position paper

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FRIENDS OF THE EARTH GERMANY

Challenges for a Sustainable Chemicals and Materials Policy

The need for transformation in a global context

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In memoriam Karl Otto Henseling

Content

Executive summary

Over the past decades the use of natural resources and the production of chemicals have increased dramatically – and a further increase is forecasted. Whereas earlier the main focus was on local effects on health and the environment, in the meantime it has become apparent that current ways of dealing with raw materials, chemicals and products manufactured from chemicals are threatening the biosphere as a whole. Due to the massive human interventions since the beginning of the industrial age, the earth has left the stable phase of the Holocene and has entered a new earth-historical period, the Anthropocene.

In 2009 and 2015 scientists introduced the concept of planetary boundaries. As part of this framework nine areas were defined in which human activities are threatening the Earth system. With the greenhouse gases causing climate change, the acidification of the oceans, damage to the ozone layer, atmospheric aerosol loading, biogeochemical flows of phosphorus and nitrogen as well as "novel entities" six of these boundaries relate to the use of resources as well as the use of chemicals and to their emissions.

The analyses show that the economic activity of humans today and current lifestyles are unsustainable and exceed the limits of our Earth system. The trends in global consumption of natural resources and energy indicate that increase is accelerating. No reversal of the trend is in sight. Humanity has already left the safe operating space.

The planetary boundary "Novel entities" has also already been exceeded. An estimated 350,000 different chemicals are produced worldwide. These include plastics, pesticides, industrial chemicals, chemicals in consumer products, antibiotics and other pharmaceuticals. These are often completely new substances that do not occur naturally, but are created as a result of human activities, and their impact on the Earth system is still largely unknown. Many of these chemicals have been stable in the environment for centuries. The examples of chlorofluorocarbons (CFCs), per- and polyfluorinated alkyl substances (PFAS) and of plastics show that substances and materials which were originally assumed not to be hazardous can also cause considerable problems. Once released into the environment these "forever chemicals" can only be retrieved again – if at all – with great difficulty.

It was already recognized in the 1970s and 1980s that taking action only when the effects of substances in the environment have been proven beyond any doubt can be too late. That is why the precautionary principle was anchored in national and international law. Based on this, measures for preventing damage should be implemented as soon as there is legitimate reason for concern. However, "business as usual" continues to be the most common rule for action. Measures have been and still are only adopted after years of delay during which damage has already occurred.

It is quickly becoming clear: We need new approaches. Mostly it is not enough to assess one chemical on its own. Contextual thinking and action are needed. The interactions among different chemicals and other stress factors – such as the changing climate, losses of biodiversity and impacts on human health – must be taken into consideration. The global dimension of material flows must be considered as well. We need a national and global chemicals and materials policy that faces these challenges.

This Friends of the Earth (FoE) Germany (Bund für Umwelt und Naturschutz Deutschland BUND) position paper "Challenges for a Sustainable Chemicals and Materials Policy – the Need for Transformation in the Global Context" presents ways for successfully introducing a sustainable chemicals and materials policy. Examples: Persistent substances should not be released to the environment and substantially fewer toxic chemicals should be produced. Where possible, fewer chemicals should be used. If a chemical or

product is necessary to be used, this should be done as efficiently as possible – in other words, with a high level of benefit. At the same time, reuse of chemicals and materials by closing the material cycles should be considered. The ultimate goal is an efficient circular economy.
The statutory regulations for chemicals, product and waste legislation must share a common basis and be closely coordinated with each other. This must be taken into account in the upcoming revision of the EU REACH Regulation. A consistent implementation of the EU "Chemicals Strategy for Sustainability" is necessary.

A sustainable chemicals and materials policy must also encompass all areas of life such as mobility, housing and construction, nutrition, clothing and consumption. It thus goes far beyond traditional chemicals policy and, similarly to climate policy, requires a comprehensive transformation of economic activity and consumer behaviour. In this regard, chemicals policy is closely related to protecting resources and safeguarding climate and must be conceived and implemented while considering such protection.

This position paper shows: Chemicals policy must be developed with a stronger focus on precautionary action and sustainability. At the international level this means using the Sustainable Development Goals (SDGs) of the United Nations as a benchmark. In assessing chemicals, persistence must be consistently regarded as the core hazard. A central goal is to develop and use sustainable chemicals which in particular are neither persistent, bioaccumulating, (eco)toxic, nor highly mobile. Sustainable chemicals and materials policy also requires a reduction in the global burden of chemicals and the overexploitation of resources through sustainable material flow management.

In the final chapter, "Guiding principles for chemicals and materials policy – Recommendations by Friends of the Earth Germany", all the guiding principles and recommendations worked out in the previous chapters are summarized. The area of "chemicals and materials policy" is presented in its broader context and measures for achieving the goals are presented. This also includes recommendations regarding research and education policy on substances.

This position paper

- demonstrates that substances have effects at the planetary level, which – in a manner similar to climate change and loss of biodiversity – are threatening the ecological balance of the entire planet;
- underscores that persistence represents a central hazard that must be systematically addressed. It is comparable to nuclear energy with its radioactive waste or to carbon dioxide in climate change, which also create long-term problems;
- focuses on the precautionary principle and a sustainable material flow management with special emphasis on sufficiency as a solution measure;
- identifies essential elements of sustainable chemistry;
- derives that legally binding international agreements are needed. A future global framework convention on sustainable management of substances, materials and resources should link the regulations on chemicals, pollutants, resources and hazardous wastes, while setting binding reduction targets.

With this position paper FoE Germany wishes to stimulate discussions on a new sustainable chemicals and materials policy.

1. Introduction

"Chemicals policy": The FoE Germany Federal Working Group on Environmental Chemicals/Toxicology coined this term as early as 1983. In the first issue, published in 1984, of the "Informationsdienst Chemie und Umwelt" (Information Service on Chemistry and the Environment), then published by FoE Germany and the Federal Association of Citizens' Initiatives for Environmental Protection (BBU), it says ([1], cf. also [2]):

> *"It is almost unbelievable that the regulation of chemical use is not a policy area in its own right, despite the serious environmental problems. There is, of course, an economic policy, a social policy, an agricultural policy – but no chemicals policy."*

Today, there exists a "chemicals policy": disasters such as in Seveso, Italy, in 1976 (Icmesa), in Bhopal, India, in 1984 (Union Carbide India Limited) and in Schweizerhalle, Switzerland, in 1986 (Sandoz) triggered a discussion on chemicals policy. In the meantime, European and German laws have been passed to protect against risks from chemicals. On the one hand, the results are impressive: Many chemical companies have been producing more safely since then. With the "Responsible Care" initiative, the chemical industry is committed to its responsibility for the safety of its production and products. Laws have also been improved: The EU chemicals regulation REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals) [3] for the first time obliges manufacturers and importers to prove on the basis of data that all their chemicals are safe for humans and the environment (applies to annual production quantities greater than 1 tonne per year). The German Federal Immission Control Act (Bundes-Immissionsschutzgesetz) regulates, among other things, the production and handling of chemicals in industrial plants. On the other hand, the exposure of humans and the environment to chemicals has actually increased in some cases and is now a global problem.

In the western industrialised countries, the concentrations of some pollutants in humans and in the environment have decreased, and technical environmental protection and some legal regulations are having an effect. Nevertheless, current chemical analysis is detecting more and more problematic chemical substances in the environment, in food and in humans, and in this way makes clear that there is still a considerable need for action. Both the micro-pollutant strategy of the FoE Germany (July 2017) [4] as well as that of the German Environment Agency (Umweltbundesamt) (April 2018) [5] show how necessary it is to take action against the multitude of chemicals in the environmental media. Furthermore, chemical production is constantly increasing worldwide. In particular, the sheer volume of plastic production endangers entire ecosystems.

The complexity of substances in consumer products is also increasing. The transparency of the ingredients of products remains poor. The same applies to many modern products such as electronic items or cars, which nowadays consist of a multitude of complex materials and building blocks. This makes reuse, repair and recycling difficult or impossible. Many valuable raw materials are lost in this way. The rapid increase in global material flows poses new challenges for chemicals and materials policy. New approaches that are considered viable, such as Power to X[1] or the use of renewable resources, have not yet been determined in terms of their real contribution to greater sustainability (see section 7.3).

After a review of over 60 years of chemicals discussion (chapter 2), we look at the guiding principles of a sustainable chemicals and materials policy (chapter 3) and devote ourselves to the global dimension of chemicals policy (chapter 4). In the EU, REACH is the central legal norm for chemical safety with significant progress and some weaknesses (chapter 5). In chapter 6 we discuss the importance of persistence

[1] Power to X refers to processes that use (renewable) energy to produce gaseous and liquid basic materials from carbon dioxide (CO_2) and hydrogen (H_2).

and other substance-related hazards before turning to the quantitative aspects of sustainable material flow management in chapter 7. In chapter 8, sustainable chemistry is presented as a solution approach. Finally, we present FoE Germany's guiding principles and recommendations for a sustainable substance policy (chapter 9).

2. A look back at more than 60 years of debate on chemistry

The debate about chemicals has changed. In the middle of the last century, the permeation of our lives with chemistry was still in its infancy, as was the chemicals policy debate. This changed in the early autumn of 1962, when Rachel Carson published the book "Silent Spring" in the USA [6]. In her book, the biologist compiled facts about the use of pesticides. That is now more than 60 years ago, but many of the issues she raised are still so topical today that the Leopoldina Academy of Sciences has given the same title to its discussion paper on pesticides [7].

Already in the 1960s and 1970s, resistance to the dangers of chemicals was growing. Environmental protection groups and local initiatives fought against the effects of environmental pollution and for clean production, use and disposal of chemical substances, and generally for a safe life in a world increasingly polluted with chemicals.

At the beginning of the 1980s, FoE Germany experts first started to think about this issue in principle. In 1983, the FoE Germany Federal Working Group on Environmental Chemicals and Toxicology coined the term "chemicals policy". In 1984, the tenth position paper of FoE Germany was published with the title "Chemicals policy – FoE Germany calls for a new policy area" [2]. It contains the following three chemicals policy guiding principles:

- A minimisation requirement should apply both to the extraction of raw materials from the environment and to the introduction of substances into the environment (sufficiency).
- The circularity principle is intended to give priority to the return of products or the recovery of substances.
- The aim is to develop an ecological design for substances. This means that – as far as possible – chemicals should be used that can be integrated into natural material cycles when released.

