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Sustainable Chemistry in the International Management of Chemicals and Waste – Analysis and Conception of Initiatives, Instruments, Funding and Network

Final report – Draft

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Abstract

The sound management of chemicals and waste is an essential building block of sustainable chemistry and is an essential cross-cutting element for the achievement of the 2030 Agenda for Sustainable Development. Strengthening the sound management of chemicals and waste in the long term has been adopted in the United Nations Environment Assembly (UNEA) Resolutions 1/5 and 2/7. Both explicitly refer to the 2020 goal for chemicals "aiming to achieve, by 2020, that chemicals are used and produced in ways that lead to the minimization of significant adverse effects on human health and the environment". However, at the international level, it has not yet become apparent how exactly this field connects with sustainable chemistry, and what the significance of topics is that belong to sustainable chemistry but not to the sound management of chemicals and waste.

Therefore, the focus of this project was the conjunction of sustainable chemistry and sound management of chemicals and the advancement of the assessment of sustainable chemistry. From this, key recommendations and conclusions can be derived that will reach an international audience, thanks to the German presidency of the ICCM Bureau until 2020 and the opening of the International Sustainable Chemistry Collaborative Centre (ISC_3). Case studies for sustainable chemistry have been identified and evaluated regarding their sustainable chemistry potential and contribution.

Key results of the project are an inventory of activities and instruments in the areas of sustainable chemistry and national and international chemicals management, indicators to distinguish between both areas, a holistic assessment scheme for sustainable chemistry and of case studies which have been assessed with this scheme.

Kurzbeschreibung

Das sichere Chemikalien- und Abfall-Management ist ein wesentlicher Baustein der Nachhaltigen Chemie und ein wesentliches Querschnittselement für die Verwirklichung der Agenda 2030 für Nachhaltige Entwicklung. In den Resolutionen 1/5 und 2/7 der Umweltversammlung der Vereinten Nationen (UNEA) wurde die langfristige Stärkung eines sicheren Chemikalien- und Abfallmanagements beschlossen. Beide beziehen sich ausdrücklich auf das 2020-Ziel für Chemikalien, wonach "bis 2020 zu erreichen [ist], dass Chemikalien so verwendet und hergestellt werden, dass signifikante nachteilige Auswirkungen für die menschliche Gesundheit und die Umwelt auf ein Mindestmaß begrenzt sind". Auf internationaler Ebene ist jedoch noch nicht deutlich geworden, wie genau dieser Bereich mit der Nachhaltigen Chemie zusammenhängt und welche Bedeutung Themen haben, die der Nachhaltigen Chemie zuzuordnen sind, nicht aber dem sicheren Chemikalien- und Abfallmanagement.

Daher lag der Schwerpunkt dieses Projekts auf der Verbindung zwischen der Nachhaltigen Chemie und dem sicheren Chemikalien- und Abfallmanagement sowie auf der Weiterentwicklung der Bewertung der Nachhaltigen Chemie. Daraus lassen sich wichtige Empfehlungen und Schlussfolgerungen ableiten, die dank der deutschen Präsidentschaft des ICCM-Büros bis 2020 und der Eröffnung des Internationalen Kompetenzzentrums für Nachhaltige Chemie (ISC3) ein internationales Publikum erreichen werden. Ferner wurden Fallstudien im Bereich der Nachhaltigen Chemie identifiziert und hinsichtlich ihres Potentials für die Nachhaltige Chemie und ihres Beitrags zur nachhaltigen Entwicklung bewertet.

Die wichtigsten Ergebnisse des Projekts sind eine Bestandsaufnahme der in den Bereichen Nachhaltige Chemie und nationales und internationales Chemikalienmanagement vorhandenen Aktivitäten und Instrumente, Indikatoren zur Unterscheidung zwischen beiden Bereichen sowie ein ganzheitliches Bewertungsschema für die Nachhaltige Chemie und Fallstudien, die anhand dieses Schemas bewertet wurden.

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BMU	Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit (Federal Ministry for the Environment, Nature Conservation and Nuclear Safety)
GHS	Globally Harmonised System of Classification, Labelling and Packaging of Chemicals
ISC_3	International Sustainable Chemistry Collaborative Centre
MEA	Multilateral Environmental Agreement
OOG	Overall Orientation and Guidance
OPS	Overarching Policy Strategy
SAICM	Strategic Approach to International Chemicals Management
SC	Sustainable Chemistry
SDG	Sustainable Development Goal
SMCW	Sound management of chemicals and waste
UBA	Umweltbundesamt (German Environment Agency)
UNEA	United Nations Environment Assembly
UNEP	United Nations Environment Programme
WP	Work package
WS	Work step
WSDD	World Summit on Sustainable Development (Johannesburg, South Africa, 2002)

Summary

Background and scope of the project

The sound management of chemicals and waste is an essential building block of sustainable chemistry and is a cross-cutting element for achieving the 2030 Agenda for Sustainable Development. Strengthening the sound management of chemicals and waste in the long term has been adopted into the United Nations Environment Assembly (UNEA) Resolutions 1/5 and 2/7. Both explicitly refer to the 2020 goal for chemicals, stated for the first time in the Johannesburg Plan of Implementation – the outcome document of the World Summit on Sustainable Development (WSSD) in Johannesburg, South Africa, 2002 – "aiming to achieve, by 2020, that chemicals are used and produced in ways that lead to the minimization of significant adverse effects on human health and the environment" (UN, 2002; paragraph 23, p. 13). This goal was later reaffirmed by e.g. the 2012 UN Conference on Sustainable Development in "The future we want".

At the international level, it has not yet become apparent how exactly sound management of chemicals connects with sustainable chemistry. Further, the significance of topics that belong to sustainable chemistry but not to the sound management of chemicals and waste are to be gauged. It is, moreover, unclear at this stage what sustainable chemistry exactly comprises and how applications, processes, products or chemicals can be evaluated concerning their contribution to sustainable chemistry.

The focus of this project was the conjunction of sustainable chemistry, sound management of chemicals and the advancement of the assessment of sustainable chemistry. From this, key recommendations and conclusions can be derived that will reach an international audience, thanks to the German presidency of the ICCM Bureau until 2020 and the opening of the International Sustainable Chemistry Collaborative Centre (ISC$_3$). Case studies for sustainable chemistry have been identified and evaluated regarding their sustainable chemistry potential and contribution.

Against this background, the project supported several activities of the German Environment Agency regarding sustainable chemistry, which are summarised in the following.

Initiatives for international management of chemicals and waste and sustainable chemistry inventory

The first step of the project work was to identify and describe individual elements from the areas of sustainable chemistry as well as national and international chemicals management. Different initiatives, instruments and funding mechanisms have been identified and described. Stakeholders and sectors involved were listed consecutively.

A stepwise search was performed, including:

a) a detailed analysis of the Green Economy report[1];
b) a targeted search for elements already known to the project team (brochures and publications);
c) a systematic and specific internet research using specific search terms

The research resulted in a preliminary list of 99 elements, which have been subject to review and adjustment in close cooperation with the project team members, the German Environment Agency and experts at national and international institutions. Through this review, the list was extended to 148 elements comprising government activities, voluntary initiatives, financial instruments, tools, projects, events and partnerships. An update, providing new findings resulted in a final set of 31 elements as agreed upon by the project team in January 2017. The complete list of 148 elements and detailed

[1] final report to the 2014 UBA project "evaluation of the possibilities of a stronger involvement of the chemicals sector in a green economy" (FKZ 3712 93 422)

descriptions of the 31 elements is available as a separate Excel document that has been provided to UBA with the first interim report.

Criteria and indicators to distinguish sustainable chemistry and sound management of chemicals

A special focus of this project was laid on criteria to distinguish sustainable chemistry and sound management of chemicals. Criteria can be used for a more detailed description of sustainable chemistry as requested by several countries and NGOs in the course of the intersessional meeting on SAICM in Brasilia in February 2017.

First, a clear understanding of the meaning of *sound management of chemicals and waste and sustainable chemistry* is a prerequisite for a distinction between the two notions and their underlying approaches as well as for the development of assessment criteria and indicators for a distinction between the two.

The notion of *sound management of chemicals* was established in the international discussion of sustainable development and chemicals management in 1992, when the UN Conference on Environment and Development (UNCED) in Rio de Janeiro adopted the Agenda 21. Chapter 19 on *“Environmentally sound management of toxic chemicals, including prevention of illegal international traffic in toxic and dangerous products”* (UN, 1992, paragraph 19) acknowledges the value of chemicals for meeting societal needs and the achievements regarding chemical safety, whilst stressing the threats that toxic chemicals pose to the environment and human health if not managed in an environmentally sound manner. Subsequent UN Conferences and international agreements refined these statements, which resulted *inter alia* in the 2020 goal for chemicals.

Discussions on definitions and criteria for sustainable or green chemistry have recently been compiled in a comprehensive way by Blum et al. (2017)[2] and IPEN (2017). According to Blum et al. (2017), criteria for sustainable chemistry for the first time where established by the 12 principles of green chemistry published by Anastas and Warner in 1998 (Anastas and Warner, 1998), and by the 12 guiding principles of sustainable chemistry as specified in EU Council Directive concerning Integrated Pollution Prevention and Control (IPPC; 96/61/EG and 2008/1/EG) in 1996. The 12 principles of green chemistry have been complemented in 2003 by Anastas and Zimmermann with the 12 principles for green engineering (Anastas and Zimmermann, 2003). The 12 IPPC guiding principles of sustainable chemistry have been further developed by UBA and OECD into the general Criteria for Sustainable Chemistry (2004); and have been taken up in the EU Council Industrial Emissions Directive (IED; 2010/75/EU) in 2010. In 2014, the OECD published a first “Definition of Sustainable Chemistry” that was updated in 2016; and in 2015 UBA developed the so-called “concept of sustainable chemistry”.

Second, a summary of all criteria that have been identified in previous tasks of this study has been elaborated, which was used to allocate their relevance for sustainable chemistry and the sound management of chemicals and waste. For the 25 parameters of sustainable chemistry that were analysed in more detail, it has become apparent that it can be difficult at times to differentiate SMCW from SC at the level of criteria and the indicators need to be considered individually. A cross check with the specific targets of the SAICM OPS provided further guidance but did not result in a final approval and development of indicators for SMCW at that stage. Indicators which apply to the two schemes have been classified as “border” indicators.

[2] Available as Annex 2 to this report.

In the end it could be concluded that there are considerable overlaps but also clear differences between the two approaches that can be used to further differentiate between the two and to develop criteria and indicators for distinction.

Criteria and indicators to assess the contribution to the 2020 goal and the 2030 Agenda for Sustainable Development

Throughout the last decades a considerable number of activities have been started to improve and promote sound management of chemicals and waste as well as sustainable chemistry, but no systematic evaluation of the contribution to the achievement of 2020 goals and to the targets of the 2030 Agenda for Sustainable Development has been conducted.

In this context, the Overall Orientation and Guidance (OOG) adopted by ICCM4 serves as an overall orientation and guidance for SAICM stakeholders in order to achieve the 2020 goal by providing priorities for the required work. It contains 11 basic elements and 6 core activities that require action at national and regional level and help SAICM stakeholders achieving the 2020 goal. The 11 basic elements have already the character of criteria to measure progress and set priorities. The 6 core activities and their corresponding action points form a basis for indicators. Both sets have been taken into consideration for the further advancement of the assessment scheme for sustainable chemistry.

The 2030 Agenda for Sustainable Development contains a number of goals and targets, which either specifically mention hazardous chemicals or are related to chemicals and sustainable chemistry. The ones identified to have direct relevance to SMCW are:

- Target No. 3.9: “By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination”
- Target No. 9.4: “By 2030, upgrade infrastructure and retrofit industries to make them sustainable, with increased resource-use efficiency and greater adoption of clean and environmentally sound technologies and industrial processes, with all countries taking action in accordance with their respective capabilities”
- Target No. 12.4: “By 2020, achieve the environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimize their adverse impacts on human health and the environment”
- Target No. 12.5: “By 2030, substantially reduce waste generation through prevention, reduction, recycling and reuse”

Sustainable chemistry, due to its broad contribution to sustainable development, addresses a number of other targets as well that are provided in a complete list covering all 169 targets in the holistic as-assessment scheme. Thereof, 25 targets directly articulate the ecological goals of sustainable chemistry, 29 targets the economic goals of sustainable chemistry and 88 targets the social goals. Altogether, 142 out of 169 targets of the 2030 Agenda directly express core goals of Sustainable Chemistry. Only 27 of these 169 targets have a weak or no direct relation to Sustainable Chemistry.

Generally, the main goal of Sustainable Chemistry is to foster sustainable development, consisting of integrated and indivisible ecological, social and economic objectives and providing a substantial contribution to the SDG.

These, as well as further results, have been used by Ralf Geiss from the German Environment Agency to prepare an assessment scheme for sustainable chemistry. The document covers a holistic description of sustainable chemistry and leads to an assessment scheme for sustainable chemistry.

Starting from the background on sustainable development (megatrends, need for sustainability), the description on sustainable chemistry continues to underline the economic importance of chemistry and its connection to sustainability, covering all three dimensions of sustainability. The concept also comprises the current view regarding the differentiation between sustainable chemistry, SMCW and green chemistry and provides a comprehensive and graphical overview of the overlaps and differences between the concepts.

The assessment scheme takes into account the planetary boundaries and the SDG of the 2030 Agenda to result in an assessment of case studies regarding all dimensions of sustainability. It describes sustainable chemistry in relation to sustainable development, green chemistry and the sound management of chemicals and waste.

Preparation of the assessment of case studies

To identify case studies on sustainable chemistry and assess them regarding their contribution to sustainable chemistry using the developed assessment scheme, several preparatory steps were conducted in the course of the project. Those steps were necessary to provide background information, select a set of case studies and to enhance the assessment scheme.

In order to prepare best practice examples for sustainable chemistry, research for relevant topics has been conducted. The search has been based on a study from the ISC_3 with the focus on "recent innovations as well as priority research and development themes, which are needed in particular for a broad industrial implementation of the concept of Sustainable Chemistry" (UBA 2017b, p. 18). From the 10 fields of applications and industrial sectors described in the study, some had to be selected as not all fields could be addressed.

To further narrow down the specific areas of research and development within the sectors, several key publications served as a basis to identify major needs in line with global sustainable development and complement the information retrieved from different study.

After this detailed research, four sectors of major interests were identified:

- Carbon Capture and Utilisation (CCU) including PTX and material use
- Use of biomass as raw material
- Polymer (recycling)
- Phosphorus recovery

As a further step for refining the assessment scheme, international environmental goals were screened and compared. They may act as drivers for research and innovation and have been elaborated with regard to major global challenges such as climate change and a growing world population.

In addition to the Paris Agreement, the SDGs of the 2030 Agenda and SAICM, additional programmes and strategies relevant for different sectors are listed in the following:

- Goals towards a pollution free planet (UNEA)
- 7th Environment Action Programme (7th EAP)
- EU Circular Economy Package
- Revised European Charter for the Protection and Sustainable Management of Soils
- One planet summit (12 commitments)
- Concept of the planetary boundaries and related policy paper of WBGU (9 dimensions)
- WWF (Power Sector Vision 2050)
- 10 Principles by UN Global Compact
- Sustainable Process Industry through Resource and Energy Efficiency (SPIRE)
- Aichi Biodiversity Targets (Conventional on Biological Diversity, CBD).

In connection to that, checklists on parameters of sustainability already developed in other projects of different authors have been searched for. They can represent helpful tools to evaluate case studies of processes and applications linked to sustainable chemistry. Most of the identified checklists address established technologies and do not point on R&D projects, which are considered to be necessary in order to reach many of the targets set in the investigated international programs. The following checklists have been evaluated:

- The Sustainability Check of Nanoproducts (“Nano Sustainability Check”) (Öko-Institut, Germany)
- The Precautionary Raster (Switzerland)
- NANOMETER (Switzerland)
- Risk Analysis and Technology Assessment (RATA, The Netherlands)
- The Guide on Sustainablade Chemicals (UBA, Germany)
- Checklist Sustainability Criteria for Chemical Leasing (UBA, Germany).

Evaluation of case studies on sustainable chemistry

A series of case studies on sustainable chemistry has been developed and described within the project and assessed using the assessment scheme for sustainable chemistry. This work was split in two different phases. At first, UBA and BMU followed the call of UNEA Resolution 2/7 that invited stakeholders with experience in sustainable chemistry to submit best practice examples to the United Nations Environment Programme (UNEP) secretariat. The second phase included the elaboration of case studies using the advanced assessment scheme described above as well as the provision of further details on selected case studies from phase one.

For the first phase, the project team developed and submitted a total set of eleven best practice examples from different industrial and economic sectors. Five of these were prepared in the frame of this project, both in word and brochure format. The case studies shall indicate “how these may enhance the sound management of chemicals, inter alia through the implementation of the 2030 Agenda for Sustainable Development, as well as the Strategic Approach to International Chemicals Management and chemicals- and waste-related multilateral environmental agreements” (UNEP, 2016a, paragraph 20, p. 4).

The case studies had to meet several criteria set by UNEP (coverage of different sectors, connection to Germany, contribution to sustainable chemistry and to the implementation of the 2030 Agenda) and were to be organised in a specific structure. In the end, the following five case studies were elaborated on by the project team:

- 3M Up-Cycling (Chemical Recycling) of PTFE
- Coop: Functional substitution of PFC-coated food wrapping by a PFC-free material
- KILIAN: long-term exposure reduction by functional, non-regrettable substitution/vegetable oil-based esters for removal of protection layers
- Prometho GmbH: Production of a safe and sustainable ink - GrüneTinte® (green ink)
- PERO Innovative Services & SAFECHEM: Cleaning of metal parts

The second phase points at the elaboration of a brochure on sustainable chemistry that shall include the assessment scheme as well as case studies that have been evaluated using this scheme, on which the UBA is currently still working on. The selection for the brochure done by UBA directly included ten German and ten international cases, after a preliminary evaluation. Although there were no absolute exclusion criteria, ten examples were not included after extensive discussion due to various points. The main reasons were unsatisfying information availability or minor contribution to sustainable development due to conflicts.

For the selection of the case studies, particular attention was paid to ensuring that all three dimensions of sustainability are addressed by the example. All selected examples contributed to the ecological and economic goals of sustainable chemistry, but it has proven to be challenging to find projects that enable significant social sustainability. The second priority in the selection of the case studies was to address as many of the four ecological goals of sustainable chemistry as possible. Beyond that, the contribution to compliance with the exceeded planetary boundaries was a selection criterion, whereby the parameters for global climate and biosphere-integrity can be considered the most important ones, forming the overarching stabilising system of the earth. Of major importance are also those systems, where the planetary boundary is known to be crossed, such as the genetic diversity and the biogeochemical fluxes. As fourth priority, topics outlined in the UBA study "Identification of Priority Topics in the Field of Sustainable Chemistry" should be covered evenly by the case studies (UBA, 2018b; p. 19f).

Compared to the case studies that have been developed to answer the call of UNEA Resolution 2/7, this phase aimed at the application of the assessment scheme and on putting the examples into a broader context, pointing at the single aspects of green chemistry, sound management of chemicals and waste as well as sustainable chemistry. The following three case studies have been elaborated:

- Aurubis: Recycling of WEEE[3]
- BASF: Use of pheromones in agriculture
- Tärnsjö Garveri: Vegetable leather tanning

The brochure shall specify the sustainable chemistry concept and stimulate discussion with actors at various levels. Among others, companies should feel encouraged to submit their examples and contributions to sustainable chemistry and have them evaluated/self-evaluate them using the assessment scheme. Therefore, the current selection does not claim to be complete or cover all sectors of the chemical(-related) industry, but rather comprises a selection made with a certain arbitrariness, which is intended to inspire actors in all areas to develop further examples.

Verification of the scheme and the case study assessments with stakeholders

The last step of this project was the implementation of one internal expert discussion with representatives from selected authorities and organisations as well as one expert discussion aiming at a wider audience from different stakeholder groups on the assessment of case studies on sustainable chemistry and the underlying assessment scheme. In this context, the project team also worked on the elaboration and assessment of three case studies on sustainable chemistry that were discussed on the second expert talk in September. In addition, the expert team revised information about previously developed case studies on sustainable chemistry.

The aim of the first event was to examine previous work in the field of sustainable chemistry, to consolidate the concept of sustainable chemistry and to identify potential areas for improvement with regard to the results to date. Among the participants were German and Austrian authorities and experts directly engaged in the development and discussion about sustainable chemistry on the German level.

The event successfully engaged different experts and included a fruitful discussion on the assessment scheme and the selection of the case studies. Feedback gained from the discussion was included in the next considerations (e.g. trying to reflect a larger number of smaller companies and start-ups in the case studies). Specifications to the description and assessment scheme have been made as a follow-up to the discussions.

The second expert discussion on sustainable chemistry also aimed at discussing the assessment scheme for sustainable chemistry based on selected case studies – this time with a wider audience and participants from different stakeholder groups (representatives of the Federal Environment Agency, (chemical) companies, NGOs, consultancies and academia). The event aimed at discussing the concept

[3] WEEE = waste electric and electronic equipment

of sustainable chemistry and in particular the assessment scheme for case studies on sustainable chemistry.

The participants found the assessment scheme and the concept for sustainable chemistry very helpful and advanced. Aspects such as a very clear communication of the aim of the assessment and the boundary conditions considered for the assessment of a case study still need to be improved. UBA will continue its work on the assessment scheme based on the valuable inputs from the expert talk.

Conclusion and next steps

In order to maintain the biological, chemical and physical stability of the earth, the economic and social activities of the world's population must be adapted and fundamentally transformed. As a starting point, global society becomes aware of its responsibility for future generations and pays attention to the model of sustainable development in all its respects.

Chemistry, and the chemical industry in particular, can make a substantial contribution to this fundamental transformation process, changing the current economic practices and social habits. The implementation of the concept of sustainable chemistry can be seen as an intersection of traditional chemistry and sustainable development. By integrating the three sustainability dimensions of economic productivity, social balance and ecological efficiency, the concept can be defined in more detail. To this end, it is necessary to clarify what sustainable development is and what objectives and principles constitute sustainable development.

The result of the extensive discussions on sustainable chemistry represents a cross section of those topics that have a chemical, ecological, economic and social aspect. Only those topics that address all of these dimensions can be considered a part of sustainable chemistry. In this context it shall be mentioned that it was difficult to identify projects with a clear reference to social aspects. This is particularly important because many stakeholders recognise sustainable chemistry as a contribution to sustainable development. However, sustainable development has a pronounced social dimension - the majority of the 2030 Agenda targets clearly describe social goals. Therefore, in case the chemical industry or other actors in the field of chemistry want to contribute convincingly to sustainable global development, projects should be supported that also show a clear social dimension. In general, participation of developing countries in sustainable chemistry projects would be desirable, since such activities typically provide clearly positive impetus in all dimensions of sustainable chemistry (UBA, 2018b).

