be weaker, delaying overall sustainability progress.

Programs supporting value chain concepts and industrial sustainability

As a complement to industrial emissions regulations or to address shortcomings in policies, jurisdictions may create or rely on programs designed to further advance sustainability objectives. These programs are often designed to support value chain concepts and aid in the application of systems thinking to promote progress in industry. Examples are described below. These programs and initiatives may be uniquely suited to consider larger parts of the value chain.

To further continuous environmental improvements, the European Commission's Eco-Management and Audit Scheme (EMAS) voluntary program requires participating organisations to review their direct impacts, including consumption of raw materials and energy and production of waste and emissions, as well as their indirect impacts through the value chain. The European Commission publishes a Sectoral Reference Document (SRD) and a technical report on Best Environmental Management Practices for each selected sector. The SRDs cover a variety of sectors, including some for which no BREF is available, such as the retail, tourism, and public administration sectors, among others. SRDs consider value chain effects and life cycle assessments as well as energy efficiency and many other environmental considerations.

The European Commission's Circular Economy Action Plan (CEAP) plan presents a set of initiatives to establish a product policy framework that will make sustainable products, services and business models the norm and transform consumption patterns so that no waste is produced in the first place. Particularly, this framework contains 'Circularity in production processes', which focuses on product value chains including textile, food, electronics, and vehicles to accelerate the transition to a circular economy throughout the value chain (EC, 2020[60]).

The European Commission's Chemicals Strategy for Sustainability Towards a Toxic-Free Environment includes some strategic elements to develop sustainable chemicals value chains, such as sustainable-by-design support network to promote cooperation and sharing of information across sectors and the value chain and identification of strategic value chains for technologies and applications relevant for the green transition (EC, 2020[31]).

Actions on legislative aspects have been taken by the European Commission's Sustainable products initiative as well, that aims to revise the Ecodesign Directive and make EU market more sustainable by placing more durable, reusable, repairable, recyclable and energy –efficient products for consumers. It will also look into the presence of harmful chemicals in products, such as textiles, furniture and electronics (EC, 2021[61]).

In the US, products that meet certain standards can qualify to display the US EPA's Safer Choice label, which is a voluntary programme that may drive consumer and retailer choice of products to buy or sell. Safer Choice has ingredient lists that focus on limiting human and environmental toxicity. Products must also meet life-cycle considerations, including considerations of use by the consumer. For example, laundry detergents should be effective in cold water to reduce consumers' energy use, and packaging should be recyclable or biodegradable to reduce waste by the consumer.

Certain states also have laws that promote green chemistry, which in turn promote the use of safer alternatives in consumer products and at industrial facilities. For instance, the California Green Chemistry Initiative authorizes the state's Department of Toxic Substances Control to identify and prioritize chemicals of concern in consumer products and create methods for identifying alternatives (DTSC, n.d.[62]). Similarly, Connecticut's green chemistry law established the Chemical Innovation Institute (UCHC, 2010[63]).

To stimulate the introduction of energy-efficient or low-carbon technologies, some countries use technology lists. For example, the United Kingdom (UK) and the Netherlands maintain lists of top performing energy saving technologies (known as the Energy Technology List in the UK (BEIS UK, 2020[64]) and the Energy List in the Netherlands (RVOnl, n.d.[65])), i.e. best available technologies for energy efficiency. Companies that install technologies from the lists are entitled to tax deductions. The UK's Energy Technology List is created and updated monthly by the UK government's Department for Business, Energy and Industrial Strategy;

manufacturers can apply to have their products included in the list. Furthermore, to encourage investment in environmentally friendly and energy efficient production process and buildings, the Flemish government offers qualifying investments (on the listed technology list a partial subsidy, ranging between 15 to 55% depending on the type of the investment (environment, energy), technology cost-effectiveness, size of the company, and other parameters). (Vlaanderen, n.d.[66])

To address value chain interactions that enable circular economy thinking, the Flanders Materials Program was launched by OVAM in 2012 aiming to streamline the initiatives on sustainable material use in Flanders/Belgium. The program focuses on closing material cycles in four economic clusters (building and construction, sustainable chemistry and plastics, bio-economy, and metals in a continuous cycle) (OVAM, 2012[67]). At present, the program is part of Circular Flanders, the hub and the inspiration for the Flemish circular economy, and functions as a partnership between governments, companies, civil society, as well as the knowledge community that will take action together (OVAM, 2020[68]). To promote sustainable chemistry and circularity in the plastics sector, strategies include design of processes which consume less raw material, use of biomass as a 'green' raw material, adapted product design, better selective collection of waste streams, and a reinforced sales market for recyclates. Further, to drive eco-innovation for energy and for sustainable chemistry, other organizations have surfaced such as: I-cleantech[24], an organization that implements eco-innovations encouraged by companies, and an innovation hub (Blue App)[25] and an incubator (BlueChem) that focus on reuse of waste and by-products and on the development of renewable chemicals and durable materials.

Industry or market associations also tend to drive progress, helping to comply or surpass minimum BAT determinations, particularly where standards might differ across countries and global value chain implications are not considered. Some voluntary programmes encouraging the adoption of a holistic systems approach for efficient management of chemicals are driven by non-state actors. Examples include:

- The Zero Discharge of Hazardous Chemicals Foundation (ZDHC)[26], a coalition of brands working in the apparel and footwear supply chains to promote safer chemical management, with a focus on developing standardized guidance for manufacturers with corresponding action plans for implementation. They take a holistic approach divided into four segments: inputs, processes, outputs, and fibre and raw materials.
- The Voluntary Emissions Control Action Programme (VECAP)[27], originally implemented in the UK to control emissions during handling and use of brominated flame retardants (BFRs) in the textile industry, has been adapted to meet the wider needs of the European textile and plastics industries. The program now covers a broader range of chemicals (other flame retardants) and provides a materials management system for use throughout the supply chain (VECAP, 2004[69]).
- The Greenhouse Gas Protocol (GHG), established by the World Resources Institute (WRI) and the World Business Council for Sustainable Development, develops and promotes the use of a global standard for corporate GHG accounting and reporting. Over the course of 20 years, the GHG Protocol has expanded to provide a comprehensive framework for measuring and managing emissions from private and public sector operations, value chains and mitigation actions, including providing sector guidance, calculation tools and trainings (GHGProtocol, n.d.[70]). To enable the assessment or accounting of GHG emissions throughout their value chain in accordance with Scope 3 GHG Protocol, countries such as the Ministry of Environment Japan have published basic guidelines to aid facilities. (MOEJ, 2014[71]).

Recognizing regulatory constraints associated with BAT determination, these programs and initiatives may be uniquely suited to consider larger parts of the value chain. The next section discusses considerations for effective integration of value chain concepts.

Notes

[1] https://eippcb.jrc.ec.europa.eu/sites/default/files/2020-01/JRC107041_NFM_bref2017.pdf

[2] https://publications.jrc.ec.europa.eu/repository/handle/JRC118627

[3] https://eippcb.jrc.ec.europa.eu/sites/default/files/2019-11/IS_Adopted_03_2012.pdf

[4] https://eippcb.jrc.ec.europa.eu/sites/default/files/2019-11/JRC113018_WT_Bref.pdf

[5] Hazardous industrial chemicals in the IED BREFs

[6] https://eippcb.jrc.ec.europa.eu/sites/default/files/2020-01/TXT_bref_D1_1.pdf

[7] Lamination and coating activities which consume solvent in excess of 150 kg per hour or 200 tonnes per day are covered in the Surface Treatment with Organic Solvents BREF.