Further publications of the Federal Working Group, e. g. on chlorine chemistry, followed ([8] – [11]).

In 1999, the German Environment Agency also described fields of action and criteria for a precautionary sustainable substance policy [12]. Among other things, the following environmental action goals, which are still relevant, are mentioned:

- The irreversible input of persistent and/or bioaccumulating foreign substances into the environment must be completely avoided, regardless of their toxicity.
- Substance inputs into the environment are to be avoided irrespective of previously identified effects and other intrinsic[2] properties if retrievability is practically impossible due to high distribution and/or low exchange (minimisation requirement).

Another impetus to address global exposure to chemicals was the publication of Theo Colburn's book "Our Stolen Future" in 1998, which drew attention to the effects of endocrine disrupting chemicals and their impact on fertility [13].

The debate has evolved since then. Today, it no longer focuses only on chlorine chemistry, but for example on substances that have a harmful effect on the endocrine system (endocrine disruptors), are persistent in the environment over long periods of time (persistent), accumulate in living organisms (bioaccumulative) or can spread over long distances (mobile). The protection of biodiversity is a central objective, along with the protection of human health.

The global distribution of released chemicals and plastics, even far from their places of origin, prove that a sustainable chemicals and materials policy is needed worldwide. This challenge is reflected in the Sustainable Development Goals (SDGs) of the United Nations (2015) ([14], [15]).

[2] Intrinsic properties are properties that belong to the object itself and make it what it is.

Over the past 25 years, it has also been increasingly recognised that the burdens on people and the environment can best be reduced when material flows are analysed and controlled, as environmental burdens increasingly arise from resource extraction, the products themselves and their disposal as waste after the end of their useful life. Today, materials policy is closely linked to resource, product and waste policy. A circular economy is therefore also a materials policy challenge.

3. Guiding principles of a sustainable chemicals and materials policy

The difficulty in finding guiding principles for a sustainable chemicals and materials policy lies in the fact that trade-offs have to be made. The production, use and disposal of synthetic chemicals must be designed in such a way that negative consequences for humans and the environment are avoided as far as possible. However, non-synthetic processes without synthetic chemicals are not always to be preferred. These can have significant disadvantages in terms of energy input, material consumption, effectiveness or health effects. A sustainable chemicals and materials policy thus goes beyond a mere chemicals policy. It encompasses the entire life cycle of products and the substances used in them. It also considers the substitution of problematic substances, the closure of material cycles and the significant reduction of the use of substances and energy. Achieving the Sustainable Development Goals (SDGs) formulated by the United Nations in 2015 is unthinkable without sustainable chemistry. This applies, for example, to renewable energy generation and storage, clean water, hygiene and health, mobility or corrosion protection.

Two guiding principles characterise a sustainable chemicals and materials policy: the precautionary principle and sustainability:

3.1 Precautionary principle

As early as 1986, the German Federal Government published guidelines on the precautionary principle [16]. According to these guidelines, environmental precaution encompasses all actions,

- which serve to avert concrete environmental hazards ("hazard prevention"),
- which serve to avoid or reduce risks to the environment in advance of hazard prevention ("risk prevention"),
- which proactively shape our future environment, in particular the protection and development of the natural foundations of life ("provision for the future").

Precaution is based on the one hand on the limited knowledge about the environment and the effects of substances, and on the other hand on the claim to preserve room for manoeuvre for the future.

In the international arena, this guiding principle is also reflected in numerous documents and treaties. In 2000, for example, the European Commission published a communication on the precautionary principle [17]. In Agenda 21 Ch. 35 Para. 3 of the United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro 1992 [18] states in this regard:

> *"In the face of threats of irreversible environmental damage, lack of full scientific understanding should not be an excuse for postponing actions which are justified in their own right. The precautionary approach could provide a basis for policies relating to complex systems that are not yet fully understood and whose consequences of disturbances cannot yet be predicted."*

The International Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR) in article 2 [19] described the principle in 1992 as follows:

> *"The Contracting Parties shall ... take all possible steps to prevent and eliminate pollution and shall take the necessary measures to protect the maritime area against the adverse effects of human activities so as to safeguard human health and to conserve marine ecosystems and, when practicable, restore marine areas which have been adversely affected. ...*
> *The Contracting Parties shall apply:*
> - *the precautionary principle, by virtue of which preventive measures are to be taken when there are reasonable grounds for concern that substances or energy introduced, directly or indirectly, into the marine environment may bring*

about hazards to human health, harm living resources and marine ecosystems, damage amenities or interfere with other legitimate uses of the sea, even when there is no conclusive evidence of a causal relationship between the inputs and the effects;
- *the polluter pays principle, by virtue of which the costs of pollution prevention, control and reduction measures are to be borne by the polluter."*

According to the precautionary principle, action must be taken as soon as there are "reasonable grounds for concern". Although the precautionary principle has found its way into numerous national, European and international regulations and is supposed to be a binding guiding principle, it is too rarely implemented consistently in chemicals policy action. The publications of the European Environment Agency "Late Lessons from Early Warnings" from 2001 and 2013 ([20], [21]) cite numerous examples of insufficient compliance with the precautionary principle (e.g. PCBs, DDT, CFCs, bisphenol A).

Precaution is always also about avoiding theoretically possible and reasonably suspected – and not (as in the case of hazard prevention) merely sufficiently probable – environmental damage. That is:
- Precaution means that any suspicion of a harmful effect should be investigated and appropriate measures taken even before the threshold of harmfulness is reached.
- Precaution requires a sufficient safety margin from the threshold of harmfulness.
- Precaution occurs when, in the case of risks that are delayed, the subsequent occurrence of damage cannot be ruled out with sufficient probability.
- Precaution can already require risk reduction when causal, empirical or statistical effect relationships are not yet completely known or proven.
- Prevention begins with environmental pollution that is not dangerous on its own, but can be harmful or avoidable in combination with other stressors.

Compliance with statutory limit values, which merely serve to protect against hazards, does not therefore satisfy the precautionary principle ([22], [23]). The precautionary principle is linked to the formulation of concrete environmental quality and action objectives to be achieved. In this respect, it is also linked to the minimisation requirement, which aims at a general improvement of the environmental situation.[3] Therefore, limit values must not be understood as maximum values that may be exploited. New scientific findings can also lead to lower limit values.

It is therefore important, even for substances that are currently considered unproblematic, to fundamentally reduce the quantities of substances entering the environment. This applies in particular to substances for which delayed and as yet unknown effects cannot be ruled out – even if such substances occur naturally (biogenically or geogenically) in the environment. A reduction in the quantities of substances is also necessary because further resources, including energy and water, are required for their use.

The OSPAR Convention also refers to the polluter-pays principle, as do the EU treaties and the German Federal Government's environmental policy. According to this principle, the costs of preventing and eliminating environmental damage must be borne by the polluter. In many cases, the respective polluters cannot be clearly identified, which is why the costs are passed on to the general public. The polluter pays principle also justifies fee regulations (in Germany, for example, the sewage fee). However, the legislator rarely makes use of this possibility. An extended producer responsibility of the industry also includes that it pays for damages caused by its products that are detected later (e.g. contaminated sites with fluorochemicals, costs for wastewater treatment for pharmaceuticals).

3 According to Art. 191 (1) of the Treaty on the Functioning of the European Union (TFEU) [24] improving the quality of the environment is an objective of the EU.

3.2 Sustainability

With the United Nations Conference on Environment and Development (UNDP) in Rio de Janeiro in 1992, the international community declared sustainable development to be a binding goal of global environmental and materials policy. Since then, sustainability has been anchored as a guiding principle in numerous national and international documents. Sustainability means meeting the needs of the present generation without compromising the opportunities of future generations. This is intended to achieve both intragenerative (within a generation) and intergenerative (between generations) justice (for the relationship between sustainability and environmental justice, see box "Environmental justice – an essential element of sustainability" on next page). Closely related to sustainability is also the concept of resilience, i. e. the ability of ecosystems to return to their original, stable state after disturbances.

Sustainable development is often divided into ecological, economic and social, with the ecological aspects describing the fairway (or guardrails) within which economic and socially equitable development can take place [25]. Many people in politics and business talk about sustainability without acting on it. The fairway is getting narrower and narrower; the current global development blatantly contradicts the requirements for sustainable development that still allows room for manoeuvre.

In 2001, the German Federal Government established the German Council for Sustainable Development as an advisory body for sustainable policies [26]. The German Environment Agency with its publications of 1998 and 2002 on a "Sustainable Germany" (Nachhaltiges Deutschland) ([27], [28]) as well as the FoE Germany with its studies "Future-proof Germany" (Zukunftsfähiges Deutschland) ([29], [30]) have shown, on the basis of several fields of action, which fundamental course must be set for a sustainability policy. In practical politics, however, sustainability is still subject to the growth proviso. The erroneous belief that "green growth" can be achieved through efficiency increases alone still prevails. Sustainability in industrialised Europe, however, also requires a fundamental change in economic policy and a political strategy for significant changes in consumption behaviour (sufficiency), also to enable the countries of the South to have development opportunities.

In terms of chemicals and material policy, sustainability means above all avoiding irreversible damage to ecosystems. To achieve this, a holistic view of material flows is needed. In science and politics, the term "Green Chemistry" has become established over the past 25 years, which refers to the products (chemicals) and their production (in particular savings in waste and energy, use of renewable resources, occupational safety, less toxic auxiliary materials). The twelve criteria for "Green Chemistry" published in 1998 by Anastas and Warner [26] as well as the criteria for "best available techniques" (BAT) in Annex III of the EU Directive 2010/75/EU on industrial emissions [32] provide benchmarks for a sustainable orientation of chemistry.

The term "sustainable chemistry" was first used almost simultaneously by the German Chemical Society (GDCh) and the Organisation for Economic Cooperation and Development (OECD) with a different meaning than "green chemistry". According to this, "Sustainable Chemistry" means production, use and disposal of chemicals and products made from them[4] (see chapter 8).

Sustainability and precaution are largely congruent in their orientation, whereby sustainability has a stronger focus on global and long-term effects and precaution focuses more on knowledge deficits. Without optimal environmental precaution, however, sustainable development is not possible.