As a major outcome following this project, UBA will develop a brochure containing case studies of sustainable chemistry processes, applications and products. They will be assessed regarding their contribution to sustainable chemistry following the developed assessment scheme. This brochure shall motivate further companies and stakeholders to apply the assessment scheme to their chemical processes and application in order to examine the sustainability and to identify weaknesses as well as potentials for improvement. Also, the work shall support the dissemination of successful examples of sustainable chemistry and encourage enterprises to engage with this topic.

Zusammenfassung

Der verantwortungsvolle Umgang mit Chemikalien und Abfällen ist ein wesentlicher Baustein einer nachhaltigen Chemie und ein wesentliches Querschnittselement für die Verwirklichung der Agenda 2030 für nachhaltige Entwicklung. In den Resolutionen 1/5 und 2/7 des Umweltprogrammes der Vereinten Nationen (UNEA) wurde eine langfristige Stärkung der ordnungsgemäßen Entsorgung von Chemikalien und Abfällen beschlossen. Beide beziehen sich ausdrücklich auf das Ziel 2020 für Chemikalien, das erstmals im Johannesburger Umsetzungsplan - dem Abschlussdokument des Weltgipfels für nachhaltige Entwicklung (WSSD) in Johannesburg, Südafrika, 2002 - formuliert wurde, "mit dem Ziel, bis 2020 zu erreichen, dass Chemikalien so verwendet und hergestellt werden, dass wesentliche nachteilige Auswirkungen auf die menschliche Gesundheit und die Umwelt minimiert werden" (UN, 2002; paragraph 23, p. 13). Dieses Ziel wurde später z.B. durch die UN-Konferenz 2012 zu nachhaltiger Entwicklung in "The future we want" bekräftigt.

Allerdings ist auf internationaler Ebene noch nicht klar geworden, wie genau dieser Bereich mit nachhaltiger Chemie verknüpft ist und welche Bedeutung Themen haben, die zur nachhaltigen Chemie gehören, nicht aber zum sog. „sound management of chemicals and waste"(SMCW). Darüber hinaus ist zum jetzigen Zeitpunkt unklar, was eine nachhaltige Chemie genau ausmacht und wie Anwendungen, Prozesse, Produkte oder Chemikalien hinsichtlich ihres Beitrags zur nachhaltigen Chemie bewertet werden können.

Daher lag der Schwerpunkt dieses Projekts auf der Verbindung von nachhaltiger Chemie SMCW und der Weiterentwicklung einer Bewertung für nachhaltige Chemie. Daraus lassen sich wichtige Empfehlungen und Schlussfolgerungen ableiten, die dank der deutschen Präsidentschaft des ICCM-Büros bis 2020 und der Eröffnung des International Sustainable Chemistry Collaborative Centre (ISC3) ein internationales Publikum erreichen werden. Fallstudien für nachhaltige Chemie wurden identifiziert und hinsichtlich ihres nachhaltigen Chemiepotenzials und ihres Beitrags bewertet.

Vor diesem Hintergrund unterstützte das Projekt mehrere Aktivitäten des Umweltbundesamtes zur nachhaltigen Chemie, die im Folgenden zusammengefasst werden.

Initiativen für ein internationales Chemikalien- und Abfallmanagement und ein nachhaltiges Chemikalieninventar

Im ersten Schritt der Projektarbeit wurden Aspekte aus den Bereichen nachhaltige Chemie sowie nationales und internationales Chemikalienmanagement identifiziert und beschrieben, was verschiedene Initiativen, Instrumente und Finanzierungsmechanismen beinhaltete. Die beteiligten Stakeholder und Sektionen wurden nacheinander aufgelistet.

Hierfür wurde eine schrittweise Suche durchgeführt, einschließlich:

a) einer detaillierten Analyse des Green Economy Reports[4];
b) einer gezielten Suche nach dem Projektteam bereits bekannten Elementen (Broschüren und Publikationen);
c) einer systematischen und spezifischen Internetrecherche unter Verwendung ausgesuchter Suchbegriffe.

Aus dieser Recherche entstand eine vorläufige Liste von 99 Elementen, die in enger Zusammenarbeit mit den Mitgliedern des Projektteams, dem UBA und Experten nationaler und internationaler Institutionen überprüft und angepasst wurden. Im Rahmen dieser Überprüfung wurde die Liste auf 148

[4] final report to the 2014 UBA project "evaluation of the possibilities of a stronger involvement of the chemicals sector in a green economy" (FKZ 3712 93 422)

Elemente erweitert, die sich aus Regierungsaktivitäten, freiwilligen Initiativen, Finanzinstrumenten, Werkzeugen, Projekten, Veranstaltungen und Partnerschaften zusammensetzen. Ein Update mit neuen Erkenntnissen führte zu einem endgültigen Inventar von 31 Elementen. Die vollständige Liste der 148 Elemente und die detaillierte Beschreibung der 31 Elemente ist als separates Excel-Dokument verfügbar, das dem UBA mit dem ersten Zwischenbericht zur Verfügung gestellt wurde.

Kriterien und Indikatoren zur Unterscheidung zwischen nachhaltiger Chemie und SMCW

Ein besonderer Schwerpunkt dieses Projekts lag auf der Definition von Kriterien zur Unterscheidung von nachhaltiger Chemie und SMCW. Solche Kriterien können für eine detailliertere Beschreibung der nachhaltigen Chemie herangezogen werden, wie sie von mehreren Ländern und NGOs im Rahmen der SAICM Zwischentagung in Brasilien im Februar 2017 gefordert wurde. Als Grundlage für die Entwicklung von Kriterien und Indikatoren für die Zuordnung der gesammelten Elemente zur nachhaltigen Chemie oder dem SMCW, wurde ein mehrstufiger Ansatz gewählt.

Zunächst ist ein klares Verständnis der Bedeutung von SMCW und nachhaltiger Chemie Voraussetzung für eine Unterscheidung zwischen den beiden Begriffen und den zugrunde liegenden Ansätzen. Selbiges gilt für die Entwicklung von Bewertungskriterien und Indikatoren für eine Unterscheidung zwischen diesen beiden Konzepten.

Der Begriff des verantwortungsvollen Umgangs mit Chemikalien (SMCW) wurde in der internationalen Diskussion über nachhaltige Entwicklung und Chemikalienmanagement 1992 festgelegt, als die UN-Konferenz für Umwelt und Entwicklung (UNCED) in Rio de Janeiro die Agenda 21 verabschiedete. Kapitel 19 über "Umweltgerechtes Management toxischer Chemikalien, einschließlich der Verhinderung des illegalen internationalen Handels mit toxischen und gefährlichen Produkten" (UN, 1992, Absatz 19) erkennt den Wert von Chemikalien für die Deckung des Bedarfs an sozialen und ethischen Aspekten und die Errungenschaften im Bereich der Chemikaliensicherheit an, betont aber auch die Gefahren, die toxische Chemikalien für die Umwelt und die menschliche Gesundheit darstellen, wenn nicht umweltgerecht mit ihnen umgegangen wird. Weitere UN-Konferenzen und internationale Vereinbarungen haben diese Konzepte weiterentwickelt, was unter anderem zum 2020 Ziel für Chemikalien führte.

Diskussionen über Definitionen und Kriterien für eine nachhaltige oder grüne Chemie wurden kürzlich in Blum et al. (2017) und in IPEN (2017) umfassend zusammengefasst. Laut Blum et al. wurden erstmals Kriterien für eine nachhaltige Chemie durch die 12 Prinzipien der grünen Chemie, die 1998 von Anastas und Warner veröffentlicht wurden (Anastas und Warner, 1998), und durch die 12 Leitprinzipien der nachhaltigen Chemie, wie sie in der EU-Ratsrichtlinie über die integrierte Vermeidung und Verminderung der Umweltverschmutzung (IPPC; 96/61/EG und 2008/1/EG) im Jahr 1996 festgelegt sind, definiert. Die 12 Prinzipien der Green Chemistry wurden 2003 durch Anastas und Zimmermann um die 12 Prinzipien des Green Engineering ergänzt (Anastas und Zimmermann, 2003). Die 12 IPPC-Leitsätze für eine nachhaltige Chemie wurden vom UBA und der OECD zu den allgemeinen Kriterien für eine nachhaltige Chemie (2004) weiterentwickelt und 2010 in die Industrie-Emissionsrichtlinie des EU-Rates (IED; 2010/75/EU) aufgenommen. Im Jahr 2014 veröffentlichte die OECD eine erste "Definition of Sustainable Chemistry", die 2016 aktualisiert wurde; im Jahr 2015 entwickelte das UBA das so genannte "Konzept der nachhaltigen Chemie".

Im zweiten Schritt wurde eine Zusammenfassung aller Kriterien, die in früheren Aufgaben dieser Studie identifiziert wurden, erarbeitet, anhand derer ihre Relevanz für eine nachhaltige Chemie und einen verantwortungsvollen Umgang mit Chemikalien und Abfällen (SMCW) bewertet wurde. Für die 25 Parameter der nachhaltigen Chemie, die genauer analysiert wurden, hat sich gezeigt, dass es manchmal schwierig sein kann, SMCW und NC mit Hilfe der Kriterien zu unterscheiden. Außerdem müssen die Indikatoren individuell betrachtet werden. Ein Abgleich mit den spezifischen Zielen des SAICM OPS lieferte weitere Anhaltspunkte, führte aber zu diesem Zeitpunkt noch nicht zu einer Entwicklung von

Indikatoren für SMCW. Die Indikatoren, die für die beiden Systeme gelten, wurden als "Grenzindikatoren" eingestuft.

Letztlich ist man zum Schluss gekommen, dass es auf Grundlage der Bewertung der Ziele, des Umfangs, der Definitionen und Kriterien, wie sie im Laufe der Zeit in verschiedenen Ansätzen für einen verantwortungsvollen Umgang mit Chemikalien und einer nachhaltigen Chemie entwickelt wurden, erhebliche Überschneidungen, aber auch deutliche Unterschiede zwischen den beiden Ansätzen gibt. Diese können genutzt werden, um zwischen den beiden Ansätzen weiter zu unterscheiden und dahingehende Kriterien und Indikatoren zu entwickeln.

Kriterien und Indikatoren zur Bewertung des Beitrags zum 2020 Ziel und zur Agenda 2030 für nachhaltige Entwicklung

In den letzten Jahrzehnten wurde eine beträchtliche Anzahl von Aktivitäten zur Verbesserung und Förderung einen verantwortungsvollen Umgang mit Chemikalien und Abfällen sowie der nachhaltigen Chemie gestartet, jedoch wurde keine systematische Bewertung des Beitrags zur Erreichung der 2020 Ziele und zu den Zielen der Agenda 2030 für nachhaltige Entwicklung durchgeführt.

In diesem Zusammenhang dient die von der ICCM4 verabschiedete „Overall Orientation and Guidance" (OOG) als allgemeine Orientierungshilfe für SAICM-Stakeholder, um das 2020 Ziel zu erreichen, indem Prioritäten für die erforderlichen Arbeiten gesetzt werden. Es enthält 11 Grundelemente und 6 Kernaktivitäten, die Maßnahmen auf nationaler und regionaler Ebene definieren und die SAICM-Stakeholder bei der Erreichung des 2020 Ziels unterstützen. Die 11 Grundelemente haben bereits den Charakter von Kriterien zur Messung von Fortschritten und zur Festlegung von Prioritäten. Die 6 Kernaktivitäten und die dazugehörigen Aktionspunkte hingegen bilden die Grundlage für Indikatoren. Beide Konzepte wurden für die weitere Entwicklung des Bewertungsschemas für nachhaltige Chemie berücksichtigt.

Die Agenda 2030 für nachhaltige Entwicklung enthält eine Reihe von Zielen und Vorgaben, die entweder ausdrücklich auf gefährliche Chemikalien hinweisen oder sich auf Chemikalien und nachhaltige Chemie beziehen. Diejenigen, die eine direkte Relevanz für SMCW haben, sind:

- Ziel Nr. 3.9: "Bis 2030 die Zahl der Todesfälle und Erkrankungen aufgrund gefährlicher Chemikalien und der Verschmutzung und Verunreinigung von Luft, Wasser und Boden erheblich verringern ".
- Ziel Nr. 9.4: "Bis 2030 die Infrastruktur modernisieren und die Industrien nachrüsten, um sie nachhaltig zu machen, mit effizienterem Ressourceneinsatz und unter vermehrter Nutzung sauberer und umweltverträglicher Technologien und Industrieprozesse, wobei alle Länder Maßnahmen entsprechend ihren jeweiligen Kapazitäten ergreifen".
- Ziel Nr. 12.4: "Bis 2020 einen umweltverträglichen Umgang mit Chemikalien und allen Abfällen während ihres gesamten Lebenszyklus in Übereinstimmung mit den vereinbarten internationalen Rahmenregelungen erreichen und ihre Freisetzung in Luft, Wasser und Boden erheblich verringern, um ihre nachteiligen Auswirkungen auf die menschliche Gesundheit und die Umwelt auf ein Mindestmaß zu beschränken".
- Ziel Nr. 12.5: "Bis 2030 das Abfallaufkommen durch Vermeidung, Verminderung, Wiederverwertung und Wiederverwendung deutlich verringern ".

Die nachhaltige Chemie befasst sich aufgrund ihres breiten Beitrags zur nachhaltigen Entwicklung auch mit einer Reihe weiterer Ziele, die in einer vollständigen Liste der 169 Targets Teil des holistischen Bewertungsschemas sind. Davon artikulieren 25 Ziele direkt die ökologischen Ziele der nachhaltigen Chemie, 29 die wirtschaftlichen Ziele der nachhaltigen Chemie und 88 die sozialen Ziele. Insgesamt drücken 142 von 169 Zielen der Agenda 2030 die Kernziele der nachhaltigen Chemie direkt aus. Nur 27 dieser 169 Targets haben einen schwachen oder gar keinen direkten Bezug zur nachhaltigen Chemie.

Generell ist das Hauptziel der nachhaltigen Chemie die Förderung einer nachhaltigen Entwicklung, bestehend aus integrierten und unteilbaren ökologischen, sozialen und wirtschaftlichen Zielen und einem wesentlichen Beitrag zur SDG.

Diese und weitere Ergebnisse wurden von Ralf Geiss (UBA) zur Erstellung eines Bewertungsschemas für nachhaltige Chemie verwendet. Das Dokument enthält eine ganzheitliche Beschreibung der nachhaltigen Chemie und führt zu einem Bewertungsschema für die nachhaltige Chemie.

Ausgehend vom erarbeiteten Hintergrund der nachhaltigen Chemie (Megatrends, Notwendigkeit der Nachhaltigkeit) liegt bei der Beschreibung des Konzeptes weiterhin die wirtschaftliche Bedeutung der Chemie. Außerdem wird deren Verbindung deren Dreidimensionalität unterstrichen. Das Konzept umfasst auch die aktuelle Sichtweise hinsichtlich der Unterscheidung zwischen nachhaltiger Chemie, SMCW und grüner Chemie und bietet einen umfassenden und grafischen Überblick über die Überschneidungen und Unterschiede zwischen den Konzepten.

Das Bewertungsschema berücksichtigt die planetaren Grenzen und die Ziele der der Agenda 2030, um eine Bewertung von Fallstudien unter Berücksichtigung aller drei Dimensionen der Nachhaltigkeit zu ermöglichen. Es beschreibt eine nachhaltige Chemie im Hinblick auf nachhaltige Entwicklung, grüne Chemie und verantwortungsvollem Umgang mit Chemikalien und Abfällen.

Vorbereitung für die Bewertung von Fallbeispielen

Um Fallstudien zur nachhaltigen Chemie zu identifizieren und anhand des entwickelten Bewertungsschemas auf ihren Beitrag zur nachhaltigen Chemie zu bewerten, wurden im Laufe des Projekts mehrere vorbereitende Schritte durchgeführt. Diese Schritte waren notwendig, um Hintergrundinformationen bereitzustellen, eine Reihe von Fallstudien auszuwählen und so das Bewertungsschema zu verbessern.

Um Best-Practice-Beispiele für eine nachhaltige Chemie zu erarbeiten, wurde zunächst eine Recherche zur Identifizierung von relevanten Themen durchgeführt. Grundlage der Suche war eine Studie des ISC3 mit dem Fokus auf " recent innovations as well as priority research and development themes, which are needed in particular for a broad industrial implementation of the concept of Sustainable Chemistry" (UBA 2017b, S. 18). Aus den 10 in der Studie beschriebenen Anwendungsbereichen und Sektoren mussten einige ausgewählt werden, da nicht alle Bereiche abgedeckt werden konnten.

Um spezifische Bereiche der Forschung und Entwicklung innerhalb der Sektoren weiter einzugrenzen, wurden mehrere Schlüsselpublikationen herangezogen und ausgewertet. Dadurch konnten die bereits gewonnen Informationen ergänzt- und Hauptbedarfsfelder hinsichtlich der globalen nachhaltigen Entwicklung ermittelt werden. Basierend auf den Ergebnissen dieser Detailrecherche konnten vier Bereiche von besonderem Interesse identifiziert werden:

- Carbon Capture and Utilisation (CCU) einschließlich PTX und Materialeinsatz
- Nutzung von Biomasse als Rohstoff
- Polymer (Recycling)
- Phosphorrückgewinnung

Als zusätzlicher Schritt für die Weiterentwicklung des Bewertungsschemas wurden internationale Umweltziele gescreent und verglichen. Diese wurden im Hinblick auf die großen globalen Herausforderungen wie den Klimawandel und eine wachsende Weltbevölkerung ausgearbeitet und können so häufig als Treiber für Forschung und Innovation fungieren.

Neben dem Pariser Abkommen, den SDGs der Agenda 2030 und SAICM sind im Folgenden weitere Programme und Strategien aufgeführt, die für verschiedene Sektoren relevant sind:

- Goals towards a pollution free planet (UNEA)
- 7th Environment Action Programme (7th EAP)

- EU Circular Economy Package
- Revised European Charter for the Protection and Sustainable Management of Soils
- One planet summit (12 commitments)
- Konzept der planetaren Grenzen und dazugehöriges Strategiepapier des WBGU (9 Dimensionen)
- WWF (Power Sector Vision 2050)
- 10 Prinzipien des UN Global Compact
- Nachhaltige Prozessindustrie durch Ressourcen- und Energieeffizienz (SPIRE)
- Aichi Biodiversitätsziele (Conventional on Biological Diversity, CBD).

In diesem Zusammenhang wurden außerdem Checklisten zu Parametern der Nachhaltigkeit gesucht, die bereits in anderen Projekten und von verschiedenen Autoren entwickelt wurden. Sie können hilfreiche Werkzeuge zur Bewertung von Fallstudien zu Prozessen und Anwendungen im Zusammenhang mit nachhaltiger Chemie darstellen. Die meisten der identifizierten Checklisten beziehen sich auf etablierte Technologien und verweisen nicht auf FuE-Projekte, die jedoch als notwendig erachtet werden, um viele der Ziele untersuchter internationaler Programme zu erreichen. Die folgenden Checklisten wurden ausgewertet:

- The Sustainability Check of Nanoproducts ("Nano Sustainability Check") (Öko-Institut, Germany)
- The Precautionary Raster (Switzerland)
- NANOMETER (Switzerland)
- Risk Analysis and Technology Assessment (RATA, The Netherlands)
- The Guide on Sustainablade Chemicals (UBA, Germany)
- Checklist Sustainability Criteria for Chemical Leasing (UBA, Germany).

Auswertung von Fallstudien zur nachhaltigen Chemie

Im Rahmen des Projekts wurde eine Reihe von Fallstudien zur nachhaltigen Chemie entwickelt, beschrieben und mit Hilfe des Bewertungsschemas für nachhaltige Chemie bewertet. Diese Arbeit wurde in zwei verschiedene Phasen aufgeteilt. Zunächst folgten UBA und BMU dem Aufruf der UNEA-Resolution 2/7, in der Stakeholder mit Erfahrung in nachhaltiger Chemie aufgefordert wurden, dem Sekretariat des Umweltprogramms der Vereinten Nationen (UNEP) Best Practice-Beispiele vorzulegen. Die zweite Phase umfasste die Ausarbeitung von Fallstudien unter Verwendung des fortgeschrittenen Bewertungsschemas sowie die Bereitstellung weiterer Details zu ausgewählten Fallstudien aus der ersten Phase.

Als Beitrag zur ersten Phase entwickelte und reichte das Projektteam insgesamt elf Best-Practice-Beispiele aus verschiedenen Industrie- und Wirtschaftsbereichen ein. Fünf davon wurden im Rahmen dieses Projekts vorbereitet, sowohl im Text- als auch im Broschürenformat. In den Fallstudien wird dargelegt, "wie diese den verantwortungsvollen Umgang mit Chemikalien verbessern können, unter anderem durch die Umsetzung der Agenda 2030 für nachhaltige Entwicklung sowie des strategischen Konzepts für das internationale Chemikalienmanagement und multilaterale Umweltübereinkommen im Zusammenhang mit Chemikalien und Abfällen" (UNEP, 2016a, Absatz 20, S. 4).

Die Fallstudien, die mehrere vom UNEP festgelegte Kriterien erfüllen mussten (Abdeckung verschiedener Sektoren, Verbindung zu Deutschland, Beitrag zur nachhaltigen Chemie und zur Umsetzung der Agenda 2030) und in einer spezifischen Struktur organisiert sein sollten. Am Ende wurden die folgenden fünf Fallstudien vom Projektteam erarbeitet:

- 3M Up-Cycling (Chemical Recycling) von PTFE
- Coop: Funktionelle Substitution von PFC-beschichteten Lebensmittelverpackung durch PFC-freies Material

- KILIAN: langfristige Reduzierung der Exposition durch funktionelle, nicht regressierbare Substitution/pflanzliche Ester auf Ölbasis zur Entfernung von Schutzschichten
- Prometho GmbH: Herstellung einer sicheren und nachhaltigen Tinte - GrüneTinte®
- PERO Innovative Services & SAFECHEM: Reinigung von Metallteilen

Die zweite Phase beinhaltete die Erarbeitung einer Broschüre zur nachhaltigen Chemie, die das Bewertungsschema sowie anhand dieses Schemas evaluierte Fallstudien enthalten soll, an denen das UBA derzeit noch arbeitet. Die Auswahl für die vom UBA erstellte Broschüre umfasste nach einer Vorprüfung zehn deutsche und zehn internationale Fallbeispiele. Obwohl es keine absoluten Ausschlusskriterien gab, wurden zehn Beispiele nach eingehender Diskussion aufgrund verschiedener Punkte nicht berücksichtigt. Dies lag vor allem an der unbefriedigenden Datenlage oder dem geringen Beitrag zur nachhaltigen Entwicklung aufgrund unterschiedlicher Konflikte.