[8] US NESHAP for printing, coating, and dyeing of fabrics and other textiles; US Effluent Guidelines for Textile Mills

[9] http://burondt.ru/NDT/NDTDocsDetail.php?UrlId=1134&etkstructure_id=1872

[10] https://publications.jrc.ec.europa.eu/repository/bitstream/JRC122816/jrc122816_sts_2020_final.pdf

[11] US NESHAP for Miscellaneous Coating Manufacturing, Paints and Allied Products Surface Coating, and Miscellaneous Organic Chemical Manufacturing; US Effluent Guidelines for Paint Formulating

[12] US NESHAP for Surface Coating of Automobiles and Light-Duty Trucks, Surface Coating of Large Appliances, Metal Can Surface Coating, Metal Coil Surface Coating, Metal Furniture Surface Coating, Miscellaneous Metal Parts and Products Surface Coating, Paint Stripping and Miscellaneous Surface Coating Operations, Plastic Parts Surface Coating, Paper and Other Web Surface Coating, Printing and Publishing Surface Coating, Shipbuilding and Ship Repair Surface Coating, Wood Building Products Surface Coating, and Wood Furniture Surface Coating; US Air NSPS Surface Coating of Metal Furniture, Flexible Vinyl and Urethane Coating and Printing, Auto and Light Duty Truck Surface Coating, Pressure Sensitive Tape and Label Surface Coating, Large Appliance Surface Coating, Metal Coil Surface Coating, Surface Coating Plastic Parts for Business Machines, Polymeric Coating of Substrates, and Beverage Can Surface Coating; US Effluent Guidelines for Coil Coating

[13] http://burondt.ru/NDT/NDTDocsDetail.php?UrlId=1126&etkstructure_id=1872

[14] http://eippcb.jrc.ec.europa.eu/sites/default/files/2019-11/ofc_bref_0806.pdf

[15] http://eippcb.jrc.ec.europa.eu/sites/default/files/2019-11/sic_bref_0907.pdf

[16] https://www.epa.gov/sites/production/files/2020-02/documents/paint-formulating_ink-formulating_dd_1975.pdf

[17] http://eippcb.jrc.ec.europa.eu/sites/default/files/2020-01/JRC118627_FDM_Bref_2019_published.pdf

[18] US NESHAP for manufacturing nutritional yeast, solvent extraction for vegetable oil production, and prepared feeds manufacturing; NSPS for grain elevators; US Effluent Guidelines for canned and preserved fruits and vegetables processing, canned and preserved seafood processing, dairy product processing, grain mills, meat and poultry processing, and sugar processing

[19] http://burondt.ru/NDT/NDTDocsDetail.php?UrlId=1144&etkstructure_id=1872

[20] http://burondt.ru/NDT/NDTDocsDetail.php?UrlId=1146&etkstructure_id=1872

[21] http://www.mee.gov.cn/ywgz/fgbz/bz/bzwb/wrfzjszc/201901/W020190104333246193415.pdf

[22] https://www.epa.gov/sites/production/files/2015-11/documents/meat-poultry-products_tdd_2004_0.pdf

[23] https://publications.jrc.ec.europa.eu/repository/handle/JRC107769

[24] https://www.cleantechflanders.com/

[25] https://bluechem.be/

[26] https://www.roadmaptozero.com/

[27] https://www.vecap.info/about-vecap/

4 Challenges associated with value chain concept consideration in BAT determination

There are several challenges to address when considering value chains as part of BAT determination in the context of BREFs. Given the diverse array of policy tools available to regulators, the first concern must be determining if BAT policy is the best place to integrate value chain concepts in environmental regulation. It is necessary to carefully consider options within existing frameworks and potential implications for implementation. For instance, regulators may evaluate what is within a facility's control or general constraints at individual installation levels, including access to information, and sector performance in achieving regulatory requirements. Introducing these lines of reasoning into BAT determination may significantly compound the already complex process of developing BREF documents.

Is BAT Policy the best or most effective option for integrating value chain considerations?

BAT policies are one tool of many available to regulators; one must consider whether BAT policy is the best option for integrating value chain considerations in a given sector. Moreover, prior to revising the scope of BREF documents to include the value chain, it is important to consider whether altering the scope in other ways might yield better outcomes.

A number of reports and studies outline cases where certain BAT framework policies impede integration of some of the more expansive value chain concepts. For instance:

- DG Environment's report considering IED contribution to circular economy notes that the IED, which sets out to reduce harmful industrial emissions across the EU, in particular through better application of BAT, may not be the best instrument to further achieve circular economy objectives. The EU policies on circular economy aim to produce environmental benefits by keeping the value of products, materials and resources in the economy for as long as possible, avoiding the generation of waste (Anderson, Natalia *et al*, 2019[41]). Another report concludes that there is no "magic bullet" in the application of the IED to improve circular material use by IED installations, as many other factors strongly determine the performance of installations with respect to circular material use (Wood E&IS GmbH, 2021[72]). The report suggests that circular economy improvements require operator decisions that are adapted to the specific circumstances of the plant. Thus, a one size fits all approach in BREFs is unlikely to be generally effective or appropriate. For most issues, allowing flexibility on how operators can improve circularity is likely to be more effective; this would be usefully supported by a dialogue between the operator and the permitting authorities.

- Also, of relevance is the Communication on the European Green Deal (EC, 2019[73]) and the ongoing revision of the IED. The Green Deal reads: “The Commission will review EU measures to address pollution from large industrial installations. It will look at the sectoral scope of the legislation and at how to make it fully consistent with climate, energy and circular economy policies”
- Scale consideration: Integrating value chain concepts during the permitting stage may be more feasible than during BREF development. The Danish Ministry suggests that it is possible for permitting authorities to establish resource efficiency related conditions in individual permits even if this is not captured in the relevant BREF (Ministry of Environment and Food of Denmark, 2016[52]). Further, a BAT-based permitting approach may seem better suited to addressing industrial emissions, considering their impact at the local level and thus the importance of reducing emissions from all installations that pollute their environment, whereas GHG emissions can be abated wherever this can be done at the lowest cost, due to their global nature. In general, the permitting process systematically considers possible positive or negative effects of a technique on other parts of the value chain or on the value chain as a whole.
- Coverage by other frameworks: The concept of GHGs including comprehensive analysis of CO_2 emissions are addressed in other frameworks, e.g., GHG Protocol Scope 3. Similarly, hazardous chemicals used in manufacturing are regulated under chemical safety laws, which may restrict the use of certain chemicals based on risk.

Challenges of a value chain perspective at the installation-level

Implementation of value chain concepts at the installation presents tangible difficulties particularly as corporate approaches to sustainability evolve (RPA, 2017[74]). Challenges discussed include impact of degree of control beyond facility boundaries, availability of information about products including broad product use versus narrow, and a company’s internalized costs and externalized benefits of value chain thinking.