[4] On German initiative, the International Sustainable Chemistry Collaborative Centre (ISC3) has been founded with the aim of advancing a transformation towards sustainable chemistry, https://www.isc3.org/.

Environmental justice – an essential element of sustainability

Environmental burdens are often unequally distributed. The poorer population usually lives in neighbourhoods with high noise pollution, low air quality, few green spaces and high heat pollution. For example, concentrations of nitrogen dioxide (NO_2) are significantly higher in congested inner cities than in green outdoor areas. The Berlin Environmental Justice Atlas impressively shows that multiple pollution levels often coincide in poorer residential neighbourhoods [33]. People with low incomes are often dependent on cheap goods with low environmental standards, e. g. textiles. However, the ecological footprint of poor people is considerably smaller than that of those who can afford expensive consumption. These differences also affect chemical pollution, e. g. by air pollutants, or – especially in less affluent European countries – the quality of water and soil. This discrepancy often takes on particularly drastic proportions among migrants and among Sinti and Roma communities in Central and Eastern Europe. They often have no regulated access to clean drinking water, settle on contaminated land with waste deposits or in the vicinity of industrial emissions [34]. The treatment of these populations can take on racist overtones [35]. In a research project of the German Environment Agency "Environmental Justice in Urban Areas", proposals are being developed to counteract this unequal distribution, e. g. participation and involvement of the population in the neighbourhoods in the development of goals and measures, integrated monitoring as well as planning and environmental legal instruments [36].

Without environmental justice, the socio-ecological transformation that societies in the countries of the North are facing will not succeed. A conversion to renewable energies and a drastic restriction of resource consumption will only succeed if it is successfully communicated to the population that prosperity and the costs of ecological and social infrastructure are distributed equitably [37].

4. Chemicals and materials policy is a planetary issue

Chemical safety and substance policy have now become a global issue.

4.1 Global exposure to chemicals

Safety and environmental standards in the production and use of chemicals in many countries of the South are still as low as they used to be in Germany and the EU some decades ago. This often has dramatic consequences in these countries: Lack of occupational safety, emissions of wastewater and exhaust air, as well as the disposal of waste, in many cases severely burden health and the environment. This is not without consequences for the countries of the North either: chemicals and pesticides that are banned here and sold profitably by chemical companies in the North to the countries of the Global South pollute the environment there and are re-imported via textiles, plastics or as impurities (contaminants) via food.

Global material flows (extraction of raw materials and trade in chemicals and finished products) have multiplied. Chemical production has increased 50-fold since 1950 and is currently doubling every 12–15 years [38]. In addition, European chemical companies have also relocated their production to developing and emerging countries. In doing so, they do not always comply with European safety standards there and thus also relocate the associated risks. There are also double standards: products that are no longer allowed to be sold in some countries because of stronger environmental regulations move to the global South or East.

Something similar is happening with waste. Large quantities of waste are exported (often illegally) from Europe and the USA to countries in the South or East. They are processed and disposed of there, sometimes under dramatic environmental and working conditions, often by unskilled workers. Not only old electrical appliances, but also entire ships for scrapping are typical examples of this. Internationally, although the Basel Convention (last amended 2022) regulates [39] the export of hazardous waste, but it cannot prevent numerous illegal material flows.

The populations of the South are often suppliers of raw materials and goods for the consumption needs of the North, both in terms of mineral resources and biogenic resources such as agricultural products. For example, poorer people in particular suffer from intensive and improper pesticide use, inadequate safety standards in mines and emissions from "dirty" industries [40].

A good overview of the global exposure to chemical substances is provided by the "Global Chemicals Outlook II" [38] of the United Nations Environment Programme (UNEP): In it, it is particularly alarming that – according to an estimate by the World Health Organisation (WHO) – the improper handling of chemicals costs 1.6 million lives worldwide every year. This shows: Chemical exposure is a frequently underestimated danger.

4.2 Planetary boundaries

In 2009, scientists from the Stockholm Resilience Centre[5,6], among others, attracted worldwide attention with the publication "A safe operating space for humanity". They presented an approach to describe the stability of our planet Earth and to define the guard rails of resilience (planetary boundaries) [41].

Over the past 10,000 years or so, the Earth system has been in a remarkably stable climatic state, which in geology is called the Holocene. This state is characterised by constant temperatures, the availability of fresh water and biogeochemical[7] material cycles that have remained largely constant over thousands of years. This is what made human development towards our current way of life possible. The stable climatic phase rendered possible the transition from hunter and gatherers to sedentary farmers with domesticated animals and plants (the Neolithic) – the basis for our current way of life.

[5] The Stockholm Resilience Centre is affiliated with Stockholm University, conducts scientific research on global problems and sees itself as a mediator between science, politics and society., https://www.stockholmresilience.org/.

[6] Resilience: Ability of an ecosystem to return to its initial state after a disturbance.

[7] Biogeochemistry deals with the chemical, biological and physical processes that underlie the structure and functions of ecosystems and landscapes. Biogeochemistry is an interdisciplinary systems science whose range of topics includes all five geochemical spheres: Biosphere, Pedosphere, Hydrosphere, Earth's Atmosphere and Lithosphere (Wikipedia, https://de.wikipedia.org/wiki/Biogeochemie).

However, at the latest with the beginning of the industrial revolution, humans have increasingly intervened in biogeochemical material cycles and thus influenced environmental conditions globally. Since the 1950s, science has documented an increased acceleration of man-made (anthropogenic) interventions in the Earth system – the so-called "Great Acceleration" ([42] – [44]). This can be seen, among other things, in climate change, declining biodiversity and nitrogen cycles that are coming apart at the seams. Fig. 1 (on next page) illustrates the great acceleration caused by human activity on the basis of numerous ecological and socio-economic parameters.

In addition, humans have released persistent chemicals, radionuclides and plastics into the environment, which can be detected in living organisms and sediments today and are likely to continue to be detected in the future. Furthermore, the large-scale use of concrete and bricks creates anthropogenic rock strata. The exploitation of mineral resources often leads to lifeless, desolate landscapes and results in the mobilisation of pollutants. Based on these observations, the science community is discussing the entry into a new geological era: the Anthropocene ([43], [45], [46]).

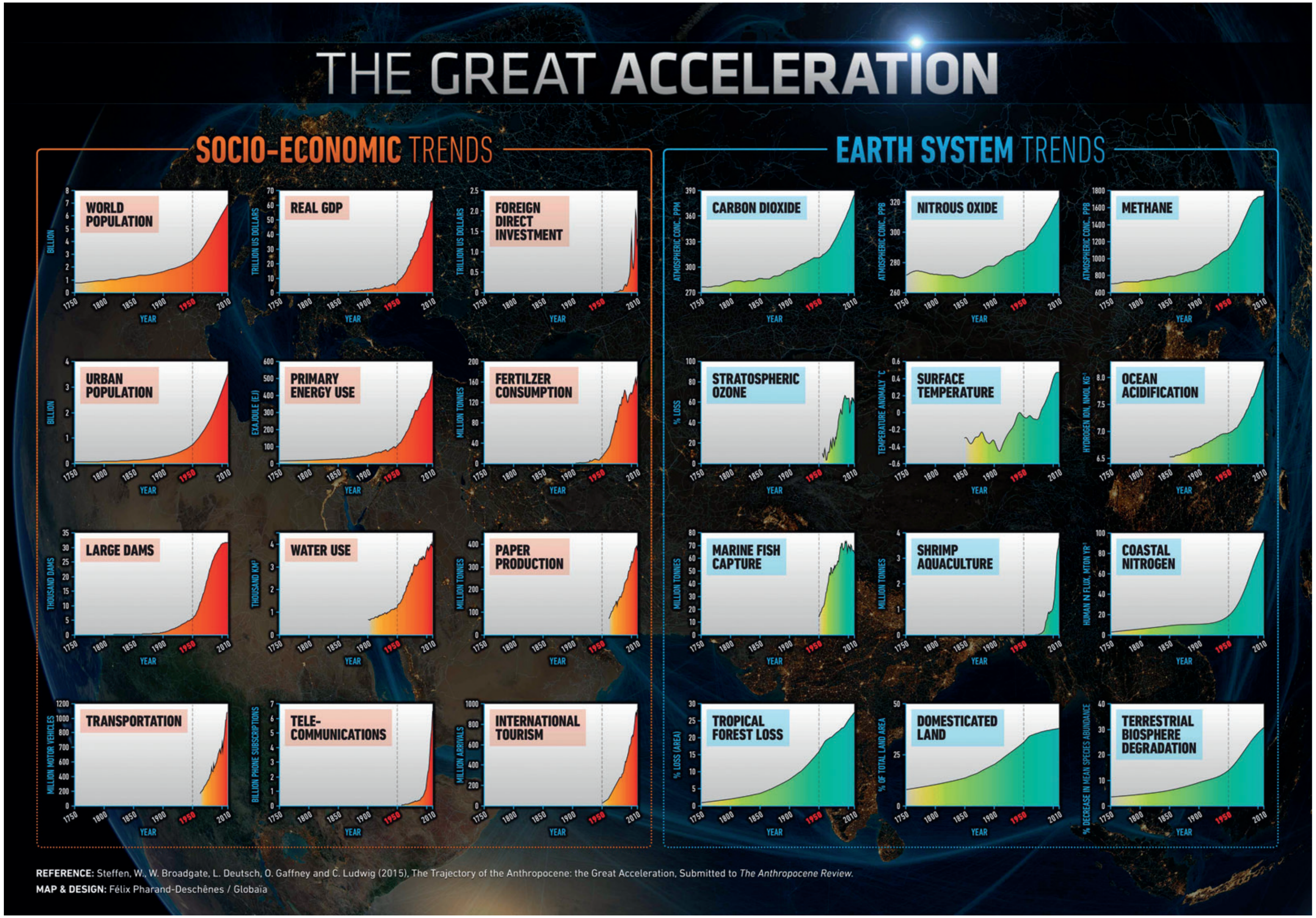

Figure 1: "The Great Acceleration": trends in some ecological and socio-economic parameters over the past 250 years [42]
(The graph illustrates that in the past hundred years in particular, processes such as population growth, water consumption and transport volumes have grown exponentially, resulting in a dramatic increase ecological parameters such as rainforest loss and ocean acidification.)