Bei der Auswahl der Fallstudien wurde insbesondere darauf geachtet, dass alle drei Dimensionen der Nachhaltigkeit durch das Beispiel berücksichtigt werden. Alle ausgewählten Beispiele haben zu den ökologischen und ökonomischen Zielen der nachhaltigen Chemie beigetragen, aber es hat sich als schwierig erwiesen, Projekte zu finden, die einen signifikanten Beitrag zur sozialen Nachhaltigkeitsdimension leisten. Die zweite Priorität bei der Auswahl der Fallstudien war es, so viele der vier definierten ökologischen Ziele der nachhaltigen Chemie wie möglich zu erreichen. Darüber hinaus war der Beitrag zur Einhaltung der planetaren Grenzen ein Auswahlkriterium, wobei die Parameter globales Klima und Biosphärenintegrität als die wichtigsten angesehen wurden, da sie das übergeordnete Stabilisierungssystem der Erde begründen. Von großer Bedeutung sind auch solche Systeme, bei denen die planetaren Grenzen bereits überschritten werden (u.a. genetische Vielfalt und die biogeochemischen Flüsse). Als vierten Schwerpunkt sollen die in der UBA-Studie "Identifikation von Schwerpunktthemen im Bereich der nachhaltigen Chemie" skizzierten Themen durch die Fallstudien gleichmäßig abgedeckt werden (UBA, 2018b; S. 19f).

Im Vergleich zu den Fallstudien, die als Antwort auf die Aufforderung der UNEA-Resolution 2/7 entwickelt wurden, zielte diese Phase auf die Anwendung des Bewertungsschemas und auf die Betrachtung der Beispiele in einem breiteren Kontext ab. Zudem wurden die einzelnen Aspekte der grünen Chemie, von SMCW sowie der nachhaltigen Chemie betrachtet und die jeweiligen Beiträge unterschieden. Die folgenden drei Fallstudien wurden erarbeitet:

- Aurubis: Recycling von Elektro- und Elektronik-Altgeräten
- BASF: Einsatz von Pheromonen in der Landwirtschaft
- Tärnsjö Garveri: Pflanzliche Ledergerbung

Die Broschüre soll das Konzept der nachhaltigen Chemie konkretisieren und die Diskussion mit Akteuren auf verschiedenen Ebenen anregen. Unter anderem sollten sich die Unternehmen ermutigt fühlen, ihre Beispiele und Beiträge zur nachhaltigen Chemie einzureichen und sie anhand des Bewertungsschemas beurteilen zu lassen oder selbst zu bewerten. Die aktuelle Auswahl erhebt daher nicht den Anspruch auf Vollständigkeit oder Abdeckung aller Bereiche der chemischen Industrie, sondern umfasst eine mit einer gewissen Beliebigkeit getroffene Auswahl, die die Akteure in allen Bereichen dazu inspirieren soll, weitere Beispiele zu entwickeln.

Überprüfung des Systems und der Fallstudienbewertungen mit den Beteiligten

Der letzte Schritt dieses Projekts war die Durchführung einer internen Expertendiskussion mit Vertretern ausgewählter Behörden und Organisationen sowie einer Expertendiskussion, die sich an ein breiteres Publikum aus verschiedenen Interessengruppen richtete und der Bewertung von Fallstudien zur nachhaltigen Chemie.

In diesem Zusammenhang arbeitete das Projektteam auch an der Ausgestaltung und Bewertung von drei Fallstudien zur nachhaltigen Chemie, die im zweiten Expertengespräch im September diskutiert wurden. Darüber hinaus überarbeitete das Projektteam die zuvor entwickelten Fallstudien zur nachhaltigen Chemie.

Ziel der ersten Veranstaltung war es, frühere Arbeiten auf dem Gebiet der nachhaltigen Chemie zu untersuchen, das Konzept der nachhaltigen Chemie zu verfestigen und Verbesserungspotenziale im Hinblick auf die bisherigen Ergebnisse zu identifizieren. Unter den Teilnehmern waren deutsche und österreichische Behördenvertreter und Experten, die sich direkt an der Entwicklung und Diskussion über nachhaltige Chemie auf deutscher Ebene beteiligten. An der Veranstaltung beteiligten sich mehrere namhafte Experten, was zu einer fruchtbaren Diskussion über das Bewertungsschema und bezüglich der Auswahl der Fallstudien führte. Das Feedback aus der Diskussion wurde in die nächsten Überlegungen einbezogen (z.B. der Versuch, eine größere Anzahl kleinerer Unternehmen und Start-ups in den Fallstudien zu berücksichtigen). Im Anschluss an die Diskussionen wurden schließlich noch Spezifikationen für das Bewertungsschema festgelegt.

Die zweite Expertendiskussion zur nachhaltigen Chemie zielte ebenfalls darauf ab, das Bewertungsschema zur nachhaltigen Chemie anhand ausgewählter Fallstudien zu diskutieren - diesmal mit einem breiteren Publikum und Teilnehmern aus verschiedenen Interessengruppen (Vertreter des UBA, Vertretern aus der (chemischen) Industrie, NGOs, Beratungsunternehmen und Wissenschaft). Ziel der Veranstaltung war es, das Konzept der nachhaltigen Chemie und insbesondere das Bewertungsschema für Fallstudien zur nachhaltigen Chemie zu diskutieren.

Das Bewertungsschema und das Konzept für eine nachhaltige Chemie fanden die Teilnehmer sehr hilfreich und bereits in einem fortgeschrittenen Zustand. Aspekte wie eine sehr klare Kommunikation des Ziels der Bewertung und der für die Bewertung einer Fallstudie berücksichtigten Randbedingungen müssen jedoch noch verbessert werden. Das UBA wird seine Arbeit an dem Bewertungsschema auf Grundlage der wertvollen Beiträge aus dem Expertengespräch fortsetzen.

Schlussfolgerungen und nächste Schritte

Um die biologische, chemische und physikalische Stabilität der Erde zu erhalten, müssen die wirtschaftlichen und sozialen Aktivitäten der Weltbevölkerung angepasst und grundlegend verändert werden. Als Ausgangspunkt muss sich die globale Gesellschaft ihrer Verantwortung für zukünftige Generationen bewusstwerden und das Modell der nachhaltigen Entwicklung berücksichtigen.

Die Chemie, und insbesondere die chemische Industrie, kann einen wesentlichen Beitrag zu diesem tiefgreifenden Transformationsprozess leisten indem sie die gegenwärtigen wirtschaftlichen Praktiken und sozialen Gewohnheiten anpasst. Die Umsetzung des Konzepts der nachhaltigen Chemie kann als Schnittstelle zwischen traditioneller Chemie und nachhaltiger Entwicklung gesehen werden. Durch die Integration der drei Nachhaltigkeitsdimensionen ökonomische Produktivität, soziales Gleichgewicht und ökologische Effizienz kann das Konzept näher definiert werden. Zu diesem Zweck ist es notwendig, zu klären, was nachhaltige Entwicklung ist und welche Ziele und Prinzipien eine nachhaltige Entwicklung vorantreiben.

Das Ergebnis der umfangreichen Diskussionen über nachhaltige Chemie ist in Querschnitt der Themen, die einen chemischen, ökologischen, wirtschaftlichen und sozialen Aspekt haben. Nur die Themen, die sich mit allen drei Dimensionen befassen, können als Teil der nachhaltigen Chemie betrachtet werden. Hierbei muss erwähnt werden, dass es schwierig war, Projekte mit einem klaren Bezug zu sozialen Aspekten zu identifizieren. Dies ist besonders wichtig, da viele Interessengruppen nachhaltige Chemie als Beitrag zur nachhaltigen Entwicklung anerkennen. Nachhaltige Entwicklung hat jedoch eine ausgeprägte soziale Dimension - die meisten der Ziele der Agenda 2030 beschreiben eindeutig sozialen Ziele. Wenn die chemische Industrie oder andere Akteure der Chemie überzeugend zu einer nachhaltigen globalen Entwicklung beitragen wollen, müssen daher jene Projekte unterstützt werden, die auch eine klare soziale Dimension aufweisen. Generell wäre eine Beteiligung der

Entwicklungsländer an nachhaltigen Chemieprojekten wünschenswert, da solche Aktivitäten typischerweise deutlich positive Impulse in allen Dimensionen einer nachhaltigen Chemie geben (UBA, 2018b).

Als wesentliches Ergebnis dieses Projekts wird das UBA eine Broschüre mit Fallstudien zu nachhaltigen chemischen Prozessen, Anwendungen und Produkten entwickeln. Sie werden nach dem entwickelten Bewertungsschema auf ihre Konformität mit nachhaltiger Chemie hin bewertet. Diese Broschüre soll weitere Unternehmen und Stakeholder motivieren, das Bewertungsschema auf ihre chemischen Prozesse und Anwendungen anzuwenden, um die Nachhaltigkeit zu untersuchen und Schwachstellen sowie Verbesserungspotenziale zu identifizieren. Darüber hinaus soll die Arbeit die Verbreitung erfolgreicher Beispiele für nachhaltige Chemie unterstützen und Unternehmen ermutigen, sich mit diesem Thema zu befassen.

1 Supporting the international management of chemicals: Background and project description

The sound management of chemicals and waste is an essential building block of sustainable chemistry and is an essential cross-cutting element for the achievement of the 2030 Agenda for Sustainable Development. Strengthening the sound management of chemicals and waste in the long term has been adopted in the United Nations Environment Assembly (UNEA) Resolutions 1/5 and 2/7. Both explicitly refer to the 2020 goal for chemicals, stated for the first time in the Johannesburg Plan of Implementation – the outcome document of the World Summit on Sustainable Development (WSSD) in Johannesburg, South Africa, 2002 – "aiming to achieve, by 2020, that chemicals are used and produced in ways that lead to the minimization of significant adverse effects on human health and the environment" (UN, 2002; paragraph 23, p. 13). This goal was later reaffirmed by e.g. the 2012 UN Conference on Sustainable Development in "The future we want".

However, at the international level, it has not yet become apparent how exactly this field connects with sustainable chemistry, and what the significance of topics is that belong to sustainable chemistry but not to the sound management of chemicals and waste. Moreover, it is unclear at this stage what sustainable chemistry exactly comprises and how applications, processes, products or chemicals can be evaluated regarding their contribution to sustainable chemistry.

Therefore, the focus of this project was the conjunction of sustainable chemistry and sound management of chemicals and the advancement of the assessment of sustainable chemistry. From this, key recommendations and conclusions can be derived that will reach an international audience, thanks to the German presidency of the ICCM Bureau until 2020 and the opening of the International Sustainable Chemistry Collaborative Centre (ISC_3). Case studies for sustainable chemistry have been identified and evaluated regarding their sustainable chemistry potential and contribution.

Specifically, the project supported several activities of the German Environment Agency regarding sustainable chemistry. This report documents the following key activities and results of the project:

- an inventory of activities and instruments in the areas of sustainable chemistry and national and international chemicals management (see chapter 2);
- indicators to distinguish between sustainable chemistry and sound management of chemicals and waste (see chapter 3);
- criteria and indicators to assess the contribution to the 2020 goal and the 2030 Agenda (see chapter 4);
- preparatory work for the assessment of the case studies (see chapter 5), in particular:
  - description of sectors with high importance to develop examples of sustainable chemistry;
  - international environmental goals which can be used as reference points to assess the impact of case studies of sustainable chemistry;
  - documentation of checklists which could be helpful to develop assessment criteria for case studies of sustainable chemistry;
- development of case studies on sustainable chemistry and assessing them using a holistic assessment scheme for sustainable chemistry (see chapter 6);
- expert discussions about the assessment scheme and the case studies involving different stakeholder groups (see chapter 7);
- conclusions and next steps (see chapter 8).

Furthermore, a draft of a mission paper for the ISC_3 has been written in this project. The main messages from this draft have been published in 2017 (Blum et al., 2017).

2 The landscape: Initiatives for international management of chemicals and waste and sustainable chemistry inventory

2.1 Aim of the inventory

In order to describe the link between sustainable chemistry and the sound management of chemicals, it is essential to find and document overlaps, interactions and interdependencies between these terms and their respective content. To that end, the first step in the project work was to identify and describe individual elements from the areas of sustainable chemistry and national and international chemicals management.

Elements were defined as initiatives (partnerships, projects, and activities), instruments (binding and non-binding conventions) and funding mechanisms. Stakeholders and sectors involved were listed. The elements were recorded on a national as well as on a regional and international level. At the national level, we distinguished between industrial and developing countries. Further details on the search method are described in the next chapter.

2.2 Search method

The project team designed a stepwise search strategy in order to identify the relevant elements of sustainable chemistry and sound management of chemicals and waste. The following paragraphs describe the search strategy. The obtained results are subject to the following chapter.

Step 1: Green Economy report

In the first step, the final report to the 2014 UBA project "evaluation of the possibilities of a stronger involvement of the chemicals sector in a green economy" (FKZ 3712 93 422) has been taken as a basis. A screening of the report and the project material resulted in a list of 28 elements related to sustainable chemistry or sound management of chemicals and waste. The majority of those elements (18 elements) are governmental activities such as international conventions or legislative frameworks. Furthermore, ten voluntary initiatives and financial instruments have been identified.

Step 2: Targeted search for elements

The second step included the targeted search for elements already known to the project team. This included mainly internet research as well as a literature search on documents related to sustainable chemistry or sound management of chemicals and waste; e.g. brochures and publications about conventions, initiatives or action plans and reports and deliverables of previous projects, in which team members were involved or that have been provided by the German Environment Agency.

The following websites were used in order to search for the elements or directly reflect the website of the element (non-exhaustive list):

- http://www.chemicalfootprint.org/
- https://chemicalwatch.com/
- http://www.greenscreenchemicals.org/
- http://www.oecdsaatoolbox.org/Home/Tools
- http://www.sustainableproduction.org/downloads/Methods-ToolsforChemHazardAss5-2011.pdf
- http://www.greenchemistryandcommerce.org/
- http://www.who.int/ipcs/methods/harmonization/areas/ra_toolkit/en/
- http://www.oecd.org/env_sustainablechemistry_platform/

- http://www.undp.org/content/undp/en/home/ourwork/environmentandenergy/focus_areas/chemicals_management/initiative-undp-unep.html
- http://chemsec.org/
- https://isc3.org/de/
- https://www.acs.org/content/acs/en/greenchemistry/about/history.html
- http://www.greenchemistryportal.org/
- http://www.fi-sch.be/en/
- http://iomctoolbox.oecd.org/default.aspx?idExec=b99e5c9e-13e2-4b3c-8fa3-8002424a4da3
- http://www.unep.org/resourceefficiency/Portals/24147/scp/sp/saferprod/pdf/Responsible_Production_Toolkit.pdf
- http://www.chemstart.org/
- http://dechema.de/en/
- http://www.suschem.org/
- http://www.oecd.org/env_sustainablechemistry_platform/
- http://www.desustainablechem.org/initiatives2.html
- http://www.nikeincchemistry.com/sustainable-and-green-chemistry
- http://en.gdch.de/

Step 3 and 4: Systematic and specific search

The search has been completed by a third and fourth step, i.e. a systematic and specific internet research. The systematic search included a range of search terms for which the first 30 results have been reviewed and, if relevant, included into the result list.

Since the systematic search has led to a very limited number of additional elements it was directly followed by a specific search (step 4): all potentially relevant or interesting websites and their referrals to keywords and additional information have been skimmed and research for this information has been conducted. Thus, in step 4 the project team followed the links or keywords retrieved from the search result in step 3 to specifically search for certain additional material.

Moreover, additional elements with a broader scope (i.e. agriculture, pesticides, pharmaceuticals and climate) and national elements from selected countries (e.g. Germany, Austria, Denmark, Sweden, Spain, UK, USA, Canada) have been identified using respective search terms. To obtain country-specific information the names of the countries or, if available, responsible organisation, have been added to the search term.

2.3 Compilation and evaluation of identified elements

The research resulted in a preliminary list of 99 elements, which have been subject to review and adjustment in close cooperation with the project team members, the German Environment Agency and experts at national and international institutions. Through this review, the list was extended to 148 elements comprising government activities, voluntary initiatives, financial instruments, tools, projects, events and partnerships.

2.4 Final set of elements

A second update to the working step (WS) provided new findings and results on the list of the elements that resulted from the work in the following WSs conducted after the finalisation of WS 1.1. The update shows the final set of 31 elements as agreed upon by the project team (German Environment Agency, Ramboll, Öko-Institut) in January 2017.

The final set comprises 31 elements and is shown in Table 1. The elements ISC_3 and SAICM[5] have been removed from the list. The former one was not fully operational at the time of the development of the list and the latter one is the basic element and the overall framework for the sound management of chemicals and waste (SMCW). Three elements have been added to the list: Together for Sustainability, the Stockholm Convention on Persistent Organic Pollutants (POPs) and the Montreal Protocol on Substances that Deplete the Ozone Layer (see no. 29-31).

The complete list of 148 elements and detailed descriptions of the 31 elements is available as a separate Excel document that has been provided to UBA with the first interim report.

Chapter 3 develops criteria to assess these elements regarding their relevance for sustainable chemistry and chemicals management.

Table 1: Final set of 31 elements as of January 2017.

No.	Element
1	ACS GCI (American Chemical Society Green Chemistry Institute)
2	Californian Safer Consumer Products program
3	Chemicals and Waste - GEF 6 Strategy
4	Chemie hoch 3
5	ChemSec (International Chemical Secretariat)
6	Dow Jones Sustainability Index (DJSI)
7	European Sustainable Chemistry Award
8	Green Chemistry & Commerce Council (GC3)
9	GreenScreen® for Safer Chemicals
10	Guide on sustainable chemicals: A decision tool for substance manufacturers, formulators and end users of chemicals (German Environment Agency (UBA))
11	International Finance Corporation - Banking on Sustainability
12	International Panel on Chemical Pollution (IPCP)
13	International POPs Elimination Network (IPEN)
14	IOMC Toolbox for Decision Making In Chemicals Management
15	German Sustainability Strategy
16	OECD Substitution and Alternatives Assessment Tool Selector
17	PAN International List of Highly Hazardous Pesticides
18	Practical Chemicals Management (CM) Toolkit
19	Product Stewardship in the Supply Chain - Joint Cefic / Fecc Product Stewardship Guidelines
20	Responsible Production: Guidance and Toolkit
21	SusChem- European Technology Platform for Sustainable Chemistry
22	Sustainable Chemistry Alliance
23	The Chemical Footprint Project
24	UNEP: Chemicals in Products (CiP) Project

[5] Strategic Approach to International Chemicals Management

25	UNEP: Costs of Inaction on the Sound Management of Chemicals
26	UNIDO Chemical Leasing
27	US EPA: Presidential Green Chemistry Challenge Award
28	Zero Discharge of Hazardous Chemicals (ZDHC)
29	Together for Sustainability[1]
30	Stockholm Convention on Persistent Organic Pollutants (POPs)[2]
31	Montreal Protocol on Substances that Deplete the Ozone Layer[3]

1 – The element has been added to the list be-cause it is an industry initiative of growing public attention and importance.
2 – The element has been added to the list be-cause it is binding and represents one of the most important international chemical conventions.
3 - The element has been added to the list be-cause it is binding and is one of the most successful international environmental agreements.

3 Criteria and indicators to distinguish sustainable chemistry and sound management of chemicals

A special focus of this project was laid on criteria to distinguish sustainable chemistry and sound management of chemicals. Criteria can be used for a more detailed description of sustainable chemistry as requested by several countries and NGOs in the course of the intersessional meeting on SAICM in Brasilia in February 2017. As a basis for developing criteria and indicators for the two concepts and to allocate the collected elements to sustainable chemistry and sound management of chemicals, including the sound management of waste (SMCW), we developed the following procedure:

- Definitions and key documents related to sustainable chemistry or SMCW have been analysed for covered parameters and existing criteria and the criteria or keywords have been extracted.
- Criteria and keywords from previous relevant projects (e.g. of the German Environment Agency) have been retrieved.
- Keywords and criteria have been compiled from the different definitions and projects and have been allocated to the two concepts.
- Overlaps were identified to result in a proposal for a first reasonable set of criteria to distinguish sustainable chemistry and SMCW.

3.1 Definitions and criteria of sustainable chemistry and sound management of chemicals

A clear understanding of the meaning of *sound management of chemicals and waste* and *sustainable chemistry* is a prerequisite for a distinction between the two notions and their underlying approaches as well as for the development of assessment criteria and indicators for a distinction between the two.

We therefore provide major definitions together with their terms and criteria for both concepts below. These provide the basis for the retrieval of criteria and indicators to distinguish sustainable chemistry and SMCW.

3.1.1 Major definitions on the sound management of chemicals and waste

The notion of *sound management of chemicals* was established in international discussion of sustainable development and chemicals management in 1992, when the UN Conference on Environment and Development (UNCED) in Rio de Janeiro adopted the Agenda 21.

Chapter 19 on *"Environmentally sound management of toxic chemicals, including prevention of illegal international traffic in toxic and dangerous products"* (UN, 1992, paragraph 19) acknowledges the value of chemicals for meeting societal needs and the achievements regarding chemical safety, whilst stressing the threats that toxic chemicals pose to the environment and human health if not managed in an environmentally sound manner.

Further UN Conferences and international agreements refined these statements, which resulted *inter alia* in the 2020 goal for chemicals.

3.1.1.1 Agenda 21

The Agenda 21 makes a close link between chemicals management and chemicals safety. In order to ensure *environmentally sound management of toxic chemicals*, chapter 19 identified the following six programme areas, where specific activities are listed:

- Expanding and accelerating international assessment of chemical risks;

- Harmonization of classification and labelling of chemicals;
- Information exchange on toxic chemicals and chemical risks;
- Establishment of risk reduction programmes;
- Strengthening of national capabilities and capacities for management of chemicals;
- Prevention of illegal international traffic in toxic and dangerous products.

For risk reduction, the Agenda set the objective to "*eliminate unacceptable or unreasonable risks and, to the extent economically feasible, to reduce risks posed by toxic chemicals, by employing a broad-based approach involving a wide range of risk reduction options and by taking precautionary measures derived from a broad-based life-cycle analysis*" (19.48).