Facility control

Different parts of the chain are often different legal entities. Generally, an installation is regulated through an installation-specific permit which controls what happens in installation boundaries. This permit may also control the inputs a facility receives to some degree. Other regulations protect workers from indoor industrial hazards, and further downstream, consumers during product use and the environment or human health during material recovery and final disposition. These laws influence decisions to continue market penetration through feedback to upstream manufacturers in the form of market pressure or indirect legislative. Similarly, facilities may adapt practices to maximize market reach and profit potential by adhering to product standards in jurisdictions other than their own locality.

Operators may have limited knowledge or control over industrial and consumer uses of their products. Product stewardship in limited sectors is gaining traction for a variety of reasons; impacts downstream may need to be traced to the producer, redesign needs to be considered for reentry into the market, recapture of valuable materials such as metals. Thus, while downstream implications should be considered, there is often a transfer of responsibility once a product leaves the facility boundary.

Facility operators, particularly medium and small business, face additional obstacles namely resource constraints that may limit the extent to which they could realistically consider actions beyond routine and immediate installation operations and inputs required. Establishing strong business relations with suppliers and engaging in cooperative endeavors to identify solutions where needed can help installations reduce their environmental footprint.

Governing bodies such as the European Chemical Agency (ECHA) help stimulate facility engagement levels across industry. According to a 2017 analysis on the impact of REACH and CLP implementation on industry sustainability strategies, it finds effective communication on the safe use of chemicals along the supply chain. Companies inform their suppliers about chemical use, and in return, manufacturers and importers provide information on how to use them safely (RPA, 2017[74]).

Information sources such as Pollutant Release and Transfer Registers (PRTR), where facilities annually disclose quantities of chemical waste released or transferred to other facilities, could be used to better understand what is within a facility's control, and help gauge progress and impact towards sustainability objectives.

Recent publications illustrate that the Toxics Release Inventory (TRI), the U.S.' PRTR, is uniquely well-suited for assessing the progress made by different industry sectors or specific facilities therein in implementing green chemistry practices, and measuring efficacy in achieving greater sustainability (DeVito, S. C.; Keenan, C.; Lazarus, D., 2015[75]; Gaona, 2018[76]). In addition to release and other waste management quantities, facilities are required to disclose their new source reduction activities to TRI using codes that describe the activities they engaged in. Beginning with the 2012 reporting year, EPA implemented six new source reduction codes for completing the TRI report that are more closely aligned with actual green chemistry practices. These codes are:

1. Introduced in-line product quality monitoring or other process analysis system;
2. Substituted a feedstock or reagent chemical with a different chemical;
3. Optimized reaction conditions or otherwise increased efficiency of synthesis;
4. Reduced or eliminated use of an organic solvent;
5. Used biotechnology in manufacturing process; and
6. Developed a new chemical product to replace a previous chemical product.

From 2012 through 2019, facilities have reported 2,606 green chemistry activities for 168 TRI chemicals and chemical categories. Green chemistry activities were reported most frequently for methanol, lead and lead compounds, toluene, copper and copper compounds, nickel and nickel compounds, and ammonia. The sectors reporting the highest number of green chemistry activities were chemical manufacturing, fabricated metals, and plastics and rubber (US EPA, n.d.[77]). Furthermore, facilities describe the methods (e.g. audit, supplier assistance, etc) used to identify the practices implemented, and can provide optional narratives to further describe their activities including expected estimated reductions (US EPA, n.d.[78]). Access to this information provides greater insight as to the activities being undertaken at industrial facilities and factors influencing them which can further the effectiveness of BAT determinations.

Product information

Where BAT guidance considers the value chain, it tends to focus on inputs from upstream industries; guidance rarely considers downstream links in the value chain, as the number of applications for a product can vary significantly from industry to industry, and even installation to installation. From the perspective of an upstream sector or facility, it may be difficult—and even meaningless—to evaluate and aggregate the environmental impacts of all use cases for downstream activities. Considering downstream links in a value chain may be much simpler for an industry if its products see relatively narrow use, as there are fewer scenarios to evaluate.

To begin evaluating and minimizing the environmental impact of downstream product use, it is important to have a complete inventory of chemical uses for the product in question. Especially when considering chemicals of concern, full understanding of the properties which make a chemical or product suited to each of its functions is essential in identifying alternatives with the necessary properties to fill the same function with fewer environmental impacts.

There are numerous resources which contain information on the use of chemicals and chemical products in industrial settings. For instance, the ECHA database allows chemical filtering based on industrial uses, sector(s) of use, and process category. Similar information is available from the US EPA's Chemical Data Reporting, accessible from the US EPA's ChemView database (US EPA, 2021[79]), and includes 'use codes' reported by industry. Filtering this information allow for the grouping of chemicals by use function. Additionally, these databases allow users to assess how broad or narrow the use of a chemical product is within one (or many) industries. These filters and analyses can help focus assessments for end users as well as upstream suppliers, especially for activities like alternatives assessments and benchmarking.

ECHA's SCIP (Substances of Concern In articles as such or in complex objects (Products)) database launched in 2020 to increase knowledge of hazardous chemicals in articles and products throughout the whole lifecycle - including at the waste stage. Through information availability to waste operators and consumers, SCIP aims to: 1) reduce hazardous substances in waste; 2) encourage substitution of those substances with safer alternatives; and 3) contribute to a better circular economy by helping waste operators ensure that such substances are not present in recycled materials (ECHA, 2020[80])

Facility-reported data available from these databases are useful in building knowledge both domestically and internationally. Complementary data are often captured in chemical registrations, chemical use reporting, and PRTRs. Standardizing the codes and descriptions used in these reports for chemical uses, management, and releases to the environment may be vital in ensuring interoperability across international databases. Additionally, use of these standardized codes in addition to free-text entries may facilitate the use of customized data queries. Moreover, standardizing codes and descriptions in these databases can allow for complementary use of databases with different data elements.

The UNs Globally Harmonized System of Classification and Labelling of Chemicals (GHS) aims to provide a single, globally harmonized system to address classification of chemicals, labels, and safety data sheets. It is updated biennially to reflect experiences in implementing its requirements into national, regional and international laws, as well as the experiences of those doing the classification and labelling (UNECE, n.d.[81]). GHS has been implemented in the US workplace through the revised Hazard Communication Standard (HCS) issued by the Occupational Safety and Health Administration (OSHA) (OSHA, n.d.[82]), and in the EU, through the classification, labelling and packaging of substances and mixtures (CLP) regulation (EC, n.d.[83]). As countries adopt these harmonized standards, consistent labelling and information will improve communication on chemicals and their hazards.

Costs and benefits of value chain thinking

It is possible that a facility may not want to incur additional expenses if the benefits are solely seen downstream of the installation. These externalized benefits may not impact the environmental performance of the facility in terms of pollution prevention or emissions control. Factors at play may be cultural, economic, or regulatory. For example, if a facility has to use a minimum amount of secondary raw material but this costs more than virgin material, this may distort the market. This is a common occurrence in the plastics value chain, where secondary plastics are more expensive than virgin plastics.

Where advancements are encouraged or even required, but not necessary for operating within allowable permit limits, incentive might aid in adoption of technology or process modifications. For example, if an industry covered by BAT is obliged to manage waste according to specifications that enhance its use in a downstream step of the value chain, the cost is typically born by the industry generating the waste while the benefit is seen downstream.