Human activities, according to Steffen et al. [47], have reached a level that could seriously disrupt the stability of the systems that have kept the Earth in its condition during the Holocene. The scientists highlight nine processes that have significantly determined the stability of the Earth system in the Holocene. These influence the global interactions between land, oceans, atmosphere and living beings, which together represent the environmental conditions on which our societies are based. The authors determined variables for the resilience of the nine identified processes (see Fig. 2).

The dramatic nature of the development is also illustrated by the report "Transformation is feasible" [48] of 2018 to the Club of Rome. In this report, four scenarios show that unrestrained economic growth will lead to a failure to achieve the sustainability goals and that only a major transformation will enable future-oriented development.

In its critique of growth, FoE Germany also makes clear that unlimited growth destroys the limited system of the earth and that a significant change in thinking and action is indispensable so that our children and grandchildren can still have a life worth living [49].

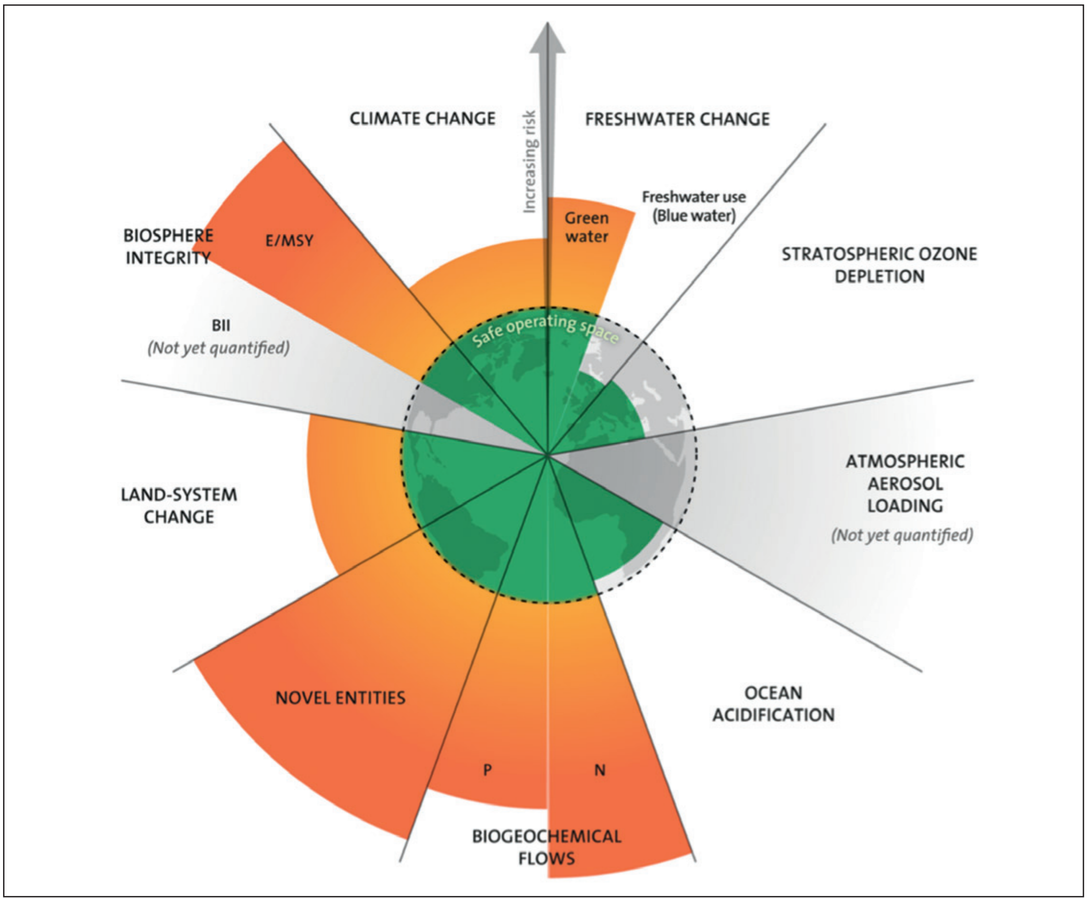

Figure 2: Planetary guard rails: processes that can disrupt Earth's stability (according to Azote for the Stockholm Resilience Centre, based on an analysis in Persson et al. [50] and Steffen et al. [47])
Explanations:
Green area: safe space for action, red area: planetary boundaries are exceeded,
BII: Biodiversity Intactness Index (functional diversity),
E/MSY: extinctions per million species-years (genetic diversity)

4.3 Planetary Boundary: "Novel entities"

One of these planetary boundaries are the "novel entities" defined by the authors as [47]:

- new substances[8] produced by human activity,
- new forms of already existing substances,
- modified life forms (genetically modified organisms or products of synthetic biology).

These each have the potential to trigger undesirable geophysical or biological effects in the Earth system.

The scientists have formulated three criteria that "novel entities" must fulfil in order to have a global impact: They are

- persistent (persist in the environment over long periods of time),
- mobile across large distances such as climate zones or continents and correspondingly widespread and
- able to affect important processes of the Earth system or its subsystems.

"Novel entities" include man-made chemicals that nature did not know before (xenobiotics). They can also be naturally occurring elements, such as metals, which are only mobilised by human activities and thus become a problem. Numerous publications have presented evidence that the burden of chemicals and plastics on the Earth system exceeds tolerable levels (e.g. [51]).

Then, in 2022, an international team of researchers [50] assessed the impact of the cocktail of synthetic chemicals, plastics and other "novel entities" released into the environment on the stability of the Earth system. The researchers assessed the suitability of a number of control variables such as production volumes, amounts of release into the environment and the proportion of hazardous chemicals that exhibit characteristics such as persistence and mobility. They concluded that despite limited data, Earth system processes are increasingly disrupted and the Earth system is at risk. According to this, humanity has exceeded the planetary boundary for novel entities.

Since 1950, chemical production has increased 50-fold. This amount is expected to triple again by 2050 [38]. An estimated 350,000 different chemicals are produced and used worldwide. These include plastics, pesticides, industrial chemicals, chemicals in consumer products, antibiotics and other pharmaceuticals. Most of these are substances that have only been generated as a result of human activity, do not occur naturally and whose effects on the Earth system are still largely unknown. Every day, considerable quantities of these new substances are released into the environment. The authors [50] call for urgent action to reduce the production and release of these substances. Among other things, they call for upper limits on the production of chemicals and plastics.

Chemical pollution is not only a problem at the global level, but also arises in operational practice at the company level. Recently, there have been suggestions on how companies that use chemicals or products with chemical ingredients can measure and reduce their chemical footprint [52]. The questions assess management strategy, chemical inventory, risks of chemicals used, strategies to reduce chemical exposure, and willingness to disclose data. A score is given. The questions are aimed at substituting hazardous substances (such as the "Substances of Very High Concern" – SVHC) according to REACH, see chapter 5) rather than reducing the volume flow of chemical products.

Further research is needed to scientifically capture and assess issues related to the quantification of chemical exposures and make them applicable to the global, national and company levels.

In the concept of planetary boundaries, further boundaries are closely linked to the requirements of a sustainable chemicals policy ([47], [41]):

- Biogeochemical material flows: In the opinion of the authors, the global pollution limits with nitrogen and phosphorus have already been reached or exceeded.

8 The term "new substances" should not be confused with "new substances" in the sense of chemicals law, which understands this to mean substances that have not been marketed before.

- Climate change: Humanity has also already left the safe space for action within this planetary boundary. The main causes of anthropogenic greenhouse gas emissions are the burning of fossil raw materials and, among other things, rice cultivation, cattle breeding and deforestation. In a background paper, FoE Germany states that material production and use have a very strong influence on the emission of greenhouse gases [53].
- Acidification of the oceans: This is strongly linked to climate change, as about 27 to 34 % of the emitted CO_2 is absorbed by the oceans and leads to a lowering of the pH value there. This makes it difficult for many marine animals to form their calcium carbonate skeletons. According to the authors, the limits for this load have not yet been reached.
- Ozone loss in the atmosphere: This has been slowed down by the measures to ban ozone-depleting substances such as CFCs and kept within globally acceptable pollution limits.
- Aerosol content of the atmosphere: The use of chemicals has significantly increased this content. However, no pollution limit has yet been defined for this planetary boundary.
- Biodiversity (functional and genetic diversity): Biodiversity is decreasing dramatically. Many species of insects, birds and other groups of organisms are becoming extinct as a result of human activity. The limits of stress have clearly been exceeded. Species extinction has many causes; among them significantly the pollution of ecosystems by chemicals, especially pesticides [7] and other anthropogenic inputs. The Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) also sees – among other causes – pollution by anthropogenic substances and the high use of pesticides, as well as intensive agriculture and forestry in general, as a major reason for the high losses of biodiversity [54]. In a background paper, FoE Germany highlights the effects of material pollution on biodiversity [53].

Six of the total of nine planetary guard rails thus have a close relationship to sustainable chemicals and materials policy. In order to keep planet Earth in a safe space of action for humanity, the various fields of action can therefore not be considered in isolation, but solutions must be sought that take these linkages into account.

4.4 International approaches

It has long been recognised that too many chemicals threaten humans and the environment. This has been officially emphasised again and again by heads of state and government. In some cases, governments have also agreed on concrete measures:

4.4.1 The commitment of the world community

In 1992, at the Conference on Environment and Development (UNCED) in Rio de Janeiro, the world community recognised the burden of chemicals and waste on the environment and humans as a global challenge. Chapters 19 and 20 of Agenda 21 [18] call for the "sound management of chemicals and waste". Ten years later, in 2002, at the World Summit on Sustainable Development (WSSD, Rio+10) [55] the international community agreed on the goal of minimising the harmful effects of chemicals in production and use by 2020.

4.4.2 United Nations activities – Sustainable Development Goals

In 2015, the UN General Assembly adopted seventeen Sustainable Development Goals (SDGs) for 2030 ([14], [15]). Among them are several environment-related goals relating to clean water, climate or the protection of terrestrial and marine ecosystems, which also include the protection of humans and the environment from hazardous chemicals. The twelfth SDG on sustainable production and consumption ("Ensure sustainable production and consumption patterns") is particularly relevant for international chemicals and materials policy. Sub-goal 12.4 refers directly to the decisions of the WSSD 2002:

"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."