In 2002, the World Summit on Sustainable Development (WSSD) in Johannesburg adopted the Johannesburg Plan of Implementation (JPOI), which contained the following chemicals-related targets:

- the implementation of a Globally Harmonized System of Classification and Labelling of Chemicals (GHS) at national level by 2008
- a goal on sustainable chemicals management (JPOI § 23; UN, 2002; paragraph 23; p. 13);
- the development, of a Strategic Approach to International Chemicals Management (SAICM) based on the Intergovernmental Forum on Chemical Safety (IFCS) (paragraph 23b);

3.1.1.2 2020 goal on chemicals

The so-called "2020 goal" as presented below does not address chemicals management as such; but is limited to the minimization of significant adverse effects and focussed on capacity building for sound management of hazardous waste:

"[…] aiming to achieve, by 2020, that chemicals are used and produced in ways that lead to the minimization of significant adverse effects on human health and the environment, using transparent science-based risk assessment procedures and science-based risk management procedures, taking into account the precautionary approach, as set out in principle 15 of the Rio Declaration on Environment and Development, and support developing countries in strengthening their capacity for the sound management of chemicals and hazardous wastes by providing technical and financial assistance" (UN, 2002; paragraph 23; p. 13).

3.1.1.3 The strategic approach on international chemicals management SAICM

The Dubai Declaration on International Chemicals Management as the basic document for Strategic Approach to International Chemicals Management (SAICM) established in 2006 as a voluntary policy framework at the first session of the international chemicals management conference (ICCM1) in Dubai, makes a clear link between chemicals safety and chemicals management. It states in addition that *"The sound management of chemicals is essential if we are to achieve sustainable development, including the eradication of poverty and disease, the improvement of human health and the environment and the elevation and maintenance of the standard of living in countries at all levels of development"* (UNEP, 2006, paragraph 1, p. 6).

It emphasises that insufficient progress has been made in international chemicals management by other legal instruments such as ILO Regulations, the Basel Convention or more recent international agreements such as the Rotterdam Convention on the Prior Informed Consent, the Stockholm Convention on Persistent Organic Pollutants or the adoption of the Globally Harmonized System for the Classification and Labelling of Chemicals (GHS; UNEP, 2006, paragraph 2, p.6).

Chemicals management is directly related to air, water and land contamination, workers exposures and long-term environmental and health risks (UNEP, 2006, paragraphs 5-6, p.6).

In paragraph 14, the declaration mentions green chemistry as one part of the benefits of chemistry for improved standards of living, public health and protection of the environment.

In paragraphs 21-26 the Dubai Declaration highlights that the focus of chemical management is on appropriate information and knowledge on chemicals throughout their life cycle, including their risks that they pose to human health and the environment; protection of highly exposed or particularly vulnerable groups, and on sound management of chemicals and hazardous waste, including prevention of illegal traffic in toxic, hazardous, banned and severely restricted chemicals, chemical products and wastes.

The scope of SAICM includes:

- Environmental, economic, social, health and labour aspects of chemical safety,
- Agricultural and industrial chemicals, with a view to promoting sustainable development and covering chemicals at all stages of their life-cycle, including in products (UNEP, 2006, paragraph 3, p. 11)

The SAICM Overarching Policy Strategy (OPS) states that deficits in information on chemicals in use and of safe management of chemicals are a major driving force for SAICM (UNEP, 2006, paragraphs 5-6, p.11), and that risk reduction is a key need in pursuing the sound management of chemicals (UNEP, 2006, paragraph 7, p.12). Besides risk assessment and management strategies as well as risk reduction measures, sound management of chemicals according to SAICM shall also include the development of safer alternatives, including alternatives to chemicals of concern (UNEP, 2006, paragraph 7d, p.13).

"The overall objective of the Strategic Approach is to achieve the sound management of chemicals throughout their life-cycle so that, by 2020, chemicals are used and produced in ways that lead to the minimization of significant adverse effects on human health and the environment" (UNEP, 2006, paragraph 13, p.14).

SAICM objectives according to the Overarching Policy Strategy (OPS) (UNEP, 2006, paragraph 14-18, p. 15-21) cover a long list of specific targets for risk reduction, knowledge and information, governance, capacity building and technical cooperation, and prevention of illegal international traffic.

Objectives in risk reduction comprise risk prevention and minimisation along the life-cycle including hazardous waste management, recycling and recovery, based on the pre-cautionary principle and a specific focus on highly exposed and vulnerable groups and eco-systems.

Specific target related to less hazardous chemicals are the ban of chemicals, that "*pose an unreasonable and otherwise unmanageable risk*" based on a risk assessment approach, and the promotion "*of environmentally sound and safer alternatives, including cleaner production, substitution of chemicals of particular concern and non-chemical alternatives*" (UNEP, 2006, paragraph 14, p.15f). The provisions and priorities follow closely the provisions set in the Stockholm Convention and in the European Chemicals legislation REACH, both in wording and content.

SAICM establishes a priority list for the assessment of groups of chemicals or chemical uses and unintended releases of chemicals that pose an unreasonable and otherwise unmanageable risk to human health and the environment: "persistent, bio-accumulative and toxic substances (PBTs); very persistent and very bio-accumulative substances; chemicals that are carcinogens or mutagens or that adversely affect, inter alia, the reproductive, endocrine, immune, or nervous systems; persistent organic pollutants (POPs), mercury and other chemicals of global concern; chemicals produced or used in high volumes; those subject to wide dispersive uses; and other chemicals of concern at the national level" (UNEP, 2006, paragraph 14, p. 15).

Targets under knowledge and information comprise the full value chain and includes information on hazards and use, including GHS as hazard communication mechanism and scientific information on chemical hazards for integration into risk assessments (UNEP, 2006, paragraph15, p.17).

Scientific research on effects, control technologies, safer chemicals and cleaner technologies and non-chemical alternatives and technologies as well as economic assessment of costs of unsound management is explicitly asked for.

Governance measures are one focus of SAICM activities. Cross-sectoral and multi stakeholder collaboration, gender balance, integration of all sectors of civil society, and corporate environmental and social responsibility are priorities together with guidance for prioritisation of actions and enforcement tools. Development of products that advance the objectives of the strategic approach can be considered an explicit product design objective.

Regarding capacity building and technical cooperation SAICM already makes the link between what was named chemical safety, poverty reduction and sustainable development. The prevention of illegal international traffic comprises toxic, hazardous, banned and severely restricted chemicals, including products incorporating these chemicals, mixtures and compounds and wastes. A comprehensive compilation of the aspects covered in SAICM is provided in the UBA SAICM brochure (UBA, 2016a).

Overall it may be concluded that sound management of chemicals according to SAICM is largely focused on existing chemicals along the entire life-cycle and is following a risk and not a hazard-based approach to chemicals management.

3.1.1.4 Rio 2012 – The future we want

In 2012, the importance of sound management of chemicals for the protection of human health and the environment and the 2020 goal were reconfirmed with slightly changed wording by the United Nations Conference on Sustainable Development (UNCSD), also known as Rio 2012, Rio+20 or Earth Summit 2012 (UNCSD).

In the concluding document "The Future we want" there is emphasis on the necessity of a full life-cycle coverage, and the commitment to "*an approach for sound management of chemicals and waste". Furthermore*, the conference text highlights the aim to "*responds in an effective, efficient, coherent and co-ordinated manner to new and emerging issues and challenges*" (UN, 2012; paragraph 213, p. 38). It is to be highlighted that waste has been added to the management request.

The United Nations Environment Assembly UNEA at its first meeting in 2014 reconfirmed the 2020 goal as well as the link between chemicals and waste and introduced a direct link to the upcoming Agenda 2030 and its sustainable development goals (UNEP, 2014; Resolution 1/5).

UNDESA (2010) and UNEP (2013b) provided an additional description of what is to be understood by sound management of chemicals (and waste).

Sound management of chemicals (UNDESA 2010, UNEP 2013b)

The sound management of chemicals, including hazardous wastes, aims to prevent and, where this is not feasible, to reduce or minimize the potential for exposure of people and the environment to toxic and hazardous chemicals as well as chemicals suspected of having such properties.

It includes prevention, reduction, remediation, minimization and elimination of risks during the life cycle of the chemicals: production, storage, transport, use and disposal, including the risks from chemicals found in products and articles.

It involves the application of the best managerial practices to chemicals, which requires strengthened governance and improved techniques and technologies at each stage of the life cycle.

Interesting is the fact that UNDESA contains one paragraph relating management to sustainable chemistry, which has not been taken up by UNEP (see below):

"Additional research and development that focuses on clean production and green/sustainable chemistry is crucial to achieve sustainable consumption and production" (UNDESA, 2010; p. 14)

3.1.1.5 2030 Agenda for Sustainable Development and further international agreements

In 2015, the 2030 Agenda for Sustainable Development with its Sustainable Development Goals (SDG) have taken up the issue of sound management of chemicals and waste. SDG 12.4 takes up the 2020 goal and specifies the approach of a sound management of chemicals and waste (SMCW).

With the adoption of the SDG the wording of the goal on chemicals management changed. In Target 12.4 the sound management of chemicals is explicitly linked to the environment and potential releases, covering all adverse impacts and all wastes, as presented in the text box below.

"By 2020, achieve the environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their re-lease to air, water and soil in order to minimize their adverse impacts on human health and the environment" (UNDESA, 2016a).

The minimisation of adverse impacts of chemicals is specifically referred to in goals for health and environmental conditions (SDG 3 and 6). Chemicals management on the other hand has many implications on other SDGs, e.g. agricultural practice to end hunger (SDG 2), global resource efficiency in production and consumption (SDG 8), sustainable industrialisation (SDG 9), energy efficiency (SDG 7), climate protection (SDG 13) and global partnerships (SDG 17).

In May 2016, UNEA resolution 2/7 reconfirmed the importance of sound management of chemicals and waste for achieving the 2020 goal and Target 12.4 of the 2030 Agenda SDG and asked for coordinated implementation and reporting efforts and active involvement of relevant industry stakeholders. Paragraph 17 specifically invites all stakeholders to submit best practices regarding sustainable chemistry in order for the UNEP secretariat to learn on how it can enhance the sound management of chemicals by supporting e.g. the 2030 Agenda, SAICM and chemicals and waste related multilateral environmental agreements (MEAs). Paragraph 18 requests the Executive Director to prepare a report on the opportunities presented by sustainable chemistry for SAICM. This shall include options for linkages to sustainable consumption and production policies and the possibilities that sustainable chemistry may offer to contribute to the 2030 Agenda.

MEAs, the Globally Harmonised System of Classification, Labelling and Packaging of Chemicals (GHS), and different instruments of the Inter-Organization Programme for the Sound Management of Chemicals (IOMC), or regional legislation such as the European REACH regulation, European legislation on plant protection products or on biocides, the California Proposition 65 and specific Japanese pieces of chemicals legislation cover specific aspects of chemicals management (UBA, 2016b).

The Basel Convention on the Control of Transboundary Movement of Hazardous Wastes and their Disposal is focussed on waste, whereas the Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade covers chemicals and pesticides. Both conventions target international transport and aim at reducing risks by export bans or informed consent to import.

The Stockholm Convention on Persistent Organic Pollutants and the Minamata Convention on Mercury focus on specific substances and substance groups of concern. The management priorities are on phase out of production and use, on risk prevention and clean up.

GHS is focussed on risk communication via harmonised labelling, IOMC instruments such as the Mutual Acceptance of Data system of the Organisation for Economic Co-operation and Development (OECD) and the International Programme on Chemical Safety (IPCS) database on chemical safety information from intergovernmental organizations (INCHEM) focus on risk assessment methodologies, data repositories and data exchange tools.

Regional legislation, such as the European REACH or legislation on plant protection products or on biocides combine a hazard and risk-based approach for chemicals management.

Criteria for sound management of chemicals can also be found in best available technology and best environmental practice (BAT/BEP) requirements as specified e.g. in the twelve guiding principles for best available technique (BAT) of the Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (IED; EU, 2010; p. 73).

The IED combines the control of emissions into all parts of the environment with process optimisation (BAT and environmental management), authorisation, monitoring, and reporting. Hence, it is an essential instrument for a safe industrial production and affects the entire chemical industry. The focus is on accident prevention, resource efficiency, minimisation of release and waste including optimised recovery and recycling, and substitution of hazardous chemicals.

3.1.2 Major definitions on sustainable chemistry

Discussions on definitions and criteria for sustainable or green chemistry have recently been compiled in a comprehensive way in Blum et al. (2017)[6], and in IPEN (2017).

According to Blum et al., criteria for sustainable chemistry for the first time where established by the 12 principles of green chemistry published by Anastas and Warner in 1998 (Anastas and Warner, 1998), and by the 12 guiding principles of sustainable chemistry as specified in EU Council Directive concerning Integrated Pollution Prevention and Control (IPPC; 96/61/EG and 2008/1/EG) in 1996.

The 12 principles of green chemistry have been complemented in 2003 by Anastas and Zimmermann with the 12 principles for green engineering (Anastas and Zimmermann, 2003). They are listed in the text boxes in the chapter below.

The 12 IPPC guiding principles of sustainable chemistry have been further developed by UBA and OECD into the general Criteria for Sustainable Chemistry (2004); and have been taken up in the EU Council Industrial Emissions Directive (IED; 2010/75/EU) in 2010.

In 2014, the OECD published a first "Definition of Sustainable Chemistry" that was updated in 2016; and in 2015 UBA developed the so-called "concept of sustainable chemistry".

These sets of principles, which form the basis for current discussions, follow a different approach, which will be explained in more detail below.

3.1.2.1 12 principles of green chemistry and green engineering

According to literature and personal communication with Paul Anastas, the 12 principles of green chemistry (Anastas & Warner, 1998) and green engineering (Anastas and Zimmermann, 2003) are particularly focussed on the design phase of new chemicals, as a complementary step to chemicals management, which is considered to cover all steps related to a sound management of existing chemicals.

The focus of the two sets of principles (which also could be considered criteria) is on optimised synthesis processes, which leads to the minimisation of hazards (toxicity, inherent benignity) and risks (emissions, targeted durability, complexity as a criterion for design choices on recycle, reuse, or beneficial disposal), together with a maximisation of resource use (energy, materials, and minimised waste). The achievement of inherent benignity and optimised resource efficiency shall be achieved by means of atom, molecular and computational chemistry in chemical synthesis. The approach is a highly sophisticated and based on latest science in the field.

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[6] Available at https://reader.elsevier.com/reader/sd/pii/S2352554117300037?token=FB708869D2053753D41C4BCABD4FC16C0702DDA97BB8E748016F67F48C14C907FC8A51BAAB930727A8DF7DC67CD5E415

IPEN emphasize the focus on hazard reduction in green chemistry (IPEN, 2017; p. 61), which shall apply to all steps in a life-cycle of a product containing chemicals, based on substitution or reduced use of hazardous chemicals. For implementation purposes however, each initiative which fulfils one of the criteria is already considered green chemistry. Examples of what has been awarded as best practice in green chemistry are accessible at the website of The Presidential Green Chemistry Challenge Awards (PGCCA)[7].

12 principles of green chemistry (Anastas & Warner ,1998)

1. **Prevention**
   It is better to prevent waste than to treat or clean up waste after it has been created.
2. **Atom Economy**
   Synthetic methods should be designed to maximize the incorporation of all materials used in the process into the final product.
3. **Less Hazardous Chemical Syntheses**
   Wherever practicable, synthetic methods should be designed to use and generate substances that possess little or no toxicity to human health and the environment.
4. **Designing Safer Chemicals**
   Chemical products should be designed to affect their desired function while minimizing their toxicity.
5. **Safer Solvents and Auxiliaries**
   The use of auxiliary substances (e.g., solvents, separation agents, etc.) should be made unnecessary wherever possible and innocuous when used.
6. **Design for Energy Efficiency**
   Energy requirements of chemical processes should be recognized for their environmental and economic impacts and should be minimized. If possible, synthetic methods should be conducted at ambient temperature and pressure.
7. **Use of Renewable Feedstocks**
   A raw material or feedstock should be renewable rather than depleting whenever technically and economically practicable.
8. **Reduce Derivatives**
   Unnecessary derivatization (use of blocking groups, protection/ deprotection, temporary modification of physical/chemical processes) should be minimized or avoided if possible, because such steps require additional reagents and can generate waste.
9. **Catalysis**
   Catalytic reagents (as selective as possible) are superior to stoichiometric reagents.
10. **Design for Degradation**
    Chemical products should be designed so that at the end of their function they break down into innocuous degradation products and do not persist in the environment.
11. **Real-time analysis for Pollution Prevention**
    Analytical methodologies need to be further developed to allow for real-time, in-process monitoring and control prior to the formation of hazardous substances.
12. **Inherently Safer Chemistry for Accident Prevention**
    Substances and the form of a substance used in a chemical process should be chosen to minimize the potential for chemical accidents, including releases, explosions, and fires.

12 principles of green engineering (Anastas and Zimmermann, 2003)

1. **Inherent Rather than Circumstantial**
   Designers need to strive to ensure that all materials and energy inputs and outputs are as inherently non-hazardous as possible.

[7] https://www.epa.gov/greenchemistry/presidential-green-chemistry-challenge-winners

2. **Prevention Instead of Treatment**
   It is better to prevent waste than to treat or clean up waste after it is formed.
3. **Design for Separation**
   Separation and purification operations should be designed to minimize energy consumption and materials use.
4. **Maximize Efficiency**
   Products, processes, and systems should be designed to maximize mass, energy, space, and time efficiency.
5. **Output-Pulled Versus Input-Pushed**
   Products, processes, and systems should be "output pulled" rather than "input pushed" through the use of energy and materials.
6. **Conserve Complexity**
   Embedded entropy and complexity must be viewed as an investment when making design.
7. **Durability Rather Than Immortality**
   Targeted durability, not immortality, should be a design goal.
8. **Meet Need, Minimize Excess**
   Design for unnecessary capacity or capability (e.g., "one size fits all") solutions should be considered a design flaw.
9. **Minimize Material Diversity**
   Material diversity in multicomponent products should be minimized to promote disassembly and value retention.
10. **Integrate Material and Energy Flows**
    Design of products, processes, and systems must include integration and interconnectivity with available energy and materials flows.
11. **Design for Commercial "Afterlife"**
    Products, processes, and systems should be designed for performance in a commercial "afterlife."
12. **Renewable Rather Than Depleting**
    Material and energy inputs should be renewable rather than depleting.

3.1.2.2 The guiding principles and definition of sustainable chemistry

Sustainable chemistry is much less clearly defined, according to IPEN (2017). IPEN considers sustainable chemistry a concept which aims to include environmental, social and economic aspects in conventional chemistry, stressing the risk to focus sustainability to resource efficiency and to greenwash continued use of hazardous chemicals (IPEN, 2017 p.65ff).

This observation is true as regards the aim of sustainable chemistry to mainstream sustainability across chemicals industry, it is not to be supported when looking to hazard as hazard reduction by substitution and green chemistry is an essential element also of sustainable chemistry.

As mentioned in Blum et al. 2017, the guiding principles on best available technology in chemical industry in the European IPPC and Industrial emission (IED) legislation are similar to the green chemistry principles but have a wider perspective as they are not restricted to the design process but cover all processes in chemicals industry or even the down-stream uses of chemicals.

Similar to Anastas' principles, the 12 IPPC principles (which have been taken up in the EU IED Directive) comprise the use of less hazardous substances, of low-waste technology, recycling and recovery, emissions and accident prevention, as well as high resource efficiency and renewable resources. However, they target chemical industrial production as such, aiming at setting benchmarks and standards for mainstream production.

For this reason, further criteria relate to commissioning dates for new or existing installations, the length of time needed to introduce the best available technique; comparable processes, facilities or methods of operation which have been tried with success on an industrial scale; and technological advances and changes in scientific knowledge and understanding or information published by public international organisations.

Criteria for determining best available techniques in chemical industry (EU 2010, p. 73)

1. the use of low-waste technology;
2. the use of less hazardous substances;
3. the furthering of recovery and recycling of substances generated and used in the process and of waste, where appropriate;
4. comparable processes, facilities or methods of operation which have been tried with success on an industrial scale;
5. technological advances and changes in scientific knowledge and understanding;
6. the nature, effects and volume of the emissions concerned;
7. the commissioning dates for new or existing installations;
8. the length of time needed to introduce the best available technique;
9. the consumption and nature of raw materials (including water) used in the process and energy efficiency;
10. the need to prevent or reduce to a minimum the overall impact of the emissions on the environment and the risks to it;
11. the need to prevent accidents and to minimise the consequences for the environment;
12. information on BAT published by public international organisations.

The UBA/OECD workshop on sustainable chemistry that took place in 2004 based on Anastas, IPPC and other discussions developed a *set of criteria for sustainable chemistry*, considered as suitable for chemicals policy development and assessment of the sustainability of the chemicals sector.

The criteria have been intended to be generic and broadly applicable as guidance for industry and policy. The criteria comprise both hazard and risk-based aspects, benign design and resource efficiency.

Differently to Anastas, the list of criteria however, includes “if possible” clauses, cost aspects (economic innovation), and comprehensive life cycle assessment.

Thus, these criteria explicitly take into account the necessity of a business case and acknowledge the need to use hazardous substances in some cases to reach required functionality.

UBA/OECD criteria for sustainable chemistry (2004; UBA 2018a)

1. Qualitative development: Use of harmless substances, or where this is impossible, substances involving a low risk for humans and the environment, and manufacturing of long-life products in a resource-saving manner;
2. Quantitative development: reduction of the consumption of natural resources, which should be renewable wherever possible; avoidance or minimization of emission or introduction of chemicals or pollutants into the environment; such measures will help to save costs;
3. Comprehensive life cycle assessment: analysis of raw material production, manufacture, processing, use and disposal of chemicals and discarded products in order to reduce the consumption of resources and energy and to avoid the use of dangerous substances;
4. Action instead of reaction: avoidance, already implemented at the stage of development and prior to marketing, of chemicals that endanger the environment and human health during their life cycle, and make excessive use of the environment as a source or sink; reduction of damage costs and the associated economic risks for enterprises and remediation costs to be covered by the state;

5. Economic innovation: sustainable chemicals, products, and production methods produce confidence in industrial users, private consumers, and customers from the public sector and thus result in competitive advantages.

The industry and value-chain approach of the IPPC guideline and the UBA/OECD criteria from 2004 have been taken up by the only existing explicit definition of sustainable chemistry published by the Organisation for Economic Co-operation and Development (OECD).