Corporate sustainability may be driven by the downstream interests of customers and the general public, with initiatives often addressing environmental issues of greatest interest to these groups. Findings from a European survey indicate that environmental categories of most concern among the general public are climate change, freshwater eutrophication, and water use. This study reinforces the need and benefit of facility consideration of value chain concepts and informing the public of corporate sustainability actions (Lupiáñez-Villanueva, *et al*, 2018[92]).

The United Nations is well positioned to promote systems thinking and cooperation. For instance, the United Nations Economic Commission for Europe (UNECE), as a multilateral platform, facilitates greater economic integration and cooperation among member States and promotes sustainable development and economic prosperity (UNECE, n.d.[84]). The trade programme, in particular, works to facilitate trade including standards for improved interactions along the value chain as evidence by recent work. A virtual dialogue was held in April 2020 to enhance transparency and traceability of information exchange in the textile and leather value chain (UNECE, 2020[85]).

Challenges associated with BREF development

BREF development requires the collaboration and coordination of numerous and various stakeholders including industry, non-governmental organizations, regulatory and permitting authorities across a variety of fields. It is important to note that smaller capacity facilities may be underrepresented in BAT development working groups which may be due to the participating plants within the technical working group are those beyond a certain threshold (as defined in Annex I of the IED). There may be significant challenges in development of timely BREF documents such as unbalanced timelines for regulatory development and technical advancement, statutory constraints on the scope of regulations, and limited data availability.

A significant challenge in BAT determination is matching the pace of regulatory development with the pace of technological advancement in certain sectors. BAT determinations take years to develop, which may present a challenge in considering the most up-to-date technologies and practices in BREF documents.

The development of BREFs and BAT determinations requires the use of data gathered at the installation level. Additionally, selected installations may serve as models for the implementation of certain techniques. There are limits to the data available to installation operators concerning other links in the value chain, and so the scope of data gathering will need to be broadened if considering a broader view of the value chain in BAT determinations.

It should be kept in mind that adding new criteria to the assessment of candidate BAT might extend the duration of this process, which already spans across several years. Expanding the scope of BREFs to include value chain considerations may necessitate examining technological advancements in up- and downstream sectors.

Furthermore, there is some concern that widening BAT assessment boundaries might dilute the focus on what can be done within the boundaries of an installation to control more local pollution threats, and that this may then reduce the control of pollution at its source.

Scope set by existing regulatory frameworks are difficult to modify and may inhibit coverage of BREFs. While opportunities for improvements may be sought incrementally if laws are revisited, addressing gaps in value chain considerations may be suited towards creative solutions such as promotion of voluntary programs or technical assistance resources.

As discussed in earlier sections and illustrated below, considering the value chain is challenging to accomplish through single BAT Reference Documents. Given need to focus on sector specifics, multiple BATs are developed to address upstream and downstream activities. Possible connections between value chains may vary widely from one company to another.

Table 2. Examples of environmental issues illustrating the challenge of considering the value chain in a single EU BAT Reference Documents.

	Case Study 1	Case Study 2	Case Study 3	Case Study 4
Value chain aspect	Influence of the quality of non-ferrous scrap produced in shredders on the environmental performance of the non-ferrous metals industry	Influence of the links used in printing processes on the deinkability of paper for recycling	Influence of livestock feed on composition of manure used for land spreading	Influence of the food animals receive prior to transport to the slaughtershouse on the amount of manure produced during transport and in slaughterhouse.
Upstream activity	Mechanical treatment of waste in shredders	Paper printing	Rearing of animals	
BREF covering upstream activity	BREF on non-ferrous metals industries	BREF on surface treatment using organic solvents	BREF on intensive rearing of poultry and pigs	
Downstream activity	Non-ferrous metals production	Depulping process	Manure application in crop production	Slaughering of animals
BREF covering downstream activity	BREF on waste treatment	BREF on production of pulp, paper and board	BREF on intensive rearing of poultry and pigs	BREF on slaughterhouses and animal by-products industries

Table based on four case studies developed by (Huybrechts, D *et al*, 2018[3]).

Keeping these challenges in mind is key when considering and expanded scope for BREF documents. It is important to carefully weigh options and start with the simplest solutions possible when expanding scope so the challenges inherent to BREF development for one sector are not compounded.

5 Possible solutions and recommendations for integrating value chain concepts into BAT determinations

There are numerous opportunities to apply value chain concepts to BAT determination to better address the environmental impacts of the whole value chain. Solutions may be tailored or broad but require careful consideration of the diverse interactions between sectors. Additionally, the exercise of defining the value chain and gaps in its consideration may highlight opportunities to leverage other regulatory and non-regulatory tools to minimize environmental impacts from industrial facilities.

How do we effectively integrate value chain concepts into BAT Reference Documents given framework limitations?

Despite the challenges and framework limitations to integrating value chain concepts into BAT Reference Documents as described in the above chapter, some research has indicated the potential benefits of and possible initial steps for such integration.

Potential for integrating value chain concepts into the existing framework

Although industrial emissions legislation has not been designed to incorporate circular economy priorities, Anderson et al. (2019[86]) emphasise that there is untapped potential for an enhanced contribution to objectives related to, in particular, waste generation, recycling rates and contribution of recycled materials to raw material demand, and innovation.

Furthermore, the report points out that if the Technical Working Groups increasingly identify circular economy concerns as Key Environmental Issues, these would to be addressed in the BAT Conclusions to a larger extent. VITO and Ricardo provide a set of recommendations as to how the IED and the BREFs could be changed to better respond to circular economy concerns (Anderson, N. *et al.*, 2019[83]), for example:

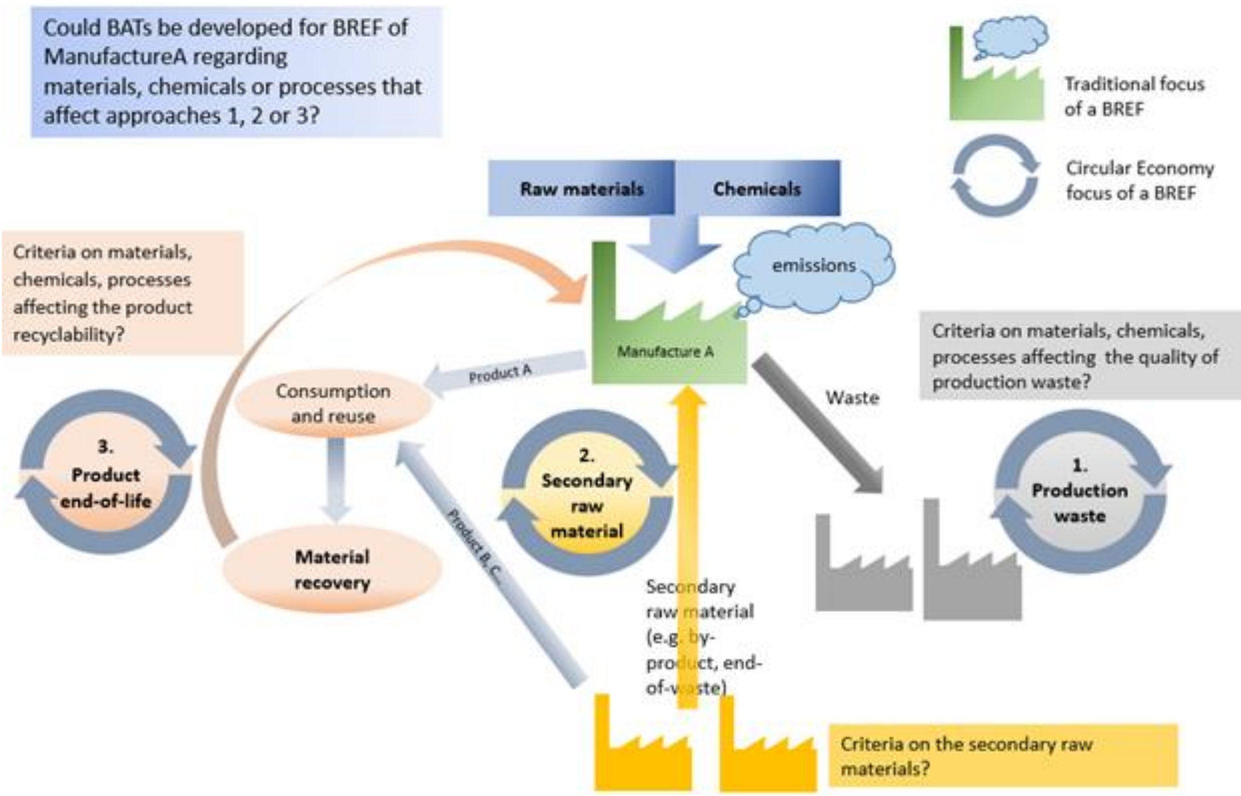
- promote better uptake of emerging techniques in industry that have a focus on circular economy;
- include experts on circular economy and from other sectors providing materials, energy or receiving by-products/wastes in the Technical Working Groups;
- add a general/overreaching BAT to all sector BAT reports requiring consideration of value chain issues; and