However, this target has not been achieved in 2020. Within the framework of the SAICM process [56] ("Strategic Approach to an International Chemicals Management", see section 4.4.4), the target is now 2030 – as with the other goals. The progress made so far is not sufficient to really improve the situation. On the contrary, the rapid increase in chemical production is offsetting many of the successes and progress already made.

Sub-goal 3.9 of SDG 3 "Ensure healthy lives and promote well-being for all at all ages" also remains particularly relevant with regard to the significant health damage caused by chemicals:

"By 2030 substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination."

The UN Environment Assembly (UNEA) has affirmed in several resolutions to intensify the international management of chemicals and waste and to achieve significant progress by 2030. In a resolution adopted by UNEA 4 [57] sustainable chemistry is also recognised as an important starting point for safe chemicals management. In addition, the goal "Towards a Pollution-free Planet" was proclaimed.

4.4.3 Global agreements

Growing international awareness of the hazards of chemicals and waste has so far led to the agreement of five legally binding international conventions:

- The Montreal Protocol [58], 1987, last amended in 2018, bans ozone-depleting substances. This first global agreement on chemicals is considered successful. Concentrations of chlorofluorocarbons (CFCs) and other ozone-depleting substances in the atmosphere are slowly declining.
  With the Kigali Amendment of 2016, fluorinated greenhouse gases are also restricted internationally [59].
- The Basel Convention [39], 1989, last amended in 2022, regulates the transboundary shipments of hazardous waste and aims to prevent illegal exports. This is succeeding to a considerable extent, but does not prevent large-scale exports of hazardous waste from industrialised countries to countries in the South and East, in part by circumventing the provisions of this agreement. In its "Global Waste Management Outlook"(GWMO) [60] UNEP emphasises that only two of the 50 largest landfills are located in industrialised countries, even though the amount of waste generated per capita is significantly higher there than in the countries of the South.
- In the Rotterdam Convention [61], 1998, last amended in 2019, the contracting states undertake to inform each other about transboundary transports of hazardous chemicals. The list of chemicals is continuously being expanded, even though consensus has still not been reached on some particularly hazardous substances such as chrysotile asbestos.
- The Stockholm Convention [62], 2001, last amended in 2019, prohibits or restricts the production and use of some persistent organic pollutants (POPs) and also minimises the unintentional formation of POPs (such as polychlorinated dibenzodioxins and polychlorinated dibenzofurans) as by-products in technical and thermal processes. Further substances are also continuously being identified and included as POPs. The global burden of listed substances appears to be gradually decreasing.
- The Minamata Convention [63], 2013, aims to reduce mercury discharges worldwide, whether they result from the use of mercury in products and processes or from the combustion of coal.

Basel, Rotterdam and Stockholm Conventions form a joint secretariat. This is intended to link chemicals and waste management in a meaningful way and make use of synergies. UNEA 5.2 (United Nations Environmental Assembly) decided in March 2022 to negotiate a global agreement on plastic production, use and waste (UNEP/EA.5/Res.14 [64]).

However, individual legally binding conventions cannot be a final solution. From FoE Germany's point of view, a global framework convention on the sustainable management of chemicals, resources and materials is therefore necessary to counter the growing threat posed to the planet by substances and to link chemicals and materials policy on an equal level with climate and biodiversity policy [65]. It is also recognised at UN level that – as UNEP Executive Director Inger Andersen points out – chemicals pollution is the third major planetary crisis alongside climate and biodiversity [66]. The planned establishment of a Science-Policy Panel, which was also decided at UNEA 5.2, can scientifically underpin the global significance of chemicals and materials policy (UNEP/EA.5/Res.8 [67]). Fig. 3 (on the next page) illustrates that the three global crises – climate change, biodiversity loss and material pressures – are closely interrelated.

In addition, there are a number of other multilateral agreements related to chemicals within the framework of UN ECE (United Nations Economic Commission for Europe), UN ILO (International Labour Organization), UN IMO (International Maritime Organization) and UN WHO (World Health Organization). The EU and Germany have ratified all these treaties.

4.4.4 The SAICM Forum

In 2006, the SAICM process ("Strategic Approach to an International Chemicals Management") [56] was launched in order to achieve the goal of minimising the negative effects of chemicals and waste in a joint, cross-sectoral process of states with non-governmental organisations (e. g. industry associations, environmental associations, trade unions). SAICM was conceived as a platform that is explicitly intended to be complementary to the other global and regional instruments of chemicals management.

This platform is used to discuss and plan global goals and measures for chemicals and waste policy. The currently important issues are:

- Lead in paint,
- Chemicals in products,
- Hazardous substance within the life cycle of electrical and electronic products,
- Nanotechnology and manufactured nanomaterials,
- Endocrine-disrupting chemicals,
- Environmentally persistent pharmaceutical pollutants,
- Perfluorinated chemicals and the transition to safer alternatives,
- Highly hazardous pesticides.

The goal of SAICM is initially a "sound management of chemicals and waste". Legally binding agreements are not adopted, but chemicals and waste policy measures are developed and adopted. These could well lead to binding international conventions in the medium term. The mandate officially ended in 2020. A successor forum is planned and is to be adopted at the next International Conference on Chemicals Management (ICCM5), which has been postponed until autumn 2023 due to the COVID19 pandemic. As a result of the intersessional process the following strategic objectives are recommended for adoption at ICCM5[9] [278]:

"A. Countries have the capacity, legal framework and institutional mechanisms in place to achieve the sound management of chemicals and waste throughout the life cycle.

B. Comprehensive and sufficient knowledge, data and information are generated, available and accessible to all to enable informed decisions and actions.

[9] *Details still under discussion.*

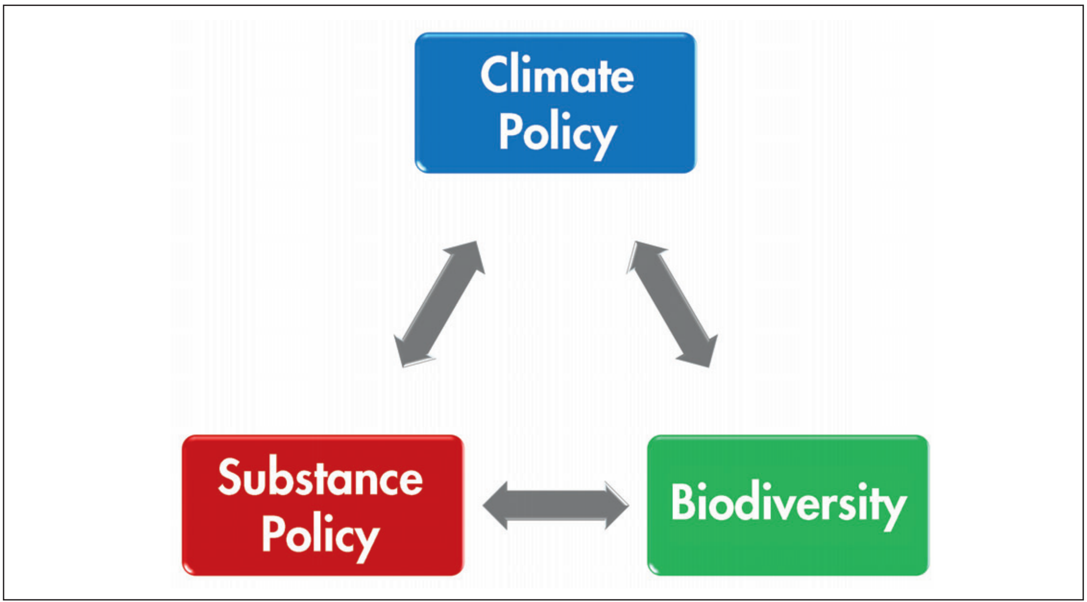

Figure 3: Link between substance policy, climate policy and biodiversity

C. Issues of concern are identified, prioritized and addressed.
D. Safer alternatives and innovative and sustainable solutions in product value chains are in place so that benefits to human health and the environment are maximized and risks are prevented or, where not feasible, minimized.
E. The sound management of chemicals and waste is transparently and accountably integrated in all relevant decision-processes."

A detailed list of individual targets in support of the strategic objectives will be discussed at ICCM5. In global initiatives, the slowest participants often set the pace. However, a more informal approach like SAICM is quite helpful because it is not burdened with the pressure of negotiating an international agreement.

4.4.5 Globally accepted testing, assessment and grading procedures

Another cornerstone of international chemicals management is the chemicals programme of the Organisation for Economic Co-operation and Development (OECD) [68]. Above all, it provides scientifically validated testing and assessment procedures that are recognised internationally.

The OECD was also involved in the development of the Globally Harmonised System (GHS) [69] which enables a globally uniform classification and labelling of the hazards of chemicals. However, in autumn 2021, only 83 countries have implemented the GHS, although this was already required by 2008. Also of concern is the finding that in the EU, 68 % of chemicals manufactured and used still have a hazard classification according to GHS [38] – also a sign that sustainable chemistry is still a distant goal even in the EU. According to its Chemicals Strategy for Sustainability (see chapter 5), the EU intends to work for GHS to be applied worldwide and to be supplemented with further hazard characteristics [70]. This includes the classification of endocrine disrupting chemicals (see section 6.5) and substances that are persistent, mobile and toxic (PMT/vPvM) (see section 6.3).

4.4.6 Despite all this: too slow and too little!

Overall, international efforts do not do justice to the size of the problem. The various measures and forums are fragmented and rarely coordinated with each other. Decisions are often not implemented. At the current rate, the problems will grow faster than the measures take effect. The global boundaries are being exceeded. As highlighted in UNEP's Global Chemicals Outlook II report [38] "Business as usual" is not a suitable solution. Solutions exist, but a far more ambitious and coordinated approach is urgently needed. This includes – as outlined above – the need to strive for an agreement with a global framework convention on the sustainable management of chemicals, materials and resources that sets legally binding standards for the production and use of chemicals and materials and also sets limits to the unsustainable growth of chemical production. It is also important to formulate legally binding targets, to set indicators for achievement and to report regularly on progress towards the targets.

It is essential for a sustainable global chemicals and materials policy that industrialised countries provide greater financial support to developing countries in the implementation of measures. There is a close connection between poverty and the lack of opportunities to implement effective management [40]. The industrialised countries must not shirk responsibility for the problems in the countries of the South. They are also directly or indirectly responsible for many environmental problems in the emerging and developing countries.