OECD defines *sustainable chemistry* as a strategic approach linked to sustainable development and covering the value chain of chemicals and chemical products from synthesis and product design through downstream uses in products to waste stage, as well as a process of innovation across all sectors to foster increased technical and environmental performance and value. Durability, reuse and recyclability as well as high value products that improve living conditions and overall sustainability are considered relevant effects of sustainable chemistry, even if this may not be explicitly mentioned in the text.

The OECD definition tries to cover classical criteria of sound management of chemicals and green chemistry with an appraisal of the benefits that chemicals may contribute to other sustainable development goals.

Sustainable chemistry definition by the OECD (OECD 2016)

Sustainable chemistry encompasses the design, manufacture and use of efficient, effective, safe and more environmentally benign chemical products and processes. Within the broad framework of sustainable development, government, academia and industry should strive to maximise resource efficiency through activities such as energy and non-renewable resource conservation, risk minimisation, pollution prevention, minimisation of waste at all stages of a product life-cycle and the development of products that are durable and can be reused and recycled.

Sustainable chemistry is also a process that stimulates innovation across all sectors to design and discover new chemicals, production processes, and product stewardship practices that will provide increased performance and increased value while meeting the goals of protecting and enhancing human health and the environment.

3.1.2.3 The concept of sustainable chemistry

The *Concept for Sustainable Chemistry* developed by UBA together with the project team follows this strategical and integrative approach, and combines classical elements of chemicals safety, and sound management of chemical and waste with green chemistry and economic aspects. It has been published in 2017 (Blum et al., 2017).

The concept is based upon various chemical safety and sustainable chemistry descriptions as well as on sustainable development schemes. In comparison to the OECD definition the new concept also integrates social aspects, such as social responsibility and decent work conditions. The concept ties explicitly onto the 17 SDG of the 2030 Agenda. The short version of the concept in 100 words is presented in the text box below.

The concept of sustainable chemistry in 100 words[8]

Sustainable chemistry contributes to positive, long-term sustainable development of society. With new approaches, technologies and structures it stimulates innovations and develops value-creating products and services.

[8] German version in tender specifications. English version taken from ISC3 background paper developed in the course of this project (see second interim report).

Sustainable chemistry uses approaches, substances, materials and processes to deliver functionalities. Therefore, it applies substitutes, alternative processes, resource recovery and efficiency. Thus, it avoids rebound effects, damage and impairments to human beings, ecosystems and resources.
Sustainable chemistry is based on a holistic approach, setting policies and measurable objectives for a continuous process of improvement. Interdisciplinary scientific research, education, consumer awareness, corporate social responsibility and sustainable entrepreneurship serve as important basis for sustainable development.

As requested by IPEN, the concept of sustainable chemistry involves green chemistry and conventional sound management of chemicals and waste as core elements, which however are expanded by resource efficiency and other sustainability aspects such as use of renewable resources, social and economic criteria (UBA, 2016b; figure 1).

The concept requests measurability of progress and is built on the following set of key criteria:

i. Minimisation of climate effects from production and products;
ii. Minimisation of adverse impacts from chemicals production and use on the environment, energy and resources;
iii. Optimisation of product design by means of innovation and knowledge exchange as well as company management, taking into consideration the full life-cycle;
iv. Minimisation of health risks from substances, production and products;
v. Generation of economic advantages by means of investments into environment and sustainable cooperation;
vi. Optimised integration of environmental, economic and social aspects into company processes in terms of transparency, education, social standards, dialogue and international cooperation.

25 quantitative indicators serve for measurement of progress to the criteria of the concept of sustainable chemistry, as presented in Table 2.

Table 2: The indicator set “Parameters of Sustainable Chemistry” (25 indicators)

KK		Indicator[9]	Target unit[10] (if necessary, adaptable to a specific application)
1	NC 1	GHG emissions	kg CO_2 equivalents over life cycle (ideally, GWP_{100} according to LCA)
2	NC 2	Raw material consumption	kg; can also be expressed in terms of loss potential(WP_{KRA}) according to LCA
2	NC 3	Raw material intensity/ productivity	kg raw material/kg product or kg product/kg raw material
2	NC 4	Percentage of renewable raw materials for material use	% of total raw material input
2	NC 5	Energy expenditure	kWh or MJ (taking into account all energy resources, i.e. renewable and non-renewable ones (upper calorific value)

9 Direct + indirect effects of sustainability tools
10 If possible, per t of product mass, alternatively per annum, for example

KK		Indicator[9]	Target unit[10] (if necessary, adaptable to a specific application)
			can also be expressed in terms of loss potential (WP_{KEA}) according to LCA
2	NC 6	Energy intensity/productivity	kWh/kg product or kg product/kWh
2	NC 7	Total water requirements	m^3 / also conceivable as water scarcity potential (WVP m^2 H_2Oe) according to LCA
2	NC 8	Percentage of recovered water	% of total water consumption
2	NC 9	Pollutant emissions into the air	amount/year (e.g. µg/a or µg/kg product), can also be expressed in terms the sum indicator "acidification potential" (kg SO_2 equivalents) and toxic injury caused by fine dust (AFP) kg PM10 equ. according to LCA
2	NC 10	Pollutant emissions into water and into soil	amount/year (e.g. µg/a or µg/kg product), can also be expressed in terms of the sum indicator „aquatic and terrestrial eutrophication potential" (EP) (kg PO43-e) according LCA
2	NC 11	Waste volume	t/a or t product
2	NC 12	Percentage of hazardous waste	% of waste emissions
3	NC 13	Sustainability information on production	% of product mass
3	NC 14	Percentage of hazardous substances (as indicator for substitution of hazardous substances)	% in product mass and classification according to CLP and further hazardous characteristics (such as PBT, endocrine disruption); calculation of environmental hazard and health hazard potential (such as Freshwater Toxicity (CF); Human Toxicity Potential (HTP_{cancer}, $HTP_{non\text{-}cancer}$; or hazardous substances potential (HSP)[11])
4	NC 15	Work-related accidents	total/year
4	NC 16	Occupational diseases	% of persons employed
5	NC 17	Economic benefits through sustainable action	€/year
5	NC 18	Intensity of capital expenditure to protect the environment and/or resources	% of total investment and € per year
5	NC 19	Market presence	Market share in % (sales enterprises divided by sales market)

11 The hazardous substances potential (HSP) is calculated from the "impact potential" of hazardous substances and the level of pollution in the product, applying the indicator "monoethylene glycol equivalents (MEG equ.)" (Bunke and Graulich 2003). The determination of the hazardous substances potential comprises three steps: determination of the impact factor W for the hazardous substance (on the basis of R phrases using an allocation table according to TRGS 440); comparison of the substance with the reference substance (monoethylene glycol); accounting of the quantities actually used. An adaptation of the new H phrases under CLP is planned.

KK		Indicator[9]	Target unit[10] (if necessary, adaptable to a specific application)
5	NC 20	Share of suppliers and contractors audited for their compliance with human rights and environmental aspects	% of all suppliers and contractors (along the entire value chain)
6	NC 21	Certification according to ISO, EMAS etc.	List of certifications
6	NC 22	Staff training and education	h/employee/year (related to the spatial system boundary)
6	NC 23	Total percentage of women	% of persons employed (related to the spatial system boundary)
6	NC24	Other benefits	% of employees in managerial positions (related to the spatial system boundary)
6	NC 25	GHG emissions	% of persons employed (related to the spatial system boundary)
-		Raw material consumption	Non-quantifiable

3.1.2.4 Voluntary progress indicators for sustainability at national level (Chemie³)

In parallel to the development of UBA's concept of sustainable chemistry, the sustainability initiative of the German chemicals industry developed a set of progress indicators (Chemie³, 2016). Whereas the set of indicators is extensive on social aspects and general sustainability criteria, there is no specific indicator related to the substitution of hazardous chemicals or green innovation. Also, this set presents a different focus of sustainable chemistry as it aims at assessing the progress of the chemical and pharmaceutical sector in this field. This is reflected by indicators measuring the number of enterprises that have defined sustainability goals, training programmes and efficiency goals.

3.2 Allocation of existing criteria to SMCW and SC

The following table provides an extensive summary of all criteria that have been identified in the previous chapters. All criteria are relevant for sustainable chemistry (see third column). The column at the far right specifies whether a criterion is also relevant for SMCW. The source of each criterion is provided in the left-hand column. It should be noted that repeating and redundant criteria have only been included once for the sake of convenience.

Table 3: Summary of identified criteria and their relevance for sustainable chemistry (SC) and the sound management of chemicals and waste (SMCW).

Source of criteria and key words	Criteria and key words	SC	SMCW
UBA SC concept 6 core criteria	Minimisation of climate effects from production and products;	✓	-
	Minimisation of adverse impacts from chemicals production and use on the environment, energy and resources;	✓	✓
	Optimisation of product design by means of innovation and knowledge exchange as well as company management, taking into consideration the full life-cycle;	✓	✓

Source of criteria and key words	Criteria and key words	SC	SMCW
	Minimisation of health risks from substances, production and products;	✓	✓
	Generation of economic advantages by means of investments into environment and sustainable cooperation;	✓	-
	Optimised integration of environmental, economic and social aspects into company processes in terms of transparency, education, social standards, dialogue and international cooperation.	✓	✓
chapter 19, Agenda 21	Expanding and accelerating international assessment of chemical risks;	✓	✓
	Harmonization of classification and labelling of chemicals; Information exchange on toxic chemicals and chemical risks;	✓	✓
	Establishment of risk reduction programmes;	✓	✓
	Strengthening of national capabilities and capacities for management of chemicals;	✓	✓
	Prevention of illegal international traffic in toxic and dangerous products.	✓	✓
OPS of SAICM	risk reduction	✓	✓
	improvement of knowledge and information	✓	✓
	good governance	✓	✓
	development of capacities and technical cooperation	✓	✓
	prevention of illegal international transboundary transport of chemicals and hazardous chemicals waste.	✓	✓
SMCW definition	prevent, to reduce or minimize the potential for exposure of people and the environment to toxic and hazardous chemicals as well as chemicals suspected of having such properties.	✓	✓
	prevention, reduction, remediation, minimization and elimination of risks during the life cycle of the chemicals	✓	✓
	application of the best managerial practices	✓	✓
	strengthened governance	✓	✓
	improved techniques and technologies at each stage of the life cycle	✓	✓
	research and development that focuses on clean production and green/sustainable chemistry	✓	✓
12 Principles Green Engineering	Inherent Rather Than Circumstantial	✓	–
	Prevention Instead of Treatment	✓	✓
	Design for Separation	✓	–
	Maximize Efficiency	✓	–
	Output-Pulled Versus Input-Pushed	✓	–
	Conserve Complexity	✓	–
	Durability Rather Than Immortality	✓	–

Source of criteria and key words	Criteria and key words	SC	SMCW
12 Principles Green Chemistry	Meet Need, Minimize Excess	✓	–
	Minimize Material Diversity	✓	–
	Integrate Material and Energy Flows	✓	–
	Design for Commercial "Afterlife"	✓	–
	Renewable Rather Than Depleting	✓	–
	Prevention	✓	✓
	Atom Economy	✓	-
	Less Hazardous Chemical Syntheses	✓	-
	Designing Safer Chemicals	✓	✓
	Safer Solvents and Auxiliaries	✓	✓
	Design for Energy Efficiency	✓	✓
	Use of Renewable Feedstocks	✓	✓
	Reduce Derivatives	✓	✓
	Catalysis	✓	–
	Design for Degradation	✓	–
	Real-time analysis for Pollution Prevention	✓	✓
	Inherently Safer Chemistry for Accident Prevention	✓	✓

The table presented above shows for each criterion whether it is applicable to both, sustainable chemistry and SMCW, or whether it is a parameter only relevant for sustainable chemistry. No criteria exist that are only relevant for SMCW since this concept is considered a part or subset of sustainable chemistry.

For the 25 parameters of sustainable chemistry that were analysed in more detail, it has become apparent that it can be difficult at times to differentiate SMCW from SC at the level of criteria and the indicators need to be considered individually. A cross check with the specific targets of the SAICM OPS provided further guidance (see interim report to the project) but did not result in a final approval and development of indicators for SMCW at that stage. Thus, for the work described in chapter 3.3, i.e. the evaluation of collected elements, has been performed based on a preliminary set of indicators allocated to SMCW or sustainable chemistry, as indicated in Table 4. Indicators which apply to the two schemes have been classified as “border” indicators. As shown in the table, a differentiation of the two schemes along the lines of existing objectives, definitions and criteria is hardly possible; thus, the project team suggested a revised approach for the distinction. The outcome of this process is presented in chapter 3.4.

Table 4: Preliminary list of indicators for identification of impact of identified activities on SC.

Allocation	Selection Indicator
Border 1	Internationional coorperation
Border 2	Governance
Border 3	Emission reduction
Border 4	Waste reduction
Border 5	Recycling
Border 6	Education and training
Border 7	Research and innovation
Border 8	Reduction exposure to chemicals
Border 9	Human rights and equality
Border 10	Biodiversity
Border 11	Area consumption
Border 12	Product design
Border 13	Safe chemicals and substitution
SC1	Energy efficiency
SC2	Material efficiency
SC3	Economic advantages
SC4	Societal well being

3.3 Assessment of elements on chemicals management against the criteria

The elements relevant for national and international chemicals management were identified and compiled in chapter 2. A set of 31 elements was found to represent the variety and diversity of elements. These have been subject to a detailed assessment regarding their relevance for sustainable chemistry using the criteria developed based on the work described in chapter 3. The assessment is available as a separate Excel file that has been provided to UBA with the first interim report to the project.

3.4 Relations and overlaps between sustainable chemistry, green chemistry and SMCW

Based on the evaluation of the objectives, the scope, the definitions and criteria as developed over time in different approaches for sound management of chemicals and sustainable chemistry, there are considerable overlaps but also clear differences between the two approaches that can be used to further differentiate between the two and to develop criteria and indicators for distinction. Key messages and graphical representations of this have been summarized in the first interim report to the project. However, this final report aims at presenting the current level of discussion and thus only lists the final outcome of the work and consultation process, which is comprehensively described in the assessment scheme for sustainable chemistry (UBA, 2018b).

Chapter 4.4 of the document summarises the distinction between GC, SMCW and sustainable chemistry (SC) as provided in the following textbox (so far available in German language only; English under development). Figure 1 graphically presents this relationship.

Schnittmengen von GC, SMCW, SC und SD (UBA, 2018b)[12]

GC – SMCW

Grüne Chemie wird durch die 12 Prinzipien der grünen Chemie definiert. Diese gehören alle zur ökologischen Dimension der nachhaltigen Entwicklung und beziehen sich vor allem auf die Produktion und das Design von Chemikalien.

Da SMCW sich auf den gesamten Lebenszyklus (inklusive Design und Produktion) einer Chemikalie bezieht, und GC auch Chemikaliensicherheit (z. B. weniger gefährliche Synthesen) verfolgt, sind manche Ziele der GC auch Ziele des SMCW. Aufgrund dessen haben GC und SMCW eine Schnittmenge.

Grüne Chemie ist nicht eine Teilmenge von SMCW, da sich SMCW in der ökologischen Dimension um Chemikaliensicherheit und nachhaltiges Abfallmanagement bemüht - grüne Chemie aber adressiert alle vier ökologischen Ziele der nachhaltigen Chemie. Diejenigen Ziele der grünen Chemie, die sich nicht auf Chemikaliensicherheit oder Abfallmanagement beziehen, wie z. B. Energieeffizienz, sind nicht Ziele des SMCW.

Das Wirkungsfeld von SMCW ist größer als dasjenige von GC weil:

- SMCW bezieht sich im Gegensatz zu GC auf den gesamten Lebenszyklus einer Chemikalie.
- Chemikaliensicherheit ein umfangreiches Ziel ist
- SMCW auch soziale Ziele (v. a. Arbeitssicherheit) verfolgt
- SMCW auch einen kleinen ökonomischen Aspekt aufweist (z. B. GHS fördert den globalen Handel mit Chemikalien)

SMCW – SC

Warum ist SMCW eine Teilmenge von SC?

Nachhaltige Chemie löst Querschnittsprobleme, die sich aus der Wechselbeziehung von Chemie, Ökologie, Sozialem und Ökonomie ergeben. Auch die Themen des SMCW entstammen dieser Wechselbeziehung. Bei den drei Dimensionen der nachhaltigen Entwicklung ist der Wirkungsbereich des SMCW jedoch geringer als bei SC:

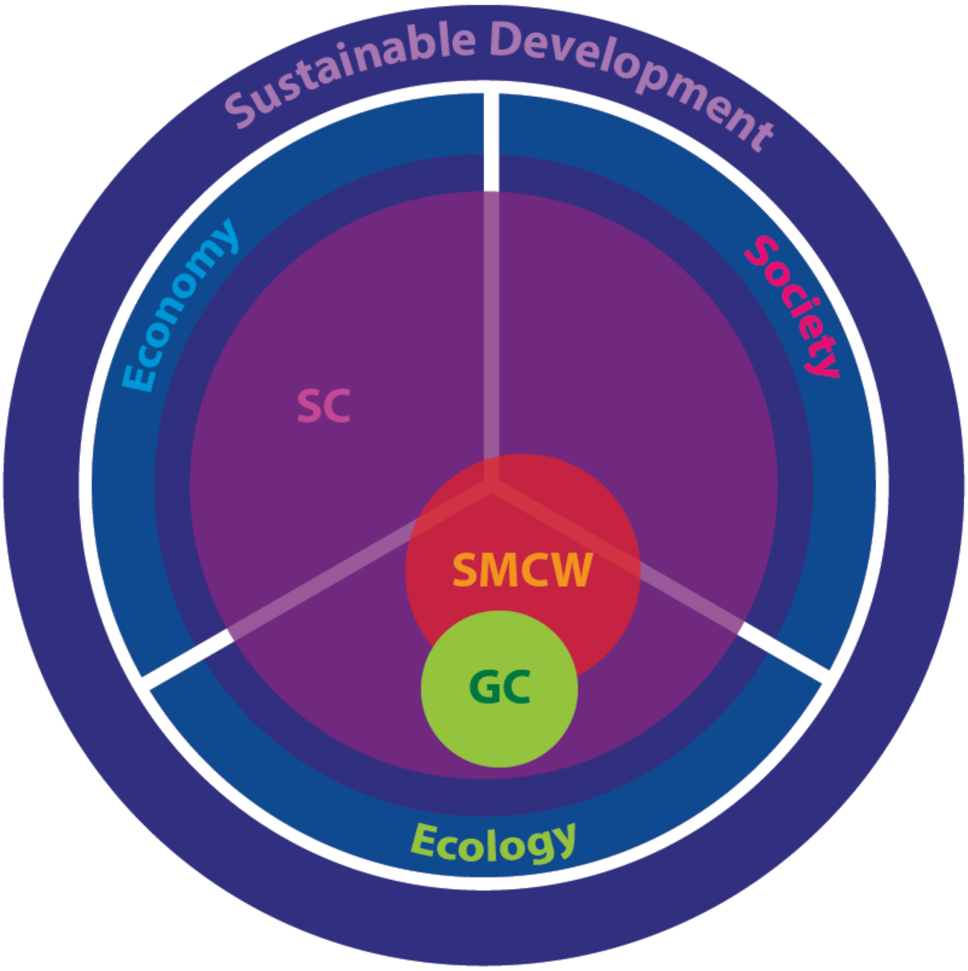
- Ökologische Dimension:
  - SMCW verfolgt vor allem Ziele der Chemikaliensicherheit und einige Ziele des nachhaltigen Abfallmanagements.
  - SC bezieht sich in vollem Umfang auf: Ressourcenschonung, Reduktion von Treibhausgas-Emissionen, Chemikaliensicherheit und nachhaltiges Abfallmanagement.
- Soziale Dimension:
  - SMCW widmet sich sozialen Aspekten der Chemikaliensicherheit
  - SC ist allen sozialen Zielen der nachhaltigen Entwicklung verpflichtet
- Ökonomische Dimension:
  - SMCW verfolgt nachhaltige ökonomische Ziele in sehr geringem Ausmaß.
  - SC ist allen ökonomischen Zielen der nachhaltigen Entwicklung verpflichtet.

SC – SD

Warum deckt SC weniger Themen ab als SD (nachhaltige Entwicklung, engl. sustainable development - SD)? Die Themen der SC entstammen der Schnittmenge von Chemie, Ökologie, Ökonomie und Gesellschaft. Die Themen des SD dagegen gehören zur Schnittmenge aus Ökologie, Ökonomie und Gesellschaft. Nicht alle Herausforderungen der nachhaltigen Entwicklung haben einen chemischen Aspekt. So ist z. B. nachhaltiger Tourismus eine Aufgabe der nachhaltigen Entwicklung, aber nicht der nachhaltigen Chemie.

12 Overlaps of green chemistry (GC), sound management of chemicals and waste (SMCW), sustainable chemistry (SC) and sustainable development (SD)

Figure 1: Overlaps between sustainable chemistry (SC), sound management of chemicals and waste (SMCW) and green chemistry (GC) in the context of sustainable development.



Source: UBA, 2018b.

4 Criteria and indicators to assess the contribution to the 2020 goal and the 2030 Agenda for Sustainable Development

Throughout the last decades a considerable number of activities have been started to improve and promote sound management of chemicals and waste as well as sustainable chemistry.

However, it has not yet been systematically evaluated how these activities contribute to the achievement of the 2020 goal and to the targets of the 2030 Agenda for Sustainable Development.

Therefore, the development of clear and transparent sustainability criteria and indicators for evaluation of individual activities against the objectives of the 2020 goal and the targets of the 2030 Agenda for sustainable development is an important target that is addressed in this report.

4.1 Criteria and indicators for SAICM's Overall Orientation and Guidance (OOG)

The OOG adopted by ICCM4 in 2015 serves as an overall orientation and guidance for SAICM stakeholders in order to achieve the 2020 goal by providing priorities for the required work.

It contains 11 basic elements and 6 core activities that require action at national and regional level and help SAICM stakeholders achieving the 2020 goal. The 11 basic elements have already the character of criteria to measure progress and set priorities. The 6 core activities and their corresponding action points form a basis for indicators. Both sets are described in the following boxes and have been taken into consideration for the further advancement of the assessment scheme for sustainable chemistry (see chapter 3.4).