- when evaluating candidate BAT, consider cross-sectoral effects and collaborate with upstream and downstream partners to also identify techniques that will reduce environmental impacts elsewhere in the value chain (Anderson, Natalia *et al*, 2018[3]).

The HAZBREF project further proposes three approaches for bringing circular economy objectives into the process of developing EU BREFs, as presented in Figure 11 (Dahlbo et al., 2021[39])

- a production waste approach, involving BAT criteria concerning materials, chemicals and processes affecting the quality of production waste;
- a secondary raw material approach, involving BAT criteria related to secondary raw materials; and
- a product end-of-life approach, involving BAT criteria on materials, chemicals and processes affecting the product recyclability.

Figure 11. Three approaches for bringing circular economy issues into the EU BREF process



Source: (Dahlbo et al., 2021[39])

A circular economy-based approach could possibly help incorporate the consideration of value chain aspects when developing BREFs, for example by introducing criteria in the assessment of techniques that concern reduced waste generation, the reuse of materials downstream in the value chain, and regeneration of natural systems. This could be done in line with VITO's (Huybrechts, D *et al*, 2018[3]) proposals for how to take a value chain approach to establishing BAT Reference Documents (see Box 3 below).

In addition, the Ministry of Environment and Food of Denmark (2016[52]) has investigated whether the EU BREFs contribute to resource efficiency in industries. Their report emphasises that some of the EU BREFs already include approaches to ensure resource efficiency; however, there is potential for making the BAT conclusions more focussed upon, or accommodating of, resource efficiency. The Ministry suggests that such an approach could be facilitated by focusing on cross-media aspects, or specifying consumption of input material as parameters for monitoring, when establishing the BAT-AELs.

Furthermore, SYKE's study (Dahlbo et al., 2021[39]) outlines how the EU BREF Guidance Document (EU, 2012[30]) addresses aspects related to raw materials, waste generation and recycling. The guidance document provides the following instructions:

- The chapter of a BREF that concerns applied processes and techniques should include information that might be relevant in the determination of BAT, such as the use of raw materials (including secondary/recycled materials), consumables and auxiliary substances/materials used, as well as handling and fate of by-products and residues/wastes.
- The BREF chapter on current emission and consumption levels should address options for the recycling and reuse of materials within the whole process or beyond.
- When considering cross media effects in assessing candidate BAT, the "limitation of the ability to reuse or recycle residues/waste" should be taken into account.

Possible initial steps for the integration

An example of how to practically integrate value chain concept in EU BAT Reference Documents is provided by VITO (2014[2]) (see Box 3).

Box 3. Proposed value chain approaches to developing EU BAT Reference Documents

VITO proposes three approaches to considering environmental impacts upstream and downstream in the value chain when developing BAT Reference Documents in the EU:

1. Systematically consider possible positive or negative effects of a technique on other parts of the value chain or on the value chain as a whole ("cross-sector effects"), as part of the evaluation of candidate BAT for a given industrial activity. This could be similar to the way in which cross-media effects are assessed in the EU BREF Process today. If a technique has negative effects on other parts of the value chain or on the value chain as a whole, it should not be considered BAT. That is, some techniques could be eliminated from the list of candidate BAT due to their negative impact in other parts of the value chain or on the value chain as a whole. Guidelines for this assessment would have to be developed.
2. Not limit the selection of BAT to techniques that reduce the environmental impact of the given industrial activity, but also consider techniques that would reduce the environmental impact in other parts the value chain, or in the value chain as a whole. That is, some techniques would be included in the list of candidate BAT or emerging techniques due to their positive impact in other parts of the value chain or on the value chain as a whole (value chain BAT), even if they don't have a positive impact, or an impact at all, on the concerned industrial activity.
3. Carry out cluster studies in preparation of the development of a new or revised BREF: representatives from related industries in the value chain would come together to identify interactions across the sectors, or for example key environmental indicators for the value chain, so that this information could feed into the process to determine BAT.

Source: : (VITO, 2014[2]).

This kind of integration has been implemented in Flemish BAT studies, which assess the candidate-BAT using three criteria: 1-technological feasibility, 2-impact on the environment as a whole, and 3- the economic feasibility expanded with its impact on the value chain (on a qualitative basis). The value chain aspect can be considered in BAT policy when prioritising the candidate-BAT. This is notable in the BAT-studies for potatoes, vegetables and fruit processing industry (Van den Abeele, Liesbet *et al*, 2016[151]) and industrial processing of meat and fish (Derden, et al., 2015).

An initial step could therefore be to strengthen existing legislation/policy (e.g. IED) to be more inclusive of value chain concepts. This could be achieved by reframing industry descriptions to be more inclusive. For example, the production of pesticides or biocides in IED Annex I (4.4) could be replaced by "sustainable integrated pest management" to allow for consideration of various options to protect crops. Furthermore, it may be possible to also integrate value chain aspects in BAT Reference Documents, including in the following ways;

- Integration of an additional chapter on chain aspects at sector level.
- Extension of the descriptive parts of techniques with focus on chain aspects (cross sector effects)
- Addition of a general BAT conclusion on 'collaboration with upstream and downstream partners in the value chain' (Value chain BAT) (VITO, 2014[2]; Huybrechts, D. *et al*, 2018[3])

To improve the knowledge and understanding of possible interactions between different processes in the value chain with respect to environmental impacts, 'cluster studies' may work effectively in the frontloading phase of BREF preparation. Within a cluster (e.g. food industry, agriculture industry, fertilizer industry, feed industry), key environmental aspects in the value chain can be discussed and it would provide background information for identifying 'cross-sector' effects and 'value chain BAT'.