FoE Germany's recommendations on international substance policy derived from chapter 4 are compiled in section 9.1.

5. European Chemicals Policy

The EU's chemicals policy is codified in numerous legal acts. The central regulation is the REACH Chemicals Regulation 1907/2006 (REACH: Registration, Evaluation, Authorization and Restriction of Chemicals) [3] which the EU agreed on at the end of 2006. REACH is the most progressive chemicals law in the world to date, with which the EU has decisively strengthened the idea of prevention: it is no longer the state or society, but manufacturers and importers who are now obliged to prove that their substances and substance mixtures can be used without risk to health and the environment. To this end, they must submit the prescribed safety data in the form of registration dossiers. The principle of "no data, no market" applies to the placing of chemicals on the market. REACH does not regulate the scope of chemical production and use.

One of the main objectives of REACH is to identify substances with particularly critical properties ("Substances of Very High Concern", SVHC) in a so-called candidate list for mandatory authorisation and to gradually replace them with less harmful or sustainable substances or processes. To strengthen this legally anchored substitution principle, SVHC subject to authorisation may only be used for a limited period of time with a special permit.

REACH is undoubtedly a great step forward, even if the regulation still has clear shortcomings [71].
In particular, the poor quality of the registration dossiers submitted has provoked clear criticism. Regular spot checks by the European Chemicals Agency (ECHA) and a study conducted by the German Federal Institute for Risk Assessment (BfR) on behalf of the German Environment Agency ([72] – [74]) showed that a very high percentage of registrations do not meet the legal requirements of REACH. The reason is often a lack of safety data on hazardous properties of substances, which are essential for an adequate risk assessment. This also concerns substances that are produced in very large quantities and used in numerous consumer products of daily use. A number of globally active companies, including those in the petroleum processing and plastics industries, also FoE Germany have not fulfilled their legal registration obligations as a FoE Germany investigation revealed [75].

The goals of European environmental policy were reformulated in the EU's Green Deal [76]. An essential element is the zero pollution ambition for a non-toxic environment [77]. This ambition goes beyond the classic chemicals policy and links it to a "circular economy" and measures against climate change and loss of biodiversity. In October 2020, the European Commission presented the "Chemicals Strategy for Sustainability" [70] with a comprehensive plan of action. According to this, substances should be "safe and sustainable by design" in the future (see chapter 8). A central element of the implementation of the chemicals strategy is the revision of the EU REACH Regulation. After extensive consultations, the European Commission was supposed to present the draft of a revised REACH Regulation by the end of 2022. This deadline has now been pushed back to the last quarter of 2023. This delay makes it unlikely that the consultations will reach a conclusion during the term of the current Commission. The chemical industry is obviously trying to prevent a quick and effective implementation [78] as demanded by environmental associations, the member states and the EU Parliament.

In the course of the past 16 years, some fundamental deficits and weaknesses of REACH have come to light [79]. The increasing use of chemicals that are harmful to the environment and human health in products highlights the need for a revision of REACH that is aligned with the precautionary principle and the EU chemicals strategy. In the EU, it takes an average of 13 years and 8 months before a chemical is officially considered hazardous and regulated [80]. This timeframe prevents dangerous chemicals and their applications from being quickly withdrawn from the market. Moreover, in the past, only individual substances were restricted. In its chemicals strategy, the EU Commission has announced that it will restrict the use of SVHC in consumer products more frequently in the future and expand the criteria for SVHC classification. Endocrine disruptors, respiratory sensitising substances and persistent substances that are highly mobile in the water cycle (PMT/vPvM) are to be explicitly included and no longer only considered as substances of "equivalent concern". Companies that use such substances in their products should therefore seek their substitution in a timely manner.

The "generic risk approach", which could contribute significantly to the simplification and acceleration of regulatory processes, is also intended to provide greater protection for consumers. So far, this approach is limited to the general prohibition of carcinogenic substances in consumer products such as food packaging, toys and other products for children, cosmetics, cleaning agents, furniture or textiles. The envisaged extension of this concept to all SVHC hazard classes could replace an elaborate risk assessment of individual applications. In a second step, a so-called impact assessment should then enable the extension of this precautionary approach to further substances in consumer products that may be harmful to the immune system, the nervous system, the respiratory organs or other specific organs.

The Chemicals Strategy for Sustainability further envisages supplementing the traditional approach of assessing each chemical individually ("substance by substance") with an assessment of groups of substances. The procedure of assessing each substance separately and restricting it if necessary takes far too long. In many cases, this has also led to inappropriate substitutions by less well studied and not yet assessed substances with similar hazard profiles ("regrettable substitutions"). Examples are the increasing substitution of bisphenol A by bisphenol S and other related compounds and the per- and polyfluorinated alkyl substances (PFAS). In the case of these, the largely banned substances PFOA and PFOS have been replaced by other equally persistent representatives of the very extensive PFAS group of substances [81]. In January 2023, Sweden, Denmark, Norway, Germany and the Netherlands submitted a restriction dossier for the entire PFAS substance group, which is now to be discussed. This procedure can be transferred to other groups of substances (e.g. phthalates and other plastic additives) and should be increasingly applied. In view of the large number of chemicals and the impossibility of evaluating them all, many experts consider simplification by grouping them as a logical consequence of the increasing burden of "novel entities" on the Earth system [82].

Another innovative measure to accelerate the assessment process, which is foreseen in the chemicals strategy, is the restriction of the further use of SVHC to essential uses. As already proven in the Montreal Protocol for ozone-depleting and/or global-warming gases, for substances of concern only those uses should be allowed (for a limited period of time) that are either necessary for health, safety or the functioning of society and for which at the same time there are no alternatives that are technically and economically feasible [83]. Here, too, the Commission has yet to make a concrete proposal on how these criteria can be specified under REACH.

The revision of the EU REACH Regulation should also address some other safety gaps that currently exist: Intermediate products, especially if they are isolated or transported off-site, require submission of data to assess the risks of handling. In order to ensure the safety of consumers and the environment, especially in the case of imported products, information requirements and controls by national authorities need to be tightened. It is also important to introduce strict rules for the steadily growing online trade of chemicals, pesticides and mixtures and to monitor them.
Finally, the data requirements for polymers should be

adapted. Knowledge about their structure, applications, physical and chemical properties is limited because polymers are widely exempted from registration under REACH. Article 138 (2) REACH Regulation [3], however, provides for the possibility of extending the registration obligation to polymers. The Commission is currently working on a proposal for the identification of polymers [84] which are to be covered by a REACH registration obligation in future (Polymers Requiring Registration, PRR). Scientists have criticised this draft because it only covers 6 % of the approximately 200,000 polymers [85].

Furthermore, the transfer of information in the product chain (downstream and upstream) must be improved, as many companies often do not pass on essential, safety-relevant information or do so only incompletely [86]. Above all, the information they need does not reach the recycling companies that produce marketable products from waste again. If product waste contains "Substances of Very High Concern" (SVHC) that may no longer be used in the meantime, this makes recycling into secondary products and their marketing even more difficult. This is to be improved by the Waste Framework Directive amended in 2018 [87]. ECHA database for SVHC in products SCIP (Substances of Concern In articles as such or in complex objects (Products)) [88] (see section 7.4.3). Since 05.01.2021 all articles containing SVHC above 0.1 % by mass have to be notified for registration in SCIP. Currently, SCIP is especially geared towards the needs of recycling companies. However, according to the result of an ECHA survey from March 2022 [89], there are still major technical hurdles that considerably limit the usefulness of SCIP for recycling companies. Thus, SCIP is also of limited benefit for the avoidance of waste containing SVHC as well as an incentive for the substitution of SVHC [90]. The collected information should also be available for consumers and enable informed purchasing decisions. However, a suitable processing of the data for consumers is still missing, which could be achieved e.g. by linking it with the data collected in the database of the LIFE-project AskREACH [91]. Via the connected smartphone apps ToxFox [92]and Scan4Chem [93] consumers can directly obtain information on existing SVHCs by scanning the product barcode. So far, consumer enquiries about SVHC (according to Article 33 (2) REACH-Regulation [3]) are often not or insufficiently answered by companies [94]. In the framework of the Ecodesign Regulation, for which the Commission presented a proposal in March 2022, information on ingredients in products could be provided in the future via a digital product passport (see section 7.4.3).

In view of international trade, however, European regulations are not sufficient. Global agreements that ensure the exchange of information on hazardous chemicals in products should be sought.

The EU CLP Regulation 1272/2008 (CLP: Classification, Labelling and Packaging) [95] is the "little sister" of REACH. It transposes the "globally harmonised system" (GHS) into European law (see section 4.4.5). It determines which hazard characteristics lead to a substance being classified as hazardous and how it must then be labelled. The chemicals strategy envisages that the following additional hazard classes will be introduced and apply in the European Economic Area: endocrine disrupting activity, immunotoxicity, neurotoxicity and persistence in combination with bioaccumulation (PBT/vPvB) and/or mobility (PMT/vPvM) [96]. This extension would be welcome as currently some substances of very high concern (SVHC) are not covered by the CLP Regulation. The EU intends to integrate this further development of classification and labelling globally into the GHS system as well.

REACH applies in principle to all chemicals. However, special groups of substances (e.g. pesticides in agriculture, biocides, pharmaceuticals, cosmetics) have their own legal requirements. It makes sense that in these cases there are more far-reaching requirements.

However, European legislation often lacks consistency. For example, it is contradictory that hazardous ingredients in pharmaceuticals, cosmetics and food additives do not have to be classified and labelled, and that the risk assessment of cosmetics is limited to health, despite their mostly environmental use. Within the framework of its chemicals strategy for sustainability, the EU Commission plans to better coordinate the assessments with each other and to avoid frictional losses ("one substance – one assessment") [70].