The 11 basic elements

SAICM's OOG identified the following 11 basic elements as critical at the national and regional levels to the attainment of sound chemicals and waste management (SAICM 2015, paragraph 19, p. 4):

(a) Legal frameworks that address the life cycle of chemicals and waste
(b) Relevant enforcement and compliance mechanisms
(c) Implementation of chemicals and waste-related multilateral environmental agreements, as well as health, labour and other relevant conventions and voluntary mechanisms
(d) Strong institutional frameworks and coordination mechanisms among relevant stakeholders
(e) Collection and systems for the transparent sharing of relevant data and information among all relevant stakeholders using a life cycle approach, such as the implementation of the Globally Harmonized System of Classification and Labelling of Chemicals
(f) Industry participation and defined responsibility across the life cycle, including cost recovery policies and systems as well as the incorporation of sound chemicals management into corporate policies and practices
(g) Inclusion of the sound management of chemicals and waste in national health, labour, social, environment and economic budgeting processes and development plans
(h) Chemicals risk assessment and risk reduction through the use of best practices
(i) Strengthened capacity to deal with chemicals accidents, including institutional strengthening for poison centres
(j) Monitoring and assessing the impacts of chemicals on health and the environment
(k) Development and promotion of environmentally sound and safer alternatives

The 6 core activities

Within the OOG, six core activity areas are mentioned for implementing the objectives set out in the Overarching Policy Strategy (OPS) towards the achievement of the overall 2020 goal (SAICM 2015, paragraph 22, p. 5):

(a) Enhance the responsibility of stakeholders: promoting and reinforcing commitment and multi-sectoral engagement;
(b) Establish and strengthen national legislative and regulatory frameworks for chemicals and waste: improving capacity to address the basic elements of the sound management of chemicals and waste and encouraging regional cooperation;
(c) Mainstream the sound management of chemicals and waste in the sustainable development agenda: advancing risk reduction and enhancing the link between the sound management of chemicals and waste and health, labour, and social and economic development planning, processes and budgets;
(d) Increase risk reduction and information sharing efforts on emerging policy issues: continuing to promote actions on issues not currently addressed in existing agreements, complementing initiatives taken by other bodies;
(e) Promote information access: increasing the accessibility of relevant information and making it understandable for all levels of society;
(f) Assess progress towards the 2020 goal of minimizing the adverse effects of chemicals on human health and the environment: identifying achievements, understanding the gaps in implementation and prioritizing actions for achievement by 2020.

4.2 Criteria and indicators for the SDGs related to chemicals

The 2030 Agenda for Sustainable Development contains a number of goals and targets, which either specifically mention hazardous chemicals or are related to chemicals and sustainable chemistry. A selection of goals and targets relevant for sustainable chemistry and SMCW is depicted in Table 5. The list is not exhaustive but covers those goals and targets with explicit reference to chemistry.

Table 5: SDG and targets specifically addressing chemicals. The bold goals have direct relevance to SMCW.

SDG No.	SDG	Target No.	Target
Goal 2	End hunger, achieve food security and improved nutrition and promote sustainable agriculture	2.1	By 2030, end hunger and ensure access by all people, in particular the poor and people in vulnerable situations, including infants, to safe, nutritious and sufficient food all year round
		2.4	By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality
Goal 3	Ensure healthy lives and promote **well-being for all at all ages**	3.4	By 2030 reduce by one-third pre-mature mortality from non-communicable diseases through prevention and treatment and promote mental health and wellbeing
		3.9	**By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination**
Goal 6		6.1	By 2030, achieve universal and equitable access to safe and affordable drinking water for all

SDG No.	SDG	Target No.	Target
	Ensure availability and sustainable management of water and sanitation for all	6.3	By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally
Goal 8	Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all	8.4	Improve global resource efficiency in consumption and production and endeavor to decouple economic growth from environmental degradation
Goal 9	**Build resilient infrastructure, promote inclusive and sustainable industrialisation and foster innovation**	**9.4**	**By 2030, upgrade infrastructure and retrofit industries to make them sustainable, with increased resource-use efficiency and greater adoption of clean and environmentally sound technologies and industrial processes, with all countries taking action in accordance with their respective capabilities**
Goal 11	Make cities and human settlements inclusive, safe, resilient and sustainable	11.1	By 2030, ensure access for all to adequate, safe and affordable housing and basic services and upgrade slums
		11.3	By 2030, enhance inclusive and sustainable urbanization and capacity for participatory, integrated and sustainable human settlement planning and management in all countries
		11.6	By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management
Goal 12	**Ensure sustainable consumption and production patterns**	**12.4**	**By 2020, achieve the environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimize their adverse impacts on human health and the environment**
		12.5	**By 2030, substantially reduce waste generation through prevention, reduction, recycling and reuse**
		12.6	Encourage companies, especially large and transnational companies, to adopt sustainable practices and to integrate sustainability information into their reporting cycle
		12.7	Promote public procurement practices that are sustainable, in accordance with national policies and priorities
Goal 14	Conserve and sustainably use the oceans, seas and marine resources for sustainable development	14.1	By 2025, prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution

SDG No.	SDG	Target No.	Target
Goal 15	Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss	15.5	Take urgent and significant action to reduce the degradation of natural habitats, halt the loss of biodiversity and, by 2020, protect and prevent the extinction of threatened species
Goal 16	Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels	16.3	Promote the rule of law at the national and international levels and ensure equal access to justice for all
		16.6	Develop effective, accountable and transparent institutions at all levels
		16.7	Ensure responsive, inclusive, participatory and representative decision-making at all levels
		16.10	Ensure public access to information and protect fundamental freedoms, in accordance with national legislation and international agreements
Goal 17	Strengthen the means of implementation and revitalize the global partnership for sustainable development	17.1-17.19	Finance: in particular for developing countries Technology: knowledge sharing and cooperation Capacity-building for SDG achievement in developing countries Trade: increase export from developing countries and promote universal, rules-based, open, non-discriminatory and equitable multilateral trading system under the World Trade Organization Systemic issues: strengthen and enhance (multi-stakeholder) partnerships and improve data availability in particular in developing countries

Sustainable chemistry, due to its broad contribution to sustainable development, addresses a number of other targets as well that are provided in a complete list covering all 169 targets in the holistic assessment scheme described in the next chapter. A summary of the relationship between sustainable chemistry and the 2030 Agenda is provided in the text box below.

Relationship between Sustainable Chemistry and the 2030 Agenda (UBA, 2018b)

Criteria for SDG and target analysis

The close relationship between the 2030 Agenda and sustainable chemistry becomes apparent when examining the extent to which the SDGs and their targets serve the goals of sustainable chemistry.

1. Ecological core SDGs and targets: SDGs and targets which directly articulate the ecological goals of Sustainable Chemistry
2. Economic core SDGs and targets: SDGs and targets which directly articulate the economic goals of Sustainable Chemistry
3. Social core SDGs and targets: SDGs and targets which directly articulate the social goals of Sustainable Chemistry
4. Targets not relevant for SC: SDG targets with a weak or without relationship to Sustainable Chemistry

Summary: Relationship between Sustainable Chemistry and the 2030 Agenda
25 targets directly articulate the ecological goals of SC.
29 targets directly articulate the economic goals of SC.
88 Targets directly articulate the social goals of SC.
Altogether, 142 out of 169 targets of the 2030 Agenda directly express core goals of Sustainable Chemistry. Only 27 of these 169 targets have a weak or no direct relation to Sustainable Chemistry.

Conclusion
Sustainable Chemistry can be described in the following way:

- The main goal of Sustainable Chemistry is to foster sustainable development.
  - SC has integrated and indivisible ecological, social and economic objectives.
  - SC provides a substantial contribution to the SDG
- Sustainable Chemistry addresses the whole life cycle of a chemical.
- Sustainable Chemistry takes the planetary boundaries into account.

4.3 Sustainable chemistry concept and assessment scheme

Based on the work performed during the course of the project and described in the previous chapters of this report, further work was conducted by the German Environment Agency and the results have been used by Ralf Geiss from the German Environment Agency to prepare an assessment scheme for sustainable chemistry. The document covers a holistic description of sustainable chemistry and leads to an assessment scheme for sustainable chemistry. This assessment scheme was used later during the project to assess case studies on sustainable chemistry and discuss them with relevant experts (see chapters 6 and 7; UBA, 2018b). The content of the document is briefly described below.

Starting from the background on sustainable chemistry (megatrends, need for sustainability), the description on sustainable chemistry continues to underline the economic importance of chemistry and its connection to sustainability, covering all three dimensions of sustainability. The concept also comprises the current view regarding the differentiation between sustainable chemistry, SMCW and green chemistry and provides a comprehensive and graphical overview of the overlaps and differences between the concepts.

The assessment scheme takes into account the planetary boundaries and the SDG of the 2030 Agenda to result in an assessment of case studies regarding all dimensions of sustainability. It covers 70 pages and is so far, available in Germany only.

Covering over 70 pages, the complete description and assessment scheme is considered the summarising outcome of the previous chapters of this report. So far, it is available in German language only.

The document describes sustainable chemistry in relation to sustainable development, green chemistry and the sound management of chemicals and waste. The summary regarding the overlaps of the concepts has already been described in chapter 3.4 and in Figure 1. The text box below summarises the goals and spheres of activity of sustainable chemistry.

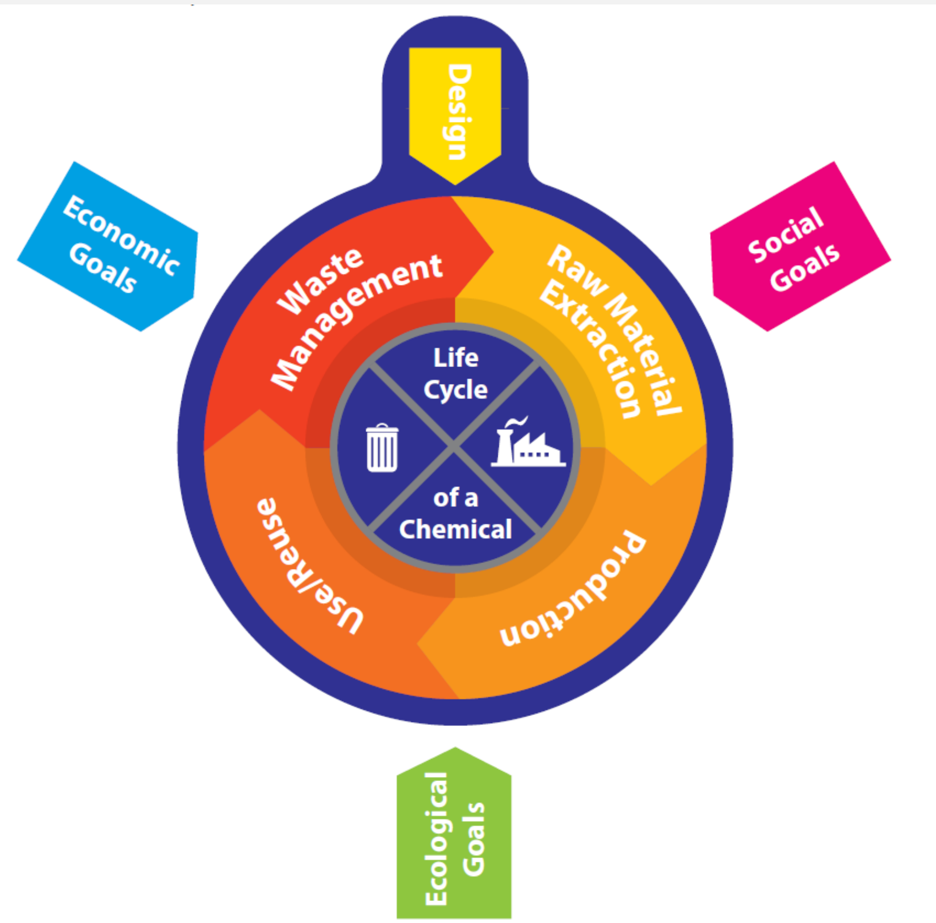
Goals and spheres of activity of sustainable chemistry (UBA, 2018b)

"Sustainable Chemistry's main goal is to foster sustainable development via cross cutting chemical, ecological, economic and social issues. This implies that topics, which do not have chemical, ecological, economic and social aspects all at once are not a part of Sustainable Chemistry.
Although its ecological dimension is based on the principles of Green Chemistry, it surpasses Green Chemistry mainly because of its crosscutting sustainable nature.

The ecological, economic and social goals of Sustainable Chemistry largely overlap with the goals of the 2030 Agenda. Therefore, Sustainable Chemistry considerably contributes to achieving the Sustainable Development Goals (SDG).
Due to close relation with sustainable development, Sustainable Chemistry is the widest of the three frameworks analysed" (green chemistry, sound management of chemicals and waste, and sustainable chemistry; UBA, 2018b).

The goals and spheres of activity are depicted in Figure 2 below. The overarching goals cover the economic, ecologic and social dimension and can be described by further sub-goals as provided in UBA, 2018b.

Figure 2: Goals (green, pink and blue) and spheres of activity (dark blue) of sustainable chemistry.



Source: UBA, 2018b.

5 Preparation for the assessment of case studies

To identify case studies on sustainable chemistry and assess them regarding their contribution to sustainable chemistry using the assessment scheme described, several preparatory steps were conducted in the course of the project to provide background information for the assessment, select the set of case studies and further develop the assessment scheme as now described in chapter 4.3 and partly in Annex 1 to this report. The chapters below present the results of the preparatory work, focussing on relevant sectors for the case studies, international environmental goals that can be taken into account when assessing the (ecological) sustainability of projects and existing checklists to identify overlaps and deficiencies of the assessment scheme[13].

5.1 Relevant sectors for case studies

In order to prepare best practice examples for sustainable chemistry, research for relevant topics has been conducted. The search has been based on a study from the ISC_3 with the focus on “recent innovations as well as priority research and development themes, which are needed in particular for a broad industrial implementation of the concept of Sustainable Chemistry” (UBA 2017b, p. 18).

The following fields of application and industrial sectors are described in the study:

i. petrochemicals and base chemicals
ii. polymers
iii. agrochemicals (pesticides)
iv. fertilisers
v. coatings, dyes, pigments and adhesives
vi. detergents, cleaning agents and personal care products
vii. chemical fibres
viii. construction chemistry
ix. pharmaceuticals
x. nanomaterials

Within the framework of the development of best practice examples, not all fields can be addressed. Therefore, a limited number of fields had to be selected.

After a first discussion with UBA, pharmaceuticals and nanomaterials are excluded from the further analysis and development of indicators since they significantly differ from other chemicals in their production and authorisation specifications or have separate documents already available.

To further narrow down the sectors and specific areas of research and development within the sectors, several key publications served as a basis to identify major needs in line with global sustainable development and complement the information retrieved from the above-mentioned study. Some of the key studies and concepts include:

- The above-mentioned ISC_3 study on priority topics as well as the study on the link between sustainable chemistry and sound management of chemicals throughout their life cycle and the 2030 Agenda for Sustainable Development and the related policy paper with a focus on the contributions of sustainable chemistry to SAICM beyond 2020
- The European Strategy for Plastics in a Circular Economy
- The concept on the planetary boundaries by Rockström et al. and Steffen et al.

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13 This report refers to the latest version of the assessment scheme. Any input and revision of the scheme has already been incorporated in the scheme and is not subject of this report.

- Status paper on phosphate recovery by Bertau et al. (2017)

The following chapters describes important sectors for the selection of the case studies, with a focus on research and development (R&D) project potential as these are of significant interest when it comes to their contribution to sustainable chemistry and the future potential of these case studies.

5.1.1 CCU

a. **PTX**

b. **material use**

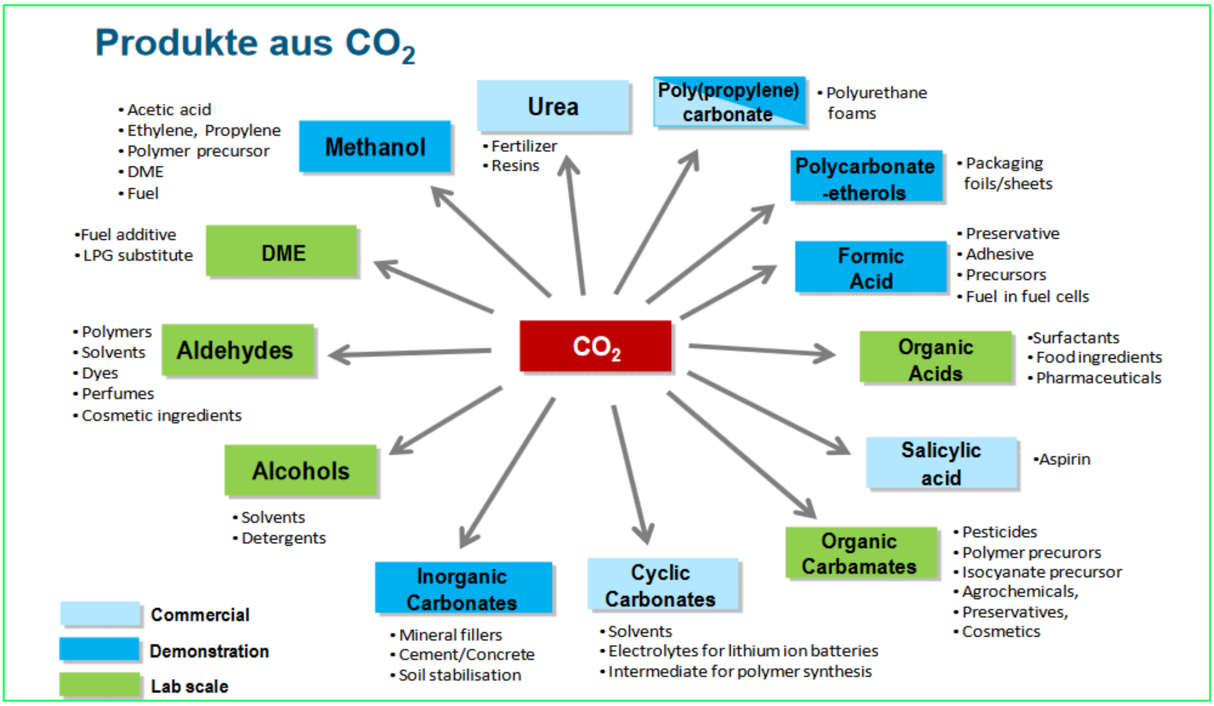
Petrochemicals and base chemicals are characterised by high production volumes and currently rely largely on fossil fuels. However, biomass or CO_2 as feedstock for production may generate high potentials in terms of progress towards several sustainability aspects, i.e. GHG emission reduction, capture and utilisation of CO_2 and non-renewable resource conservation. On the other hand, such potentials need to be carefully balanced with possible negative impacts, e.g. using biomass or spatial and agricultural resources for chemicals production instead of food generation. In addition, energy and other resources are also required for alternative feedstocks and may reduce the positive impact significantly. Thus, CO_2 and biomass as feedstock present important fields for research and development where a careful balancing between the positive and negative sustainability impacts is essential.

The use of CO_2 in CCU can be categorised into direct utilisation (e.g. for beverages), use in materials and use as energy carrier (PTX[14])

A large variety of products can potentially be produced from CO_2. The following figure presents products made from CO_2 together with the technological development status.

[14] PTX is a collective term for power to gas, power to liquid and power to heat and may – depending on the definition – also comprise power to chemicals and power to product. For this study however, we distinguish between PTX and material usage of CO_2 from CCU.

Figure 3: Products which can be produced based on CO_2 and indication of development status of the related technologies.



Source: Dechema, Fona, 2017, https://www.fona.de/mediathek/forum/2017/beitrag/w1_ausfelder_florian_01_presentation_forum2017.pdf

5.1.2 Use of biomass as raw material

As described above, biomass usage as feedstock to the chemical industry, both for base chemicals as well as for polymers (see next paragraph), may not be sustainable solutions if produced in competition with food production. Therefore, the use of 2nd or 3rd generation biomass can present an alternative but still needs to be carefully assessed, e.g. also in terms of biodiversity and ecosystem impacts as well as energy demand (UBA 2017, p. 25 and 27).

Using biomass as raw material on a large scale would also impact several of the planetary boundaries defined by Steffen et al. (2017) and Rockström et al. (2009). This concerns specifically land-system changes and genetic diversity (destruction of natural habitats for biomass production, especially in the case of monocultures) and adverse effects on biogeochemical flows excessive through fertilisation.

To assess the use of biomass as feedstock regarding the sustainable chemistry parameters, the work on the checklist will look into one R&D project in this sector; as far as possible, biorefineries and their implications for the sustainability of biomass use as a feedstock may be considered when assessing the R&D project.

5.1.3 Polymer (recycling)

Plastics have been identified as a key priority in the EU Action Plan for a circular economy and the European Commission adopted the European Strategy for Plastics in a Circular Economy in January 2018. The strategy is aiming at the transformation of the way plastics and plastics products are designed, produced, used and recycled and *inter alia* want to ensure “that all plastics packaging is recyclable by 2030” (European Commission 2018, p. 1); see also text box 1.

The following facts underline the high importance of polymers for a sustainable chemistry (see email correspondence with Ralf Geiss, 13.3. 2018):

- About 8% of the globally used fossil resources (oil, gas, coal) are used for chemical syntheses
- The German raw material supply for the organic chemical industry was based on 87% fossil and 13% renewable resources in 2013
- About 75% of the material flows in the chemical industry are related to polymers

Plastics and their recycling are also closely related to CCU and bio-based materials, as innovations in this sector are mainly focussing on changing the feedstock from petrochemicals to bio-based or CO2 feedstocks (UBA 2017, p. 27). The European plastics strategy aims at successfully establishing a market for recycled and innovative plastics and alternative feedstocks (with the prerequisite of being more sustainable than non-renewable solutions).

According to the plastics strategy, the quality of plastics recycling needs to be improved, expanded and modernised, amongst others. Voluntary commitments from the industry are expected to reach this and other goals expressed in the strategy (European Commission 2018, p. 7).

Plastic packaging accounts for about 60 % of post-consumer plastic waste (European Commission 2018, p. 7 from Plastics Europe).

Plastic recycling, in particular of waste from the construction and demolition, automotive, furniture and electronics sectors, may be hampered by a lack of information about the possible presence of substances of concern (European Commission 2018, p. 8). Applying sustainable chemistry would significantly contribute to solving this problem through various ways (e.g. benign by design, design for recycling, cooperation and information sharing along the supply chain). Also, the position paper of UBA (2016b) on increased plastic recycling and the use of recyclates highlights the large potentials for increased plastic recycling and mentions the environmentally friendly and recyclable product design as one of seven prerequisites for a functioning plastic recycling economy.