Another option may be to produce variant BAT Reference Documents ("Value Chain BREFs") from those which are sectoral and local pollution reduction focused and incorporate value chain and global issue considerations. The focus of developing such "Value Chain BREFs" would be on applying a "value chain adaptation" strategy to incorporate value chain criteria, for example: up- and down- stream considerations on material sustainability/resource efficiency, decarbonisation, waste minimisation, hazard reduction and substitution, and product stewardship.

To aid in developing the above options such as Value Chain BAT or Value Chain BREFs, a set of prompt questions could be used as reminders of value chain factors that may impact the installation and the overall upstream and downstream activity of the industrial sector. Facilitating the consideration of wider value chain approaches in this way will help develop value chain thinking and reduce the potential for narrower sector approaches to defining BAT, allowing cross sectoral/societal synergies to be explored and exploited.

While this work proposes that further research is required to define such "screening criteria", including how they may relate to specific sectors and how barriers may be overcome, it is anticipated that their definition will be informed by the principles listed in Annex 5.B (on green chemistry) and Annex 5.C (on sustainable chemistry), and other related green industrial production principles. Candidate criteria could be developed from critical environmental factors including:

- Resource efficiency and circular economy potential
- Requirements to utilise certain percentages of recovered materials
- Waste minimisation
- Decarbonisation / global climate impacts
- Impact on stratospheric ozone
- Energy efficiency
- Water resource conservation
- Biodiversity impact
- Hazard & risk prevention / elimination / substitution
- Land quality impacts

- Human health impact
- Ecological impact
- Air quality impacts (local)
- Persistence / biodegradability / bioaccumulation
- Control at source and precaution

How do we effectively utilise existing resources to facilitate value chain approaches?

Existing BAT and BREF production approaches have strengths which can be built upon. To identify relevant value chain interactions and facilitate their consideration during BAT determination, existing schemes, legislation, programmes, and other resources related to value chain interactions could be retained and adapted. Existing approaches may be modified and used to develop a screening methodology to allow sector BAT to be considered in this wider context. A list of resources and tools is available at the Annex 5.A which are used by various stakeholders and global regulatory bodies to increase of value chain considerations.

Leveraging information schemes

Flow of information within installations and between suppliers and customers is key to considering value chain approaches for minimizing environmental impacts at the installation level. Similarly, information sharing between experts at various links in the value chain is key to integrating value chain approaches during BAT determination.

A strategy for introducing circular economy-based approaches to BAT determination is through use of Circular Economy Labelling and Information Schemes (CELIS). CELIS facilitate enhanced information sharing across tiers of the value chain, enabling better management of environmentally related risks and uncertainties in supply chains (OECD, 2019[10]). Examples of CELIS include Business2Business (B2B) labels, which are used for information transfer between businesses either upstream (e.g. for sustainable sourcing) or downstream (e.g. for different end-of-life purposes and waste management) (OECD, 2019[10]).

Many existing B2B schemes seek to optimise environmental performance at the installation level, e.g. by facilitating enforcement of already defined standards, targets or emission limits. In the context of BAT implementation, such schemes could encourage industrial installations to consider value chain aspects when seeking compliance with their BAT-based permit conditions.

In addition, there would be value in setting up similar schemes to ensure information sharing at the preceding stage, i.e. during the process to determine BAT and associated environmental performance levels (BAT-AEPLs) for a given industrial activity, to make sure that information from different parts of the value chain are taken into account. In line with this idea, VITO (2014[2]) proposes carrying out cluster studies in preparation of the development of a new or revised BREF: representatives from related industries in the value chain would come together to identify interactions across the sectors, or for example key environmental indicators for the value chain, so that this information could feed into the process to determine BAT.

In the US, regulators often engage with government partners (federal, state, local, and tribal) and other interested parties (such as industries and environmental groups) early in the process of establishing emissions regulations. The discussion with the stakeholders continues following rule completion to achieve effective implementation (US EPA). Thus, although US regulations are generally restricted to emissions from facilities and generally do not consider up- or down- stream impacts, these formal and informal engagement processes may facilitate the consideration of value chain implications and circular economy objectives, such as facility emission impacts due to changes in raw material to reduce pollution.

There may be hesitancy to share technological or best practice information by industry due to concerns about competition or ownership of intellectual property. For instance, formulators participating in industry fora on green chemistry or chemical substitution may be reluctant to share information about their innovations due to concerns that they will lose a competitive advantage. This may be overcome by more actively identifying and promoting example best practices. Award programs to recognize facilities leading in environmental performance is another mechanism that can be leveraged to incentivize and promote greater information exchange.

Raising awareness of relevant programmes and regulations

Leveraging trusted "eco-label" approaches may aid in shifting decision-making to more sustainable alternatives and limiting downstream impacts from industrial or consumer use. According to a European study, certification of products is seen as a trustworthy label feature where these labels are broadly standardized (Lupiáñez-Villanueva *et al*, 2018[92]). Further, product environmental footprint (PEF) labels which provide companies with a common way of measuring environmental performance are preferred to standard eco-labels (OpenLCA, n.d.[87]). As governments and organizations work towards developing standardized environmental performance labels for classes of products and industrial inputs, BAT policies should consider pointing to a limited set of trusted labels.

Including information on relevant regulations and programs may allow for more accurate assessments and implementation of certain value chain concepts. These voluntary or mandatory practises such as consumer product labelling, chemical use and release reporting, and workplace safety standards should be included in BREF documents to present a more comprehensive account of industrial operations. Such information may be key in gauging feasibility of value chain integration in BAT determination. For instance, the consumer product standards from the US Consumer Safety Product Commission may have significant influence on patterns of chemical use and substitution through product labelling requirements and certain product safety standards (flammability, hazardous substances in children's toys, etc.); this influence may act as a driver or barrier to substitutions depending on the product and applicable regulations. Accounting for this influence in BAT determination may allow for better consideration of what chemical substitutions are feasible.

Greater use of life cycle assessment resources

Tools such as life cycle analysis and input-output models could be employed to a greater extent in BAT determinations to aid in the tracking and managing of resources and in finding pollution prevention opportunities. The model below shows how environmental management address all three steps of a product's life cycle: input, production and output (see Figure 12).

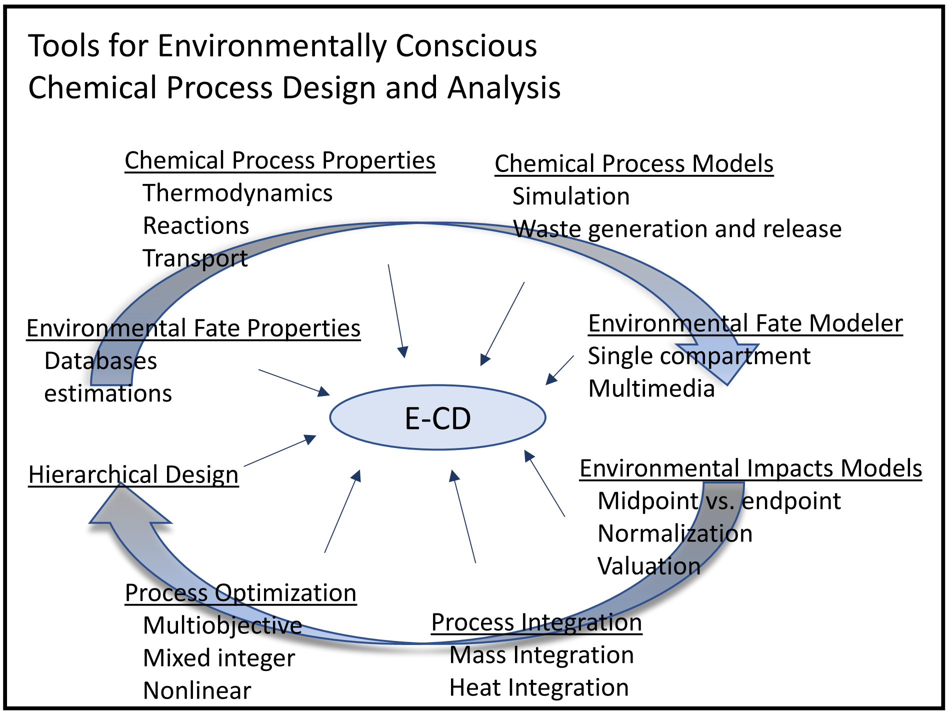
Figure 12. Steps of the life cycle enhanced through a Value Chain Lens