In addition to the REACH and CLP Regulations, there are a number of other EU sectoral substance laws. Particularly worthy of mention are the Pesticides Regulation [97], the Biocides Regulation [98] and the legislation on human [99] and veterinary medicinal products [100]. The active substances in these preparations have a physiological effect on the target organisms (humans, animals, "harmful organisms") and must therefore be examined more closely before they are authorised so that harmful effects on humans and the environment are avoided. Despite all the tests carried out as part of the authorisation process, agricultural pesticides still represent a serious environmental burden and are partly responsible for the decline in biodiversity ([7], [101]). A decrease in pesticide use cannot be observed and can only be achieved through a change in agricultural practice towards an agroecological farming system that largely abstains from pesticides [102]. In the non-agricultural sector, (often the same) poisons are used to protect materials and control harmful or annoying organisms. Often the goal could be achieved by non-chemical alternatives. As with agricultural pesticides, effective measures are needed to reduce biocide exposure. Active pharmaceutical ingredients are often no less effective than pesticides in their side effects on the environment. The consumption of pharmaceuticals is continuously increasing as a result of demographic development. They are excreted again or disposed of improperly, thus polluting water and soil. It is only for a short time that their effects on the environment have been examined as part of the authorisation process, but only in rare exceptional cases with the result of a refusal of authorisation. In a position paper, FoE Germany has described the environmental pollution caused by pharmaceuticals and called for numerous measures to reduce it [103].

FoE Germany's recommendations for European chemicals legislation derived from chapter 5 are compiled in section 9.2.

6. Substance evaluation – Persistence and other critical substance properties

Substances are assessed on the basis of their (potentially) hazardous properties. The testing of toxic and ecotoxic effects plays an essential role thereby. If substances prove to be toxic to humans or the environment, they are only tolerable – if at all – in very low concentrations below the threshold values. However, toxicity and ecotoxicity do not alone determine the hazardousness of a substance. Other substance properties are also important in assessing whether a chemical poses a risk or a hazard to humans or the environment (see box "Hazard or risk?"): Persistence, bioaccumulation, mobility, hormonal effects and others. Indirect effects can also occur and mixtures of substances can have stronger effects than the individual substances. Some materials, e.g. nanomaterials or fibres, trigger special effects due to their shape (see section 6.7).

6.1 Persistence as a central environmental problem

Substances that cause global problems are usually long-lived (persistent) and can spread from the place of their entry by wind or water or accumulate in organisms and in the food chain. Persistence is therefore a key feature that significantly contributes to the burden of chemicals on humans and the environment.

Even without a (known) negative effect, persistent substances have a hazard potential. They can remain in the environment for a long time, spread widely, accumulate in certain compartments and lead to completely unexpected interactions with different substances or organisms ([104] – [106]). This has been impressively demonstrated by the example of chlorofluorocarbons (CFCs). In the case of persistent sub-

Hazard or risk?

Classical chemical assessment is based on comparing effect and exposure. If the expected or measured exposure (concentrations/doses in breath, in food, in the body or in the environment) is higher than the effect threshold, a risk is identified that must be reduced. On the one hand, this approach has proven successful because in this way immediate poisoning of humans and the environment can be detected and avoided. On the other hand, it requires the examination of each individual exposure situation, which can be a considerable effort. Furthermore, this approach ignores the fact that for persistent and mobile substances, persistent and bioaccumulating substances, and substances with irreversible effects, exposure and effect are decoupled, i.e. the effects occur after a delay or spatially remote from the time/location of exposure. In such cases, an exposure-effect comparison leads to incorrect results. If adverse effects are detected at a later stage, the substance is no longer retrievable from the environment. REACH calls such chemicals substances of very high concern (SVHC) and aims at a substitution of such substances and their applications. In these cases, it is not necessary to evaluate individual exposure scenarios, but the need for action arises solely from the hazardousness of the substance. The hazard-based assessment should be extended to all "substances of concern" [70], i.e. also for example, extremely persistent chemicals ("forever chemicals") as well as microplastics or highly toxic chemicals. If the sustainability goal of a "toxic-free environment" is to be achieved, it is essential to phase out hazardous chemicals as completely as possible. The risk approach is only justified for chemicals that do not meet the above criteria and in retrospect for the assessment of pollution (e.g. contaminated sites, water pollution, waste) and monitoring results.

stances, the consequences of not knowing about unrecognised effects can thus be extraordinarily great.

Persistence is particularly critical when it occurs together with bioaccumulation (see section 6.2) or mobility in the water cycle (see section 6.3). In the past 20 years, it has also gained importance in the regulatory assessment of chemicals in combination with bioaccumulation: Under REACH, substances that are very persistent and bioaccumulate strongly are classified as "Substances of Very High Concern", even without a proven problematic effect.[10] These are the "vPvB" substances ("very persistent and very bioaccumulative"). Other EU legal standards, such as the Pesticides Regulation [97] and the Biocides Regulation [98] also provide strict provisions for persistent and bioaccumulative active substances with the aim of a "phase out". At the international level, the Stockholm Convention regulates some persistent organic pollutants (POPs) (see section 4.4).

Persistence also affects groups of substances that have not been in the focus so far. Special attention is currently being paid to per- and polyfluorinated alkyl substances (PFAS). Several 1,000 chemicals belong to this group of substances. What they all have in common is that they are extremely persistent and only degrade after decades or longer. They are therefore classified as "forever chemicals". PFAS are used in numerous technical applications and areas of life, including as foam extinguishing agents, in hard chrome plating, in the impregnation of textiles and carpets, and for coating food packaging, e.g. for "fast food". The recycling of products containing PFAS, e.g. packaging, leads to the carry-over of PFAS. Contaminated sites of PFAS are e.g. due to the land application of contaminated materials such as residues from paper production.

Many PFAS are not only extremely persistent, but also accumulate in the food web, are mobile and toxic to humans and environmental organisms at low concentrations. Manufacturers have reacted to the banning of individual PFAS by substituting them with other, less well-studied fluorochemicals. PFAS are therefore a prime example of the need for group assessment [107]. In January 2023, four Member States and Norway submitted a dossier to the Commission on the restriction of the entire group of substances PFASs [108]. In a background paper "Fluorochemicals – long-lived, dangerous, avoidable", FoE Germany outlined the hazardous nature of this group of substances and called for a complete phase-out of PFAS uses by 2025, especially from consumer-related applications ([81], [109]).

Plastics are another example of extremely durable substances. Plastics in the environment, for example, were until recently considered an aesthetic problem at best. In the meantime, however, plastics have become a serious problem, even though they are mostly neither toxic nor bioaccumulative themselves.[11] The European Chemicals Agency ECHA states that an important property of microplastics is their "extreme" persistence. Microplastics should therefore be treated in the same way as non-threshold substances, similar to PBT/vPvB substances, where any release into the environment is assumed to pose risks [110]. In 2022, the EU Commission presented the proposal for a Restriction Directive [111].

Specifically added microplastics and those produced by abrasion from plastic materials, textiles and vehicle tyres (see box "Tyre abrasion – a major source of microplastics" on next page) end up in the environment in significant quantities. Much of it ends up in the oceans. Marine organisms, especially plankton eaters, ingest the persistent particles and starve to death with filled stomachs because they cannot digest the plastics. Via the food web, they then also reach higher organisms such as fish and marine mammals, and via these also the human body. A measuring programme of five federal states in Germany showed that plastic particles are also widespread in rivers and lakes

[10] Substances that are persistent, bioaccumulative and toxic (PBT substances) are also considered "Substances of Very High Concern" under REACH.

[11] However, some plastics contain toxic additives which – if not fixed – can escape during the use phase or are released during the treatment of waste.

[112]. Even snow samples from the Antarctic are not free of microplastic particles [113]. The contamination of soils is also very serious. Composts, digestate from biogas plants and sewage sludge contain plastic residues, so that all agricultural soils today contain microplastics and also residues of macroplastics [114].

Since the majority of plastic waste inputs are via sources in Asia and Africa [115] (partly from European plastic waste exported there), the environmental problems caused by macro- and microplastics are likely to be even more serious there than in Europe. The ongoing negotiations on a global plastics convention should lead to environmentally sound production, use and disposal of plastic waste (see section 4.4.3).

The large quantities combined with the poor degradability make plastics one of the most pressing global environmental problems today. In addition, additives in plastics such as plasticisers, antioxidants, UV stabilisers and flame retardants pose a serious environmental problem. For example, Henkel et al. showed that phthalate plasticisers dissolve out of PVC microparticles over decades [116]. Plastic parts in the environment can also – like many other small particles – absorb pollutants from the aqueous environment, accumulate them and transport them into the bodies of living organisms [117].

According to Australian research, humans ingest an average of 5 g per week of microplastics [123]. In the meantime, scientists at the Medical University of Vienna and the Austrian Federal Environment Agency have also detected plastic particles in human stool samples. Initial indications show that this may promote inflammatory reactions in the intestine ([124], [125]). Plastic particles can even be detected in the saliva of newborns and in breast milk ([126], [127]) (see also section 7.4.4).

Tyre wear – a major source of microplastics

A major source of microplastics in the environment is the abrasion of car tyres [118]. Experts see it as a major source of soil pollution, air pollution in cities, water pollution from roads and even pollution of the oceans [119]. The chemical composition of tyres and the resulting microparticles is extremely complex and mostly unknown. Numerous chemicals are added to obtain the desired product characteristics of the tyres. In a study by the University of Vienna, the authors demonstrated that several additives are eluted from tyre particles and taken up by lettuce plants [120]. These include oxidation inhibitors, which are intended to prevent ozone from attacking the tyre matrix. A common inhibitor is 6PPD. Research by Washington State University suggests that this additive is responsible for the widespread death of silver salmon on the Pacific coast of the USA. As tyre particles wash off the roads into salmon waters, toxic ingredients, especially 6PPD quinone, dissolve and lead to the death of salmons [121]. 6PPD quinone is the oxidation product of 6PPD, which is formed when it reacts with ozone, i.e. when it performs its function. 6PPD-quinone is extremely toxic. Already at 95 ng/L, 50 % of silver salmon are killed in laboratory tests [122].

The case highlights a clear gap in the EU chemicals regulations REACH and CLP. The original chemical substances (here: 6PPD) are examined and classified. When used as intended, these react with other substances and form secondary products with possibly hazardous properties. In such cases, the secondary products must also be examined and evaluated.

6.2 (Bio-)Accumulation

Persistent substances that bioaccumulate are particularly problematic. They are often hardly soluble in water and accumulate in living organisms – mostly because of their fat solubility. Some heavy metals such as mercury and cadmium are also bioaccumulative. Animals at the end of food chains or food webs are therefore particularly at risk. The pollutants are passed on along the food chains (biomagnification), so that the highest concentrations of such substances are found in animals such as seals, birds of prey or even humans. Therefore, these creatures are at greater risk from harmful effects. Examples of such substances are flame retardants such as polybrominated diphenyl ethers (PBDEs) and hexabromocyclododecane (HBCD) as well as polychlorinated biphenyls (PCBs), which were used in transformers, hydraulic fluids and joint sealants, among others.