“Achieving the objectives laid out in [the European Strategy for Plastics in a Circular Economy] will require major investments in both infrastructure and innovation” (European Commission 2018, p. 13). In order to judge if R&D projects regarding plastics (recycling) are in line with sustainable chemistry goals, the checklist will present a useful tool. Thus, polymer recycling is selected as a sector on which the checklist development will be based, and one R&D project of this sector can be subject to a closer analysis with the checklist.

Potential R&D projects for the analysis are included in the ISC_3 study 2 (UBA 2017, Table 4, p. 28ff).

The European Commission’s Pledging Campaign (pledge submission deadline June2018) to boost the uptake of recycled plastics may induce a new and additional R&D projects on polymer recycling that need to be evaluated in the future (European Commission 2018).

Box 1: ‘A vision for Europe’s new plastics economy’

“A smart, innovative and sustainable plastics industry, where design and production fully respect the needs of reuse, repair, and recycling, brings growth and jobs to Europe and helps cut EU's greenhouse gas emissions and dependence on imported fossil fuels.

[...]

The market for recycled and innovative plastics is successfully established, with clear growth perspectives as more products incorporate some recycled content. Demand for recycled plastics in Europe has grown four-fold, providing a stable flow of revenues for the recycling sector and job security for its growing workforce. [...]

Innovative materials and alternative feedstocks for plastic production are developed and used where evidence clearly shows that they are more sustainable compared to the non-renewable alternatives. This supports efforts on decarbonisation and creating additional opportunities for growth.”

Source: European Commission (2018): A European Strategy for Plastics in a Circular Economy

5.1.4 Phosphorus recovery

Phosphorus, together with nitrogen, has the potential to significantly impact aquatic systems if the additional anthropogenic activation (i.e. additional introduction of nutrients into environmental compartments), mainly due to agricultural activities, persists. The global cycles of these two elements have already been – and will be further – perturbed, shifting more and more states of aquatic bodies from clear to turbid water. Excessive inflow to oceans of these two elements can lead to ocean anoxic events, having the potential to cause mass extinctions of marine life (Rockström et al. 2009b; p.474).

Being one of the three main nutrients, phosphorus together with nitrogen and potassium influences plant metabolism as well as plant health in particular and cannot be replaced by other substances. Phosphate must be present in soil in sufficient quantity and in a plant available form, which in turn is linked to mobilisation processes, during which reserves built up from past fertilising events are made available over long periods of time. Since the long turn utilisation cannot be proven experimentally, farmers tend to apply phosphorus fertilisers excessively, which can lead to the eutrophication of neighbouring ecosystems, in the cases where enough phosphorus is already present in the soil (Schnug et al. 2014).

In 2016, 261 million tonnes of raw phosphate were mined worldwide and approx. 54 million tonnes of phosphate fertilizer were produced. Due to growing world population as well as enhancing living standards in developing countries, it is estimated that the demand for phosphate will double until 2050 (USGS, 2017). Being a limited resource, it is important to apply phosphate efficiently and to limit or even avoid phosphate containing wastes.

The recovery of resources from waste represents an alternative business model to leverage economic benefits from sustainable chemistry, including the recovery of phosphorus from sewage sludge. Processes have been developed e.g. by BioCover, Yara:Trap, RecoPhos®, REPHOS® and many more or currently under development (BMUB 2017; p. 15).

Due to the legal situation, a significant increase in R&D actions is expected in this area, since with the new Sewage Sludge Ordinance (AbfKlärV[15]) the legislator introduced a transitional period at the beginning of 2015, from the end of which in 2029 phosphate must be recovered from sewage sludge or sewage sludge ashes. The starting point was the German government's coalition agreement of 2013 to phase out the agricultural recycling of sewage sludge for fertilisation purposes due to the increasing contamination with persistent organic compounds. Taking into consideration the differences concerning technical requirements and local operating parameters of each individual wastewater treatment plant, it is unlikely that there will be a common solution for all plant operators (Bertau et al., 2017). Thus, the development of solutions requires extensive testing and careful assessments of R&D projects currently under development taking place mainly on individual basis and small scales.

To assess the suitability of technologies for phosphorus recovery currently being under development regarding the sustainable chemistry parameters, the work on the checklist will look into one R&D project in this sector.

5.2 International environmental goals

International environmental goals may act as drivers for research and innovation. They have been elaborated with regard to major global challenges such as climate change and a growing world population. A central target was set with the Paris Agreement, maintaining the temperature increase below 1.5°C. The UN Sustainable Development Goals of the 2030 Agenda, which were adopted in 2015 to end

[15] https://www.gesetze-im-internet.de/abfkl_rv_2017/AbfKl%C3%A4rV.pdf

poverty, protect the planet and ensure prosperity for all until 2030 represent a more overarching approach. Directly connected to chemical industries is the Strategic Approach to International Chemicals Management (SAICM) aiming at a sound management of chemicals until 2020.

In addition to those, a collection of further environmental goals that might act as drivers for innovation are listed below. This non-exhaustive list includes programmes and strategies that are relevant for different sectors:

- Goals towards a pollution free planet (UNEA)
- 7th Environment Action Programme (7th EAP)
- EU Circular Economy Package
- Revised European Charter for the Protection and Sustainable Management of Soils
- One planet summit (12 commitments)
- Concept of the planetary boundaries and related policy paper of WBGU (9 dimensions)
- WWF (Power Sector Vision 2050)
- 10 Principles by UN Global Compact
- Sustainable Process Industry through Resource and Energy Efficiency (SPIRE)
- Aichi Biodiversity Targets (Conventional on Biological Diversity, CBD).

Plastics recycling and CO_2 or biomass as a feedstock for instance can contribute to international environmental goals, in particular the Paris Agreement (European Commission 2018, p. 5). The analysis of the projects and case studies therefore can also include an assessment of the global environmental goals that are addressed by the project.

5.3 Evaluation of existing checklists

Checklists on parameters of sustainability can be a helpful tool to evaluate case studies of sustainable chemistry. Specific check lists have already been developed in a number of other projects by different authors. Most of these checklists address established case studies no innovative or R&D projects. The following checklists have been evaluated:

- The Sustainability Check of Nanoproducts ("Nano Sustainability Check") (Öko-Institut, Germany)
- The Precautionary Raster (Switzerland)
- NANOMETER (Switzerland)
- Risk Analysis and Technology Assessment (RATA, The Netherlands)
- The Guide on Sustainable Chemicals (UBA, Germany)
- Checklist Sustainability Criteria for Chemical Leasing (UBA, Germany).

For each of these tools, a short characterization is given in the following sections with information on aim, structure and (if applicable) number and type of indicators used.

5.3.1 The Sustainability Check of Nanoproducts (Öko-Institut, Germany)

The Nano Sustainability Check, provides a systematic grid for an integrated approach relative to sustainability aspects of nanotechnological applications. The approach chosen allows to serve as a strategic radar system for an internal estimation of opportunities and risks, in order to be able, for example, to anticipate beneficial effects for the environment and to identify new markets on the one hand, and on the other to strive to avoid bad investments and dangers to the society (Möller et al., 2012).

The aspects investigated within the Nano Sustainability Check are represented in the form of a total of 14 key performance indicators. The focus is on aspects of environmental and climate protection, which are – as far as possible – considered from a quantitative point of view. In addition, questions relating to the fields of occupational safety and health are examined, as well as benefit and socio-economic aspects. Due to the complexity of the issue, in many cases only a qualitative assessment is possible with view to these aspects.

Even in such cases, however, the use of specifically formulated criteria and key questions enables a transformation of the qualitative approach into a semi-quantitative, comparative assessment between Nano- and reference products.

The following key performance indicators have been selected for the Nano Sustainability Check:

- Product Carbon Footprint
- Energy Efficiency
- Exposure at workplace
- Benefits of use
- Life cycle costs
- Risks for human health and the environment
- Aspects of accidents
- Symbolic benefits beyond the benefits of the use
- Effect on work places
- Benefits for society
- Legal framework and opportunities for research funding
- Recyclability
- Resource availability
- Risk acceptance and risk awareness.

The results of the individual key performance indicators are combined into a single representation. To this purpose, the "SWOT analysis" originally derived from business administration is taken up and adapted for the purposes of the Nano Sustainability Check. The established tool of strategic management combines an inward-looking strength / weakness analysis with an opportunity / threats analysis which is related to environmental factors.

The following figure shows an example for a SWOT matrix regarding a glass sheet with a nanomaterial coating.

Figure 4: Nano Sustainability Check: example of a SWOT Matrix used to show the results of the application of the key indicators.

Source: Möller et al., 2012

5.3.2 The Precautionary Matrix for Nanomaterials (Switzerland)

The development of the precautionary matrix for products and applications that involve synthetic nanomaterials has been the core measure of the Swiss Action Plan on Synthetic Nanomaterials (from 2008)[3]. This action plan aimed to empower industry, commerce and trade to take greater responsibility in this area and to apply the precautionary principle in a goal oriented and cost-effective manner. The measures decided in 2008 for handling nanomaterials has been adapted to new findings in 2012. This also applies to the precautionary matrix.

The assessment methods for the different approval and authorisation procedures are today not tailored to nanomaterials. The precautionary matrix complements the existing non-nanospecific assessment methods with an evaluation of the risk provisions. It should therefore always be employed in parallel to the existing assessment methods and not instead of them (FOPH, 2013).

The present precautionary matrix helps businesses to assess the need for nanospecific measures (precautionary need) for synthetic nanomaterials and their applications for employees, consumers and the environment, based on selected parameters. In addition, it helps to identify potential sources of risk in the development, production, use and disposal of synthetic nanomaterials. However, this pragmatic approach should not in any way be compared with a nanospecific risk assessment process.

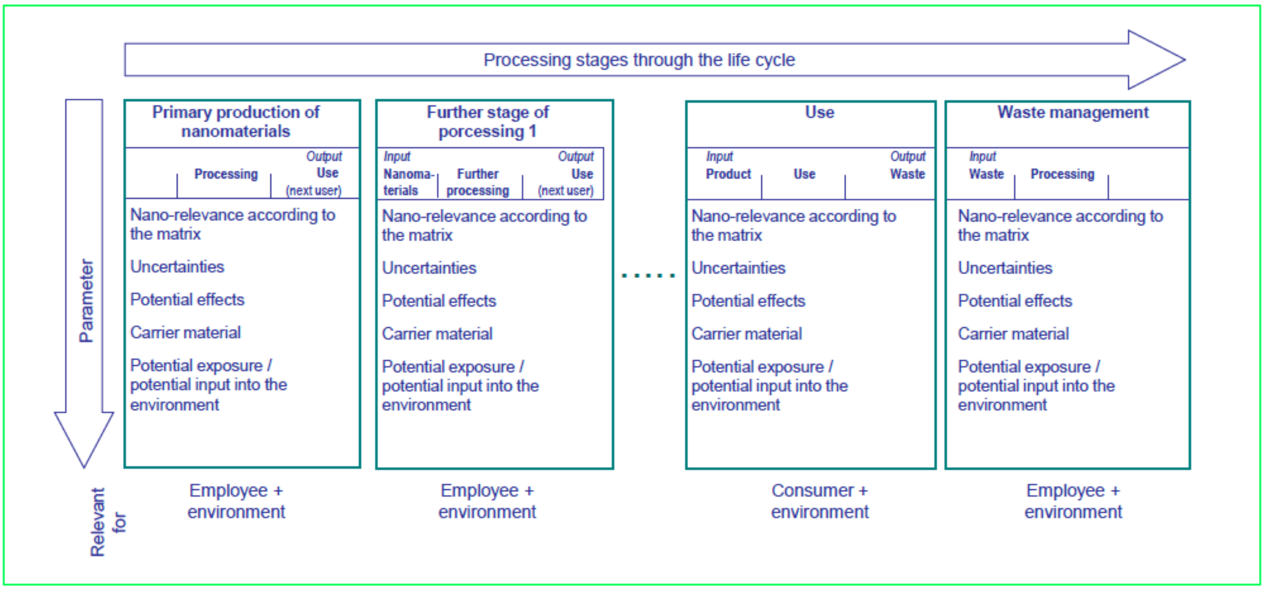
Rather, the risk potential should be classified to show what action is appropriate:

- "Class A": The nanospecific need for action for the considered materials, products and applications can be rated as low and does not need further clarification.
- "Class B": Nanospecific action is needed. Existing measures should be reviewed, further clarification undertaken and, if necessary, measures to reduce the risk associated with development, manufacturing, use and disposal implemented in the interests of precaution.

The precautionary matrix can be used to estimate the precautionary need for the health of employees and consumers and for the environment at various points of the entire life cycle of nanomaterials. The following processes in the life cycle are considered (see Figure 5):

- Research and development
- Production (including primary production, further and final processing, storage, packaging processes and transport)
- Use
- Waste management (reuse, recycling, disposal).

Figure 5: Parameters of the Precautionary Matrix for nanomaterials along the life cycle.



Source: FOPH, 2013

The Precautionary Matrix refers to a limited set of assessment criteria:

- Specific technical conditions e.g. size distribution of primary particles, potential of formation of agglomerates, deagglomeration under environmental conditions, available information regarding origin of raw materials and further life cycle steps of the assessed nanomaterial
- Potential effects, using the indicators reactivity and stability
- Potential exposure of humans (work place and consumers)
- Potential emission into the environment.

5.3.3 NANOMETER (Switzerland)

The NanoMeter is a tool for the assessment of applications that are enabled by nanotechnologies. It has been developed in the research project “observatoryNANO” from 2008 – 2012. It aims to help businesses to identify opportunities and risks of single nano applications that are currently under development or already on the market.

It covers the aspects health and environment, energy and resources, precaution, privacy as well as further ethical and societally relevant issues, i.e. issues that go beyond standard product assessments.

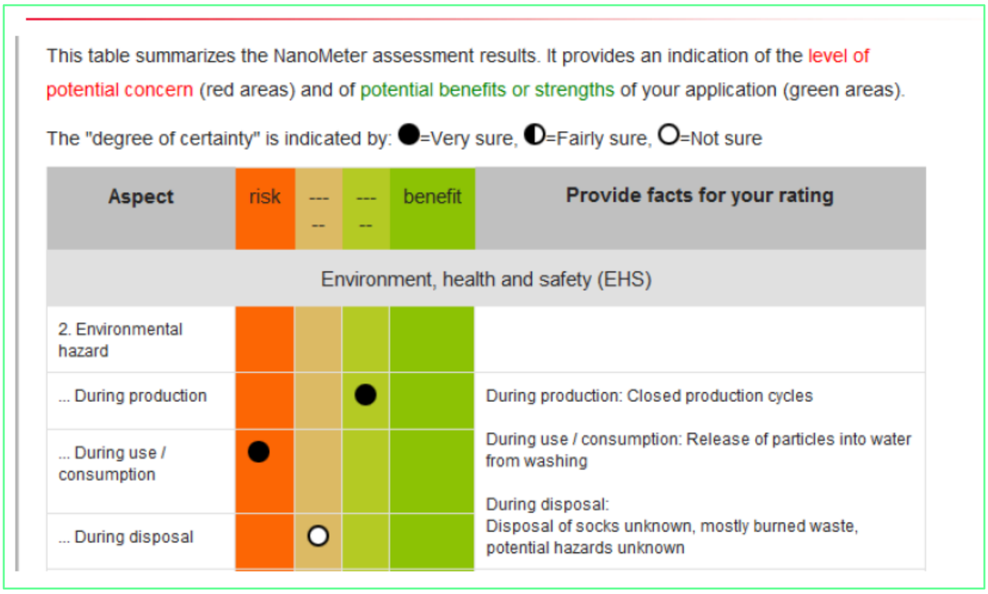
Starting from a nanotechnology-enabled product, ingredient or application, the users answer questions that guide them through relevant opportunity and risk areas. If needed, "further information" links can be followed. After about 30 minutes the users get the results, condensed in a PDF document. The use of the NanoMeter results in:

- the identification of knowledge gaps.
- an overview on aspects where the application could possibly be improved.
- a basis for measures to ensure performance, acceptance and, possibly, market success.

The purpose of the NanoMeter is to make important findings of nanotechnology research practically applicable for businesses. Many nano-applications are still under development or have just recently been put onto the market. The NanoMeter makes developers and business people understand which risks and also opportunities - that a single application may bring with it - need a closer look. The NanoMeter gives guidance to experts, offering them to make their knowledge, experiences and scientific or personal insecurity regarding a specific application more explicit.

The result of the NanoMeter does not rank an application nor can it point at risks and opportunities that are likely to come. It only highlights areas where actual knowledge, risk assessment procedures and internal business governance structures lack attention. The results are presented in a way supporting individuals to reflect on their own knowledge and practices and to enable them to easily share their findings and perceptions with colleagues or partners (ObservatoryNano, 2011). The following figure shows an example for the results obtained from the use of the NanoMeter.

Figure 6: Application of the NanoMeter: Indication of potential concerns and potential benefits or strength regarding environmental hazards.


This table summarizes the NanoMeter assessment results. It provides an indication of the level of potential concern (red areas) and of potential benefits or strengths of your application (green areas).

The "degree of certainty" is indicated by: ●=Very sure, ◐=Fairly sure, ○=Not sure

Aspect	risk	-----	-----	benefit	Provide facts for your rating
Environment, health and safety (EHS)					
2. Environmental hazard					
... During production			●		During production: Closed production cycles
... During use / consumption	●				During use / consumption: Release of particles into water from washing
... During disposal		○			During disposal: Disposal of socks unknown, mostly burned waste, potential hazards unknown

Source: Biermann, 2011

5.3.4 Risk Analysis and Technology Assessment (RATA, The Netherlands)

A specific set of questions to identify risks of new technologies on an early stage has been development in a large Dutch research project on nanomaterials. It is called RATA which stands for Risk Analysis and Technology assessment. The following table shows the structure and the key questions of RATA (van Wezel, 2018).

Table 6: Set of questions to check RATA awareness, based on the key question: What is the experience of your organization with risk analysis and technology assessment?

Risk analysis	Technology assessment
RA 1. Is your product less risky than existing products?	TA 1. Which other stakeholders, besides suppliers and customers, could you imagine?
RA 2. What are new aspects, related to already authorized products?	TA 2. How will these stakeholders be affected in both positive and negative ways?
RA 3. What is the "nano" aspect of your development?	TA 3. How does this new technology influence stakeholders' responsibilities and liabilities?
RA 4. What is the legislative framework for market introduction?	TA 4. How does this new technology influence the relationship between stakeholders?
RA 5. Are there any discussions on "nano" within this legislative framework?	TA 5. What is society missing out on, both positive and negative effects, if your idea does not reach the market?
RA 6. What do you already know on the safety aspects?	TA 6. Which different possible futures could you imagine with your development?
RA 7. Do you have any information on the intrinsic hazardous aspects?	
RA 8. Do you have information on the environmental fate and behavior?	
RA 9. Can material be released in significant quantities during the production, use, or waste phase?	
RA 10. Could you minimize emissions?	

RATA = risk analysis and technology assessment.

Source: van Wezel, 2018

5.3.5 The Guide on Sustainable Chemicals (UBA, Germany)

The Guide on Sustainable Chemicals has been developed for UBA in order to support especially small and medium sized enterprises in the selection of more sustainable chemicals (Reihlen et al., 2016). For the evaluation of sustainability of chemicals, the following eight substance-specific criteria should be used as a first step. They refer to the substance itself- regardless of the situation of use:

- Mentioning in lists of "problematic substances"
- Dangerous physicochemical properties
- Human toxicity
- Problematic properties related to the environment
- Mobility
- Emission of greenhouse gases
- Resource consumption
- Responsibility in the supply chain

By means of the colours green, yellow and red, the guide shows the results of an inspection: high need for action, indications of need for action or no evidence that the users of the guide should undertake any initiative. If data gaps appear, the colour white is chosen.

Probably, the elimination of problematic substances will not be possible in all cases. Setting out use-specific criteria, the guide provides clues as to how the use of problematic substances can be made more sustainable. Seven criteria are proposed that relate to the use:

- the emission potential
- the user groups
- the used amount
- the waste stage
- the substitution alternatives

- the benefits of a chemical / its use
- the innovation potential of a chemical / its use.

5.3.6 Checklist Sustainability Criteria for Chemical Leasing (UBA, Germany)

Chemical Leasing is a business model that focuses on the function or service provided by chemicals. In contrast to traditional business models, the user of a chemical no longer pays the supplier per kilogram, tonne or litter of chemical, but per functional unit. In order to ensure that a Chemical Leasing approach follows high quality standards, five internationally agreed sustainability criteria[16] have been formulated which shall be fulfilled (Abraham et al., 2017):

- Reduction of adverse impacts for environment, health, energy and resource consumption caused by chemicals and their application and production processes
- No substitution of chemicals by substances with a higher risk
- Improved handling and storage of chemicals to prevent and minimize risks
- Economic and social benefits are generated; a contract should contain the objective of continuous improvements and should enable a fair and transparent sharing of the benefits between the partners
- Monitoring of the improvements needs to be possible

A checklist has been developed which aims to enable enterprises to get an overview of the necessary data for to meet the Chemical Leasing sustainability criteria and highlights conflicting goals or criteria that are potentially not fulfilled. Moreover, the checklist supports those enterprises that are interested in Chemical Leasing but have not yet made experiences or have reservations towards the controllability and fairness among the business partners as it provides an overview of the quality assurance of the business model.

The indicator checklist provides an overview of the five sustainability criteria for Chemical Leasing as well as of the sub-criteria and indicators. It shall support enterprise representatives and service providers to conduct a first assessment of the indicators of their Chemical Leasing project.

A colour code ('signal lamp') denotes for every indicator whether it has been developing towards the envisaged direction of the sub-criterion (positive development is denoted in green and steady results are colour-coded neutrally) or if a parameter has shown a negative development (e.g. 'increased' = red) and therefore questions the fulfilment of the sub-criterion and requires further investigation of the (conflicting) goals and potential trade-offs. The checklist is shown in the following table.

Table 7: The Indicator Checklist on Sustainability of Chemical Leasing projects. The "signal lam" functions means: red light indicates that fulfilment of criterion is in question.