Input	Production	Output
• Key performance indicators KPI • Substituting virgin material with recycled material • Review and record	• Minimum efficiency • Good housekeeping • Resource management • Audit and improve • Resource efficiency upon procurement and design • Retrofitting existing equipment • Reporting publicly	• Segregation • Recycling of waste streams • Assessing value • Assessing value and turning waste into by-products
• Environmental management • Resource efficiency in BAT AEL		

Source: (Ministry of Environment and Food of Denmark, 2016[52])

Other tools for environmental impact assessment of process designs include (Anastas et al., 2007[88]): Resource Efficiency Guidebook (REG) (Bryson J, 2019[89]); Simultaneous Comparison of Environmental and Non-Environmental Process Criteria (SCENE) (Chen, 2004[90]); Waste Reduction Algorithm (WAR) (U.S. EPA, n.d.[91]); and Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI) (U.S. EPA, n.d.[92]) . As illustrated in Figure 13, chemical process design and analysis tools could aid in holistic consideration of impacts.

Figure 13. Schematic of David Shonnard's tools for environmentally conscious chemical process design and analysis



Source: (Allen and Shonnard, 2001[93])

Incorporating Indicators or Additional Metrics

Considering the diverse industries regulated under technology-based standards and the many ways value chain concepts can be applied, it is important to devise a standardized methodology for considering relevant value chain interactions during BAT determination that may still yield tailored solutions. Thus, existing indicators or metrics for considering value chain aspects used in sub-jurisdictions or globally would be worth considering.

Industrial facilities could be encouraged to use harmonized metrics, maintain public accountability, and increase communication along the supply chain. It has been suggested that such information could be made publicly accessible through a QR code on the label (Lupiáñez-Villanueva, Francisco *et al*, 2018[92]). As an example, BAT guidance could recommend communication on the following elements:

- Products Production phase information (some metrics are specific to certain industrial activities): Country of origin, traceability (i.e. kilometres covered to reach the point of sale), type of energy consumed to produce it, quantity of energy consumed to produce it, polluting and contaminating impact, impact on global warming, water usage, type of livestock feeding, livestock habitat (e.g. natural vs. farmed), GMO content, and level of dioxins.
- Products Use phase information: Toxicity on the body or health, energy consumption, level of pollution or contaminates, biodegradability, and potential to be recycled or reused.

Sectoral Reference Document (SRD) and a technical report on Best Environmental Management Practices for each selected sector published by the European Commission provide environmental performance indicators, some of which target supply chain management and fostering a more circular economy. Those indicators link to environmental pressures addressed including resource efficiency, emission to air, energy & climate change, biodiversity, and hazardous substances (EC, 2019[94]).

Studying and identifying those indicators and metrics would facilitate the development of a screening methodology to allow sector BAT to be considered in this wider context, and more specifically, the 'screening criteria' proposed above as a possible initial step.

Continuing the exploration of solutions

While some possible strategies for the application of value chain approaches to BAT determinations have been proposed above, further research is still needed to accelerate progress toward identifying practices that more effectively consider an industry's entire value chain to reduce overall environmental impacts as well as individual manufacturing sites within a given sector. This section describes some possible topics to explore the solutions.

In response to an increased understanding of global environmental issues, industry is evolving, and may be very different in the future. BAT is largely focused on controlling emissions from those industries with the greatest "pollution" potential. With current society's evolving understanding of environmental issues and risk, and expectation that regulatory authorities and stakeholders will implement practices that address these issues and mitigate risk, there is an opportunity to revisit the sectors covered to reflect those with the greatest impact, including impacts on wider value chain issues. Consequently, there may be interest in expanding the scope of BREFs to other sectors. Examples for consideration in the food production sector include intensive cattle farming, and aquaculture. These sectors generate significant pollution with cattle rearing as the largest EU source of methane emissions, but are currently excluded from the scope of the IED, whilst intensive pigs and poultry rearing is covered. The coverage for other sectors could be broadened. For example, coverage under production of cement, lime, and magnesium oxide could be expanded to include other construction minerals such as gypsum, which uses a processes similar to cement and lime production. Similarly, inclusion of asphalt could capitalise on opportunities to promote alternative techniques and non-petroleum-based, renewable raw materials.

Resource efficiency and decarbonisation are major themes across all sectors and as pressures continue to mount on resources, greater consideration is required of how value chains will be altered by energy supplies. For instance, in decades to come, it is anticipated that more abundant renewable and/or lower carbon (and cost) energy will be available – this could permit development of new resource efficiency solutions that are presently uneconomic and environmentally harmful due to displaced emissions from energy generation. Such approaches may allow the recovery of critical elements from ores and waste materials at efficiencies that are presently unimaginable. However, the transition time for the delivery of low carbon energy is expected to be some decades, and indeed availability is not guaranteed. As such there is also a danger of "complacency" from an over-reliance on this.

A best practices study can also be undertaken to highlight industrial synergies through analysis of industrial clusters and interactions. A BAT-best practice document could gather examples of clusters to further discussions on synergistic relationships, and identify circumstances and criteria where such "sector coupling" might be specifically beneficial (Ellen MacArthur Foundation, n.d.[95]; EC, n.d.[96]; EC, 2015[97]).

Although this study focussed upon the application of value chain approaches to industrial sector BAT, it has also been noted that value chain BAT approaches may, in principle, be applicable to broader strategic decisions such as the development of city planning, energy and waste strategy development. To some degree, these may already be reflected in wider strategic and life-cycle based policy. Example initiatives might include:

- Sustainable cities BAT – noting the global trend to greater urbanisation, BAT type approaches may be used to describe examples of how city planning and development has addressed key environmental issues to deliver more sustainable and higher resource efficiency approaches. Key sub-issues consist of energy and water supply management, sustainable buildings and transport, and waste and resources management.
- Sustainable Energy BAT - approaching energy strategically and regionally would allow comparison of technology mixes used to address decarbonisation and security of supply, whilst also placing these decisions in the context of affordability (to consumers) and locally specific factors such as resource availability, historical constraints (e.g., current infrastructure departure points).
- Sustainable Resources and Waste Management BAT – the identification of BAT resources and waste management approaches for major societal waste streams may help integrate value chain approaches and allow the sharing of best practices.
- Sustainable Mobility BAT – the transport of goods and people are a major contributor to global consumption and emissions. A BAT approach may help in assessing favourable transport strategies, systems, and planning.