In addition, metabolites of chemicals can occur in comparatively high concentrations in organisms. In 2018, researchers showed that the serum of Canadian polar bears contained a cocktail of metabolites of halogenated substances. They concluded that the risks of bioaccumulation have apparently been given too little attention so far [128].

Bioaccumulation is thus also a frequently underestimated exposure and hazard characteristic in classical risk assessment, which endangers humans and the environment, especially in the case of persistent substances. The use of some strongly bioaccumulating substances is already banned or limited by the EU chemicals regulation REACH or the Stockholm Convention.

Accumulation of substances in certain environmental media is also possible. For instance, chlorofluorocarbons (CFCs) and hydrofluorocarbons (HFCs) accumulate in the atmosphere, damage the ozone layer and/or contribute to the greenhouse effect.

6.3 Mobility

If persistent substances are water-soluble (polar), they can often easily seep into soils and sediments and be transported over long distances in groundwater. If groundwater or bank filtrate is used for drinking water, such mobile substances can hardly be removed again in water treatment.

The EU REACH Regulation does not yet provide for a systematic identification and evaluation of these hazard characteristics. However, it is possible to classify substances as "Substances of Very High Concern" (SVHC) if there is an equivalent level of concern (see chapter 5). The Member State Committee of ECHA has now classified two perfluorinated chemicals (HFPO-DA and PFBS) as SVHC due to their mobility and persistence [129]. The German Environment Agency has developed an assessment concept with criteria that make it possible to identify substances that are persistent (P), mobile in the water cycle (M) and toxic (T) – so-called PMT substances – or that are very persistent and very mobile – so-called vPvM substances[12] [130]. According to its "Chemicals Strategy for Sustainability", the EU Commission intends to systematically assess and – if necessary – restrict PMT substances in the future [70].

6.4 Indirect effects

In the case of harmful effects on the environment, the focus has so far mostly been on ecotoxicity, which is certainly important. However, it is becoming apparent that some persistent substances cause damage more indirectly. Six examples are:

- Pesticides: Some active substances harm living organisms not only through direct toxic effects, but also by altering agricultural biocommunities. If herbicides eliminate wild herbs, for example, insects and thus birds are deprived of their livelihoods. Insect and bird mortality in turn leads to a decline in biodiversity.
- CFCs: The destruction of the ozone layer by these substances causes stronger short-wave UV radiation

12 PMT substances are persistent, mobile and toxic, vPvM substances are very persistent and very mobile; see also [131].

on earth, which harms living organisms. Chlorofluorocarbons (CFCs), like hydrofluorocarbons (HFCs) and some other stable gases, also have a very high global warming potential.

- Plastics: Most polymers are not toxic in the sense of a direct toxic effect. They nevertheless harm living organisms because they can cover habitats, block the stomachs of marine animals or penetrate cells as microparticles, damage tissue and transport pollutants (see section 6.1).
- Phosphate: The scarcity of this important natural nutrient was a central problem of food security until industrialisation. The mass use of phosphorus as a fertiliser (in the course of the Great Acceleration – see section 4.2) is now leading to massive overfertilization (eutrophication) worldwide, both in inland waters and terrestrial ecosystems and in the world's oceans [132]. The consequences are a lack of oxygen and a threat to aquatic communities.
- Reactive nitrogen compounds (especially ammonia/ammonium, nitrates, nitrous oxide and other nitrogen oxides): The anthropogenic multiplication of the natural input of reactive nitrogen compounds into the environment leads to various problems: These include toxic effects, e.g. from ammonia or nitrogen oxides (NO and NO2). Ammonia and nitrate (from nitrogen oxides) cause overfertilization and impairment of terrestrial ecosystems through inputs via the atmosphere. Nitrate leads to groundwater pollution and overfertilization. Nitrous oxide (N_2O) contributes to global warming due to its high greenhouse potential. The 8th Conference of the International Nitrogen Initiative (INI), organised in 2021 by Germany as host, has summarised the most important approaches to combating the nitrogen crisis in its Berlin Declaration [133]. The UNEA 5.2 (United Nations Environmental Assembly) has subsequently addressed the problem of environmental overload with reactive nitrogen [134]. It became a UNEP topic (see section 4.3). The aim is to reduce the inputs of reactive nitrogen in such a way that the planetary boundaries are respected in the future.
- Carbon dioxide (CO_2): This gas is also a persistent substance. The combustion of fossil fuels for electricity, mobility, heat and other technical processes (e.g. chemical production, cement production) has released and continues to release huge amounts of CO_2, which is the primary cause of climate change.

All these problems can no longer be solved with traditional assessment instruments alone, such as the classical risk assessment with a calculated exposure-effect comparison.

6.5 Hormonal effects

Various substances can interact with the hormonal (endocrine) system of humans or animals (endocrine disruptors, ED). They simulate or block the effect of the body's own hormones or influence their formation, transport and degradation. Lack of fertility, decreasing sperm count and quality, malformations of the reproductive organs, increased incidence of various hormone-dependent cancers (such as breast and prostate cancer) are described in the literature as possible consequences of exposure to EDs [135]. Effects on the sex hormones are widespread, but disorders of the thyroid gland and steroid synthesis have also been discussed in many cases.

The manifold disturbances caused by endocrine disruptors can occur at very low concentrations in early developmental stages (for example, in embryos and foetuses) and cause considerable, often irreversible health disorders in humans or negative population dynamic effects in organisms in the environment. Since the effects can be stronger at low doses than at higher doses ("non monotonic dose responses") [136] and the time of exposure also has a decisive influence, the approach of traditional risk assessment often leads to erroneous conclusions. Regulation in accordance with the precautionary principle is therefore important here, especially for applications close to the consumer and for applications with discharges to the environment.

Endocrine disruptors disrupt not only the endocrine system of humans, but also the endocrine system of environmental organisms, e. g. with regard to larval development, reproductive ability, sex ratios or imposex of animals. The effects of endocrine disruptors on environmental organisms must therefore be taken just as seriously as the health effects [137].

Hormonally harmful substances are often bulk chemicals such as bisphenols used in polycarbonate plastics and epoxy resins (e. g. interior coatings of food cans), plasticisers (phthalates) found in flooring, synthetic leather, shoes and, despite legal restrictions, still in every fifth plastic toy [138], flame retardants in upholstered furniture up to agricultural pesticides and antimicrobial cleaning agents. The World Health Organization (WHO) has identified nearly 800 endocrine disrupting chemicals [139].

Attempts to update an existing EU Community Strategy on Endocrine Disruptors from 1999 on the basis of new scientific evidence and by naming concrete measures to combat the problem have not been successful [140]. A study commissioned by the Petitions Committee of the European Parliament presents the available evidence, makes recommendations for effective protection against endocrine disruptors and lists the associated health effects and costs [141]. The issue has been under political discussion since the mid-1990s. There are no scientific reasons for the slow pace of regulation. The European Parliament and several Member States repeatedly urged action, but internal discussions within the Commission and intense lobbying by industry prevented progress. It is to be feared that such delays will continue.

In 2017 and 2018, the EU Commission issued two regulations ([142], [143]) to define endocrine-disrupting properties of pesticides and biocides, which could also be applied to other substance groups. However, this definition sets high hurdles and requires comprehensive test results. Presumably, therefore, only a few substances will be identified as endocrine disruptors. A category of substances for which there is a reasonable suspicion of endocrine disruption (analogous to carcinogenic and mutagenic substances) was not envisaged. The present criteria are therefore obviously insufficiently guided by the precautionary principle. Even though the standardisation of test methods that reliably clarify whether endocrine effects occur is still in progress, a comprehensive compilation of test methods has now been developed at OECD level [144].

In its EU Chemicals Strategy for Sustainability [70] of autumn 2020, the EU Commission admitted that legislation regarding endocrine disrupting substances needs to be reformed in order to effectively protect humans and the environment from such substances in the future. The chemicals strategy therefore envisages that the rules for identifying chemicals will be revised and new hazard classes introduced under the Classification and Labelling and Packaging of Chemicals Regulation (CLP Regulation), including for substances with endocrine-disrupting effects on humans and the environment. On 19 December 2022, the Commission adopted proposals for a revised version of the CLP Regulation [96] and for a delegated act to introduce new hazard classes [145].

The success of these measures will depend to a large extent on another measure announced in the chemicals strategy as part of the REACH revision (see chapter 5): the introduction of the preventive generic approach to the risk assessment of chemicals, in particular also to stop the use of endocrine disruptors in consumer products.

Measures to reduce the risks of ED are also possible at national level. For example, France published an action plan on endocrine disruptors in 2019 [146] and the Federal Ministry for the Environment, Nature

Conservation, Nuclear Safety and Consumer Protection (BMUV) is currently also considering drawing up such a plan.

Exposure of humans and the environment to endocrine disruptors must therefore be prevented and, even in the case of suspected substances, mitigated as far as possible as a precautionary measure.

6.6 Irreversible damage to health

Particularly serious adverse health effects caused by chemicals are carcinogenicity and mutagenicity, as well as effects on fertility (reproductive toxicity) and the endocrine system (endocrine effects). They usually lead to irreversible damage and in many cases no threshold value can be determined for the occurrence of a harmful effect. The hormone-dependent breast and prostate cancers have increased by 0.75 – 1.00 % annually in the last decades [147]. These values take into account the age-related increase of cancer incidences. Since genetic factors change the incidences in a different time frame, environmental factors, especially increased exposure to chemicals, are suggested as the cause.

As our existing monitoring systems apparently do not offer sufficient protection, it should be considered how the time period from the first findings of suspicious indications of the above-mentioned effects to effective regulatory measures can be shortened. A concerted procedure should be established to generate validated scientific findings with the participation of science and the public. In this way, it could be decided in a shorter period of time whether there is a need for regulation.

6.7 Nanomaterials and other novel materials

In accordance with Regulation (EU) No 2018/1881 [148] the nanoform of materials is defined in Annex VI of REACH as the form of a natural or manufactured substance containing particles whose external dimensions are between 1 and 100 nm for at least 50 % of the particles in at least one dimension.[13] The particles may be unbound or