Sustainability criteria	Sub-criteria	Indicators for Chemical Leasing	Screening	Comment or specification
1	Pollutants emitted into the air	Nitrogen oxides (NO_X)	☐ decreased ☐ equal ☐ increased	
		Ammonia (NH_3)	☐ decreased ☐ equal ☐ increased	

[16] http://chemicalleasing.org/concept/sustainability-criteria

Reduction of adverse impacts for environment, health, energy and resource consumption caused by chemicals and their application and production processes		Sulphur dioxide (SO_2)	☐ decreased ☐ equal ☐ increased	
		Non-methane volatile organic compounds (NMVOC, e.g. benzene)	☐ decreased ☐ equal ☐ increased	
		Particulate matter (PM2.5/PM10)	☐ decreased ☐ equal ☐ increased	
		POPs (persistent organic pollutants)	☐ decreased ☐ equal ☐ increased	*Which one(s)?*
		Heavy metals (e.g. mercury)	☐ decreased ☐ equal ☐ increased	*Which one(s)?*
		Other emissions into the air ………………………	☐ decreased ☐ equal ☐ increased	
	Pollutants emitted in waste water	COD (chemical oxygen demand)	☐ decreased ☐ equal ☐ increased	
		BOD (biological oxygen demand)	☐ decreased ☐ equal ☐ increased	
		AOX (adsorbable organic halogen compounds)	☐ decreased ☐ equal ☐ increased	
		POPs (persistent organic pollutants)	☐ decreased ☐ equal ☐ increased	*Which one(s)?*
		Heavy metals (e.g. mercury)	☐ decreased ☐ equal ☐ increased	*Which one(s)?*
		Nitrogen compounds	☐ decreased ☐ equal ☐ increased	
		Phosphorus compounds	☐ decreased ☐ equal ☐ increased	
		Other emissions in waste water ………………………	☐ decreased ☐ equal ☐ increased	
		Waste volume (e.g. in metric tonnes)	☐ decreased ☐ equal ☐ increased	

	Volume of waste and waste water (total and hazardous waste)	Waste water (e.g. in m³)	☐ decreased ☐ equal ☐ increased	
		Tonnes or % of hazardous waste	☐ decreased ☐ equal ☐ increased	
	Energy demand during the application	kWh or MJ (separately for electric and thermal energy demand)	☐ decreased ☐ equal ☐ increased	
	Energy demand (indirect) in the supply chain	kWh or MJ	☐ decreased ☐ equal ☐ increased	
	Greenhouse gas emissions during the application	Amount of CO_2 equivalents	☐ decreased ☐ equal ☐ increased	
	Resource demand during the application	Amount of chemicals	☐ decreased ☐ equal ☐ increased	*Which one(s)?*
		Amount of water	☐ decreased ☐ equal ☐ increased	
		Amount of other resources in the supply chain in kg, m³, l (e.g. recycling)	☐ decreased ☐ equal ☐ increased	*Which one(s)?*
2 **No substitution of chemicals by substances with a higher risk**	Substitution of the chemical	Did a substitution of one or more chemicals take place (different substance or improved quality)?	☐ yes ☐ no	*If no: Continue with criterion 3*
	Material characteristics of substitutes	Safety Data Sheet (SDS) of the substitute	☐ available ☐ not available	
		Hazards for environment and health (e.g. CMR[17] substances, irritant, bio-accumulative)	☐ decreased ☐ equal ☐ increased	
		Other hazards (e.g. flammability)	☐ decreased ☐ equal ☐ increased	
	Overall risk	Altered risks due to the substitution (overall assessment and reasons)	☐ decreased ☐ equal ☐ increased	
	Available information base	Safety Data Sheets (SDS) for hazardous substances according to GHS	☐ available ☐ not available	

[17] substances classified as carcinogenic, mutagenic, or toxic for reproduction

3. Improved handling and storage of chemicals to prevent and minimise risks		Is the information actively used (e.g. is it read by workers or is there a notice at the production site or are trainings performed)?	☐ yes ☐ partly ☐ no	
	Number and extend of work accidents	Number of work accidents per year	☐ decreased ☐ equal ☐ increased	
		Severity of the work accidents	☐ decreased ☐ equal ☐ increased	
	Exposure of workers	Type of exposure (per hazardous substance, if applicable)	☐ dermal ☐ inhalative ☐ oral	
		Level of exposure, e.g. concentration of pollutants in the air in mg/m³ (separately per hazardous substance)	☐ decreased ☐ equal ☐ increased	
		Duration of exposure in min/day (separately per hazardous substance)	☐ decreased ☐ equal ☐ increased	
		Description of the measures that caused a change in the direct contact or exposure of workers to the applied chemical (e.g. personal protective equipment, air extraction are in place and in use)		
	Risk of accidents resulting from the application of chemicals	Change of risk	☐ decreased ☐ equal ☐ increased	
		Description of the reasons for the changed risk (e.g. performance of hazard or risk assessments, availability of operating instructions for applying the chemical, derivation and implementation of measures, probability and severity of accidents, prevention measures)		
	Risk of accidents resulting from the storage of chemicals	Change of risk	☐ decreased ☐ equal ☐ increased	
		Description of the reasons for the changed risk (e.g. provision of instructions for the proper (and combined) storage and handling (e.g. for delivery, application) of the provided chemical by the supplier, derivation and implementation of measures, probability and severity of accidents, prevention measures)		
	Costs for the user	e.g. €/year	☐ decreased ☐ equal ☐ increased	

4 Economic and social benefits are generated; a contract should contain the objective of continuous improvements and should enable a fair and transparent sharing of the benefits between the partners		If possible distinguish between costs for chemicals, maintenance, energy demand, complaints, etc.		
	Economic performance of the supplier	e.g. €/year	☐ improved ☐ equal ☐ decreased	
		Description of the changes in business relations with customers (e.g. sole supplier, long-term planning security)		
	Business opportunities	New customers or sales opportunities?	☐ yes ☐ no	
		New fulfilment of requirements for labels, certificates, etc.?	☐ yes ☐ no	
		New business developments or innovations?	☐ yes ☐ no	
	Qualification of employees	Hours for training and education per employee per year (possibly including the topic) or description of changes in personnel structure and/or costs	☐ more training/ qualification ☐ equal	
	Creation of new jobs	Number of jobs that are related to the application at the user side	☐ more ☐ equal ☐ less	
		Number of jobs that are related to the application at the supplier side	☐ more ☐ equal ☐ less	
5 Monitoring of the improvements needs to be possible	Measurement of the indicators for the criteria 1-4	Are the relevant parameters monitored?	☐ yes ☐ partly ☐ no	
		Is an improved monitoring process established?	☐ yes ☐ partly ☐ no	

Source: Abraham et al., 2017

6 Evaluation of case studies on sustainable chemistry

A series of case studies on sustainable chemistry has been developed and described within the project and assessed using the assessment scheme for sustainable chemistry. The case studies will be used by the German Environment Agency as starting point for the publication of a brochure on sustainable chemistry.

6.1 The assessment scheme for sustainable chemistry

As mentioned in chapters 3.4 and 4.3, a holistic assessment scheme for sustainable chemistry has been elaborated by UBA based on the preliminary work of this project. The chapters already summarised the assessment scheme regarding

- the relationships and overlaps between sustainable chemistry, the sound management of chemicals and waste, green chemistry and sustainable development (chapter 3.4); and
- the goals and spheres of activity of sustainable chemistry (chapter 4.3).

The document comprises over 70 pages describing the context of sustainable chemistry in sustainable development and how case studies can be assessed regarding the fulfilment of goals of sustainable chemistry. In addition, the document entails a list of case studies that will be developed for the brochure by UBA. In the course of this project, several case studies have been identified, described and analysed by the project team to contribute to the brochure (see next chapter).

6.2 Case studies on sustainable chemistry

The development of case studies was conducted in two different phases. At first, UBA and BMU followed the call of UNEA Resolution 2/7 that invited stakeholders with experience in sustainable chemistry to submit best practice examples to the United Nations Environment Programme (UNEP) secretariat. The second phase included the elaboration of case studies using the advanced assessment scheme described above as well as the provision of further details on selected case studies from phase one.

6.2.1 Case studies to contribute to the call by UNEA Resolution 2/7

In 2016, UNEA Resolution 2/7, paragraph 20, invited stakeholders with experience in sustainable chemistry to submit best practice examples to the UNEP secretariat. BMU and UBA followed the call together with the project team by developing and submitting a total set of eleven best practice examples from different industrial and economic sectors. Five of these examples were prepared in the frame of this project; both in a word and brochure version. The case studies shall indicate "how these may enhance the sound management of chemicals, inter alia through the implementation of the 2030 Agenda for Sustainable Development, as well as the Strategic Approach to International Chemicals Management and chemicals- and waste-related multilateral environmental agreements" (UNEP, 2016a, paragraph 20, p. 4).

The case studies were to meet several criteria. These included that the examples shall come from industrialised, newly industrialising and developing countries, and should have a connection to Germany. Different industrial and economic sectors should be covered, and the examples had to show the contribution of sustainable chemistry to the implementation of the 2030 Agenda. The following variants were possible:

- Cases of successful chemical and non-chemical alternatives introduced to the market
- Cases of broad research and development initiatives

- Cases of successful business models and company start-ups
- Cases on the reform of chemistry curricula
- Broader initiatives by governments, non-governmental organisations or the private sector, including the retail sector

The documentation of the case studies was structured as follows:

1. Abstract
2. Process introduction/product description
3. Chemical life cycle
4. Sustainability assessment
    a. Environmental assessment
    b. Economic assessment
    c. Social assessment
    d. Assessment of future significance: the 2030 Agenda; including core targets and indirect targets addressed by the example
5. Green chemistry, sound management of chemicals and waste and sustainable chemistry
6. Literature/background information

The following five case studies were elaborated by the project team and are provided in Annex 2 to this report.

- 3M Up-Cycling (Chemical Recycling) of PTFE
- Coop: Functional substitution of PFC-coated food wrapping by a PFC-free material
- KILIAN: long-term exposure reduction by functional, non-regrettable substitution/vegetable oil-based esters for removal of protection layers
- Prometho GmbH: Production of a safe and sustainable ink - GrüneTinte® (green ink)
- PERO Innovative Services & SAFECHEM: Cleaning of metal parts.

6.2.2 Case studies to examine the assessment scheme

As stated above, UBA is currently working on a brochure on sustainable chemistry that shall include the assessment scheme as well as case studies that have been evaluated using this scheme. The selection of case studies for the brochure was performed by UBA directly. Ten German and ten international examples have been selected to be included after a first evaluation provided that they address different aspects or levels of sustainable chemistry and sufficient information was available for their thorough analysis. Although there were no absolute exclusion criteria, ten examples were not included after extensive discussion due to various points (e.g. use of bio-raw materials and possible competition with foodstuffs, lack of reference to the chemical industry, toxicity of the substance or upstream chain, lack of information, etc.). In general, the search for sufficient information for the holistic evaluation using the evaluation scheme turned out to be very resource- and time-consuming. This occasionally led to the exclusion of examples in order to avoid an assessment based on incomplete information and thus the risk of misinterpretation of the example.

For the selection of the case studies, particular attention was paid to ensuring that all three dimensions of sustainability are addressed by the example. All selected examples contributed to the ecological and economic goals of sustainable chemistry, but it has proven to be challenging to find projects that enable significant social sustainability. The second priority in the selection of the case studies was to address as many of the four ecological goals of sustainable chemistry as possible. Beyond that, the contribution to compliance with the exceeded planetary boundaries was a selection criterion, whereby the parameters for global climate and biosphere-integrity can be considered the most important ones, forming the overarching stabilising system of the earth. Of major importance are also those systems, where the planetary boundary is certain to be crossed, such as the genetic diversity and the biogeochemical fluxes. As fourth priority, topics outlined in the UBA study “Identification of Priority Topics in the Field of Sustainable Chemistry” should be covered evenly by the case studies (UBA, 2018b; p. 19f).

Compared to the case studies described under 6.2.1, this phase aimed at the application of the assessment scheme and on putting the examples into a broader context, pointing at the single aspects of green chemistry, sound management of chemicals and waste as well as sustainable chemistry. The project team further investigated the performance of the single case studies with regard to the SDG and the planetary boundaries; following the structure of the scheme. For each case study, the project team also described the context and the process or application. The case studies are available as separate documents and are attached to this report in Annex 2.

The following three case studies have been elaborated:

- Aurubis: Recycling of WEEE[18]
- BASF: Use of pheromones in agriculture
- Tärnsjö Garveri: Vegetable leather tanning

In addition, four out of the five case studies descried in chapter 6.2.1 will be part of the brochure. The remaining case studies are developed by the German Environment Agency and cover the following topics:

- Acidification of manure in agriculture: reduction of ammonia emissions
- Aquafil/Desso: Cradle-to-cradle concept for carpets
- BASF: Fair-trade programme in Morocco yielding argan oil
- Clariant: waste water treatment NITREA
- Covestro: Cardyon™ CO_2 utilisation
- CRI: methanol synthesis from CO_2 and H_2
- Danisco: substitution of PCV plasticisers
- Dow/BASF: Hydrogen Peroxide Propene Oxide-Prozess
- Exxon/ITQ Valencia: optimised ethene separation
- LanzaTech: ethanol production with CO
- Noventura: SF6-free switchboards
- RecyCoal: Production of coal briquettes in Africa
- Remondis: phosphate recycling from sewage sludge (TetraPhos®)

The brochure shall be available on the UBA website and specify the sustainable chemistry concept and stimulate discussion with actors at various levels. Among others, companies should feel encouraged to submit their examples and contributions to sustainable chemistry and have them evaluated/self-evaluate them using the assessment scheme. Therefore, the current selection does not claim to be complete or cover all sectors of the chemical(-related) industry, but rather comprises a selection made with a certain arbitrariness, which is intended to inspire actors in all areas to develop further examples.

[18] WEEE = waste electric and electronic equipment

7 Verification of the scheme and the case study assessments with stakeholders

Within this project on sustainable chemistry in international management of chemicals and waste, the project team conducted one internal expert discussion with representatives from selected authorities and organisations as well as one expert discussion aiming at a wider audience from different stakeholder groups on the assessment of case studies on sustainable chemistry and the underlying assessment scheme. Both expert discussions took place in Berlin.

In this context, the project team also worked on the elaboration and assessment of three case studies on sustainable chemistry that were discussed on the second expert talk in September. In addition, the expert team revised information about previously developed case studies on sustainable chemistry.

This chapter summarises the results of the work in regard to the expert discussions and the case studies on sustainable chemistry.

7.1 Expert discussions on sustainable chemistry

7.1.1 First expert discussion

The first of the two scheduled expert discussions on sustainable chemistry took place on 19 April 2018 in Berlin in the Ramboll office. The following table provides further information about the organizational details of the event. The event was conducted in German; thus, some information such as title and agenda are provided in German.

Title	FACHGESPRÄCH Diskussion von Fallbeispielen zur nachhaltigen Chemie (NC)
Date and time	Thursday, 19. April 2018: 10.00 – 16.00
Place	Ramboll-Büro Berlin, Saarbrücker Str. 20/21, 10405 Berlin
Agenda	See Annex 3
Participants	13 participants; for details see Annex 3
Outcome	See Annex 3

The aim of the event was to conduct an internal expert discussion (German and Austrian authorities and experts directly engaged in the development and discussion about sustainable chemistry on the German level) to examine previous work in the field of sustainable chemistry, to consolidate the concept of sustainable chemistry and to identify potential areas for improvement with regard to the results to date.

The minutes of the meeting are available in the Annex 3 to this report and describe the outcome in detail. Overall, it can be summarised that the event successfully engaged different experts and included a fruitful discussion on the assessment scheme and the selection of the case studies. Feedback gained from the discussion was included in the next considerations (e.g. trying to reflect a larger number of smaller companies and start-ups in the case studies). Also, specifications to the description and assessment scheme have been made as a follow-up to the discussions.

It was agreed that the next step shall include a similar discussion and presentation of the scheme and its application to experts from different stakeholder groups, including industry, academia and civil society. Thus, the second expert discussion took place.

7.1.2 Second expert discussion

The second expert discussion on sustainable chemistry took place on 10 September 2018 at the UBA premises in Berlin (Bismarckplatz). The event also aimed at discussing the assessment scheme for sustainable chemistry based on selected case studies – this time with a wider audience and participants from different stakeholder groups. The following table provides further information about the organisational details of the event. Registration to the event was done using a website (see here), which also contained the agenda and e.g. travel information to the event.

Title	FACHGESPRÄCH Nachhaltigkeitsbewertung von Fallbeispielen zur nachhaltigen Chemie
Date and time	Monday, 10 September 2018, 10.00 – 16.00 h
Place	Umweltbundesamt / German Environment Agency, Bismarckplatz 1, 14193 Berlin
Agenda	See Annex 4
Participants	29 participants; for details see Annex 4
Outcome	See Annex 4

The aim of the event was to conduct an expert discussion with a broader group of stakeholders including representatives of the Federal Environment Agency, (chemical) companies, NGOs, consultancies and academia. The event aimed at discussing the concept of sustainable chemistry and in particular the assessment scheme for case studies on sustainable chemistry. On the basis of four case studies, the applicability of the assessment scheme was discussed in separate groups. The following four case studies were discussed in the individual working groups:

1. CO_2 utilisation for polyurethane synthesis
2. Phosphate recycling from sewage sludge
3. Use of pheromones for pest control in agriculture
4. Vegetable leather tanning.

Details about the discussion are provided in the minutes of the meeting in Annex 4. Overall, the participants found the assessment scheme and the concept for sustainable chemistry very helpful and advanced. Aspects such as a very clear communication of the aim of the assessment and the boundary conditions considered for the assessment of a case study still need to be improved. UBA will continue its work on the assessment scheme based on the valuable inputs from the expert talk.

8 Conclusions and next steps

In order to maintain the biological, chemical and physical stability of the earth, the economic and social activities of the world's population must be adapted and fundamentally transformed. As a starting point, global society becomes aware of its responsibility for future generations and pays attention to the model of sustainable development in all its actions.

Chemistry, and the chemical industry in particular, can make a substantial contribution to this fundamental transformation process, changing the current economic practices and social habits. The implementation of the concept of sustainable chemistry can be seen as an intersection of traditional chemistry and sustainable development. By integrating the three sustainability dimensions of economic productivity, social balance and ecological efficiency, the concept can be defined more in detail, which is crucial for the provision of the concept with commitment and orientation. To this end, it is necessary to clarify what sustainable development is and what objectives and principles constitute sustainable development. This clarification is necessary because no internationally recognised understanding of sustainability has yet been established.

This project aimed at contributing to this understanding and supporting UBA in its work to further advance the understanding and evaluation of the concept of sustainable chemistry.

As described in the previous chapters, extensive preparatory work has been carried out in the field of sustainable chemistry in the course of this project in order to further develop the assessment scheme for sustainable chemistry elaborated by UBA. This preparatory work comprised detailed analysis of the landscape of sustainable chemistry, listing e.g. initiatives in this field, developing criteria based on key goals for sustainable chemistry, such as SAICM, the 2020 goal and the SDG. Moreover, relevant sectors and international environmental goals as well as existing means to evaluate chemical processes or products have been analysed by the project team to generate input to UBA's work on the advancement of the sustainable chemistry description and scheme.

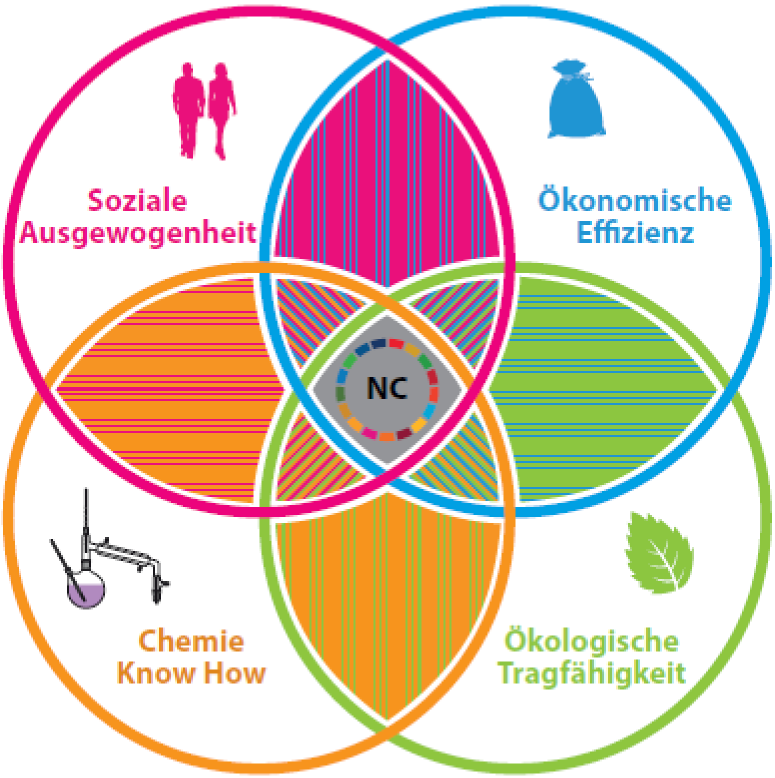
The scheme obtained was then verified by assessing case studies from different chemical industry sectors and discussed both on an internal workshop with representatives from UBA and BMU amongst others, and on an external expert discussion with national and international stakeholders (see chapters 7.1.1 and 7.1.2).

As depicted in Figure 7, the result of the extensive discussions on sustainable chemistry is an interception of those topics that have a chemical, ecological, economic and social aspect. Only those topics that address all of these dimensions can be considered a part of sustainable chemistry.

In this context is shall be mentioned that it was difficult to identify projects with a clear reference to social aspects. This is particularly important because many stakeholders recognise sustainable chemistry as a contribution to sustainable development. However, sustainable development has a pronounced social dimension - the majority of the 2030 Agenda targets clearly describe social goals. Therefore, in case the chemical industry or other actors in the field of chemistry want to contribute convincingly to sustainable global development, projects should be supported that also show a clear social dimension. In general, participation of developing countries in sustainable chemistry projects would be desirable, since such activities typically provide clearly positive impetus in all dimensions of sustainable chemistry (UBA, 2018b).

As a major outcome following this project, UBA will develop a brochure containing case studies of sustainable chemistry processes, applications and products. They will be assessed regarding their contribution to sustainable chemistry following the developed assessment scheme. This brochure shall motivate further companies and stakeholders to apply the assessment scheme to their chemical processes and application in order to examine the sustainability and to identify weaknesses as well as potentials for improvement. Also, the work shall support the dissemination of successful examples of sustainable chemistry and encourage enterprises to engage in this topic.

Figure 7: Sustainable chemistry (NC) as interception between chemistry, economy, social aspects and ecology.



Source: UBA, 2018b

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Annex

Several documents are provided together with this report:

1. Partial description and assessment scheme used for the case studies (see chapter 4.3 and 6.1)
2. Case studies as described in chapter 6.2
3. Minutes of the first expert discussion on 19 April 2018, including agenda and list of participants
4. Minutes of the second expert discussion on 10 September 2018, including agenda and list of participants