Similarly, this study considered four concepts that embrace the value chain perspective and strive for reduced environmental and human health impacts; however, the BAT determination process could be informed by other inclusive concepts. One example is the nature-based philosophy coined by Dr. Nies, as "Floriescence", which describes a coherent vision for human flourishing on a thriving planet. This concept enables envisioning and implementing ways of living, both locally and globally, that are deeply attractive, just, and engaging, promoting both human and ecological well-being (Nies, May 2019[98]). As value chain concepts and resources are explored, it may be possible to infuse the BAT determination process with more consistent and effective evaluation strategies.

Annex 5.A. List of Resources

Below is a compilation of tools and resources relevant to increasing value chain consideration under labelling or information schemes and alternative assessment tools. These existing resources help to strengthen awareness of the interactions among various stakeholders and global regulatory frameworks to facilitate expanded consideration of chemical communication, chemical alternatives, advances in technology, among other pollution prevention options.

Chemical information and communication

- **Various chemical information links**
  - California Department of Toxics Substance Control - https://dtsc.ca.gov/scp/chemical-information/
- **Communications in the supply chain**
  - European Chemicals Agency - https://echa.europa.eu/communication-in-the-supply-chain
- **Safety data sheets**
  - European Chemicals Agency - https://echa.europa.eu/safety-data-sheets
- **Factsheet on safety data sheets and exposure scenarios**
  - European Chemicals Agency - https://echa.europa.eu/documents/10162/22372335/downstream_sds_en.pdf/f3963ab4-4691-427b-97cc-f0d4b39368e9
- **Guidance and tools for downstream users - in brief**
  - European Chemicals Agency - https://echa.europa.eu/documents/10162/21332507/du_in_brief_en.pdf/d4a10071-6f56-7a88-215a-008514189b42
- **Hazard Communication, Occupational Safety and Health Administration**
  - U.S. Department of Labor - https://www.osha.gov/dsg/hazcom/.
- **Global directory of Ecolabels**
  - EcoLabels Index - http://www.ecolabelindex.com/ecolabels/
  - European Commission EcoLabel - https://ec.europa.eu/environment/ecolabel/
- **Circular Economy Labelling and Information Schemes (CELIS)**
  - Business2Business (B2B) labels – ENV/EPOC/WPRPW(2019)2/FINAL

Chemical/Technology alternatives and assessment tools

- **Green chemistry**
  - University of Illinois Library - https://guides.library.illinois.edu/p2/sectors/green-chemistry
- **Software tools and databases**

- University of Illinois Library - https://guides.library.illinois.edu/p2/tools

- **Alternatives assessment tools and frameworks**
  - Organisation of Economic Cooperation and Development (OECD)- http://www.oecdsaatoolbox.org/
- **Technology Diffusion**
  - University of Illinois Library - https://guides.library.illinois.edu/p2/tech-diffusion
- **Life Cycle Assessment and Sustainability Modeling Suite**
  - Open LCA software - https://www.openlca.org/openlca/

Annex 5.B. The 12 Principles of Green Chemistry

1. **Prevent waste**: Design chemical syntheses to prevent waste. Leave no waste to treat or clean up.
2. **Maximize atom economy**: Design syntheses so that the final product contains the maximum proportion of the starting materials. Waste few or no atoms.
3. **Design less hazardous chemical syntheses**: Design syntheses to use and generate substances with little or no toxicity to either humans or the environment.
4. **Design safer chemicals and products**: Design chemical products that are fully effective yet have little or no toxicity.
5. **Use safer solvents and reaction conditions**: Avoid using solvents, separation agents, or other auxiliary chemicals. If you must use these chemicals, use safer ones.
6. **Increase energy efficiency**: Run chemical reactions at room temperature and pressure whenever possible.
7. **Use renewable feedstocks**: Use starting materials (also known as feedstocks) that are renewable rather than depletable. The source of renewable feedstocks is often agricultural products or the wastes of other processes; the source of depletable feedstocks is often fossil fuels (petroleum, natural gas, or coal) or mining operations.
8. **Avoid chemical derivatives**: Avoid using blocking or protecting groups or any temporary modifications if possible. Derivatives use additional reagents and generate waste.
9. **Use catalysts, not stoichiometric reagents**: Minimize waste by using catalytic reactions. Catalysts are effective in small amounts and can carry out a single reaction many times. They are preferable to stoichiometric reagents, which are used in excess and carry out a reaction only once.
10. **Design chemicals and products to degrade after use**: Design chemical products to break down to innocuous substances after use so that they do not accumulate in the environment.
11. **Analyze in real time to prevent pollution**: Include in-process, real-time monitoring and control during syntheses to minimize or eliminate the formation of byproducts.
12. **Minimize the potential for accidents**: Design chemicals and their physical forms (solid, liquid, or gas) to minimize the potential for chemical accidents including explosions, fires, and releases to the environment.

Source: (US EPA, n.d.[11])

Annex 5.C. The 9 Principles of Sustainable Chemistry

Rule 1: If possible, only use substances (as such, in mixtures or in articles) which are not mentioned on lists of problematic substances. This way you avoid losing raw materials because of legitimate restrictions.

Rule 2: Using problematic substances, assess the different uses and potential users of the substance as such. If the substance cannot be exchanged, you have to take responsibility for the consequences of its use. Never only evaluate the substance in isolation but think through the entire lifecycle!

Rule 3: As much as possible use substances which are not dangerous to human health (in particular none which are classified as carcinogenic, mutagenic or reprotoxic), which are easily degraded, don't bioaccumulate and don't widely disperse in the environment. With these substances you have to put less effort in risk management measures.

Rule 4: Don't use substances which require a high degree of risk management according to the easy-to-use workplace control scheme for hazardous substances or the COSHH approach!

Rule 5: Prefer substances which are available in excess or made from renewable resources to substances which are scarce and produced from fossil raw materials! On the one hand, you will pay less for them. On the other, they will probably still be available for you in 20 years.

Rule 6: Avoid long-distance transports at any stage of the supply chain, in particular for substances which you use in high amounts! Transport always correlates with higher environmental stress.

Rule 7: Pay attention to a low energy and water consumption of substances you use in large amounts as well as to a low generation of wastes in manufacturing and use! That way you conserve limited resources.

Rule 8: Assess whether your suppliers conform to high environmental and social standards. Select substances considering the transparency of the supply chain and the commitment of its actors to sustainability! That is how you support enterprises that do their responsibility in the supply chain justice.

Rule 9: Furthermore, products should not be put on the market for which a societal benefit and a benefit for consumers can not be identified.

Source: (Reihlen, A *et al*, 2016[15])

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In the transition towards a non-polluting, resource efficient industry, greater consideration of value chains shows potential to deliver greater overall environmental benefit than less integrated approaches that focus on individual stages, such as installation or sectoral emissions. Actions taken at the design and manufacturing, or other product life phases, can influence environmental impacts at other stages such as material processing, and waste recycling. The overall life-cycle impacts need to be accounted for at the outset.

This report assesses how value chain approaches are/should be incorporated in BAT determinations and related environmental regulatory and policy concepts to accelerate progress toward identifying practices that more effectively consider an industry's entire value chain to reduce overall environmental impacts as well as individual manufacturing sites within a given sector.

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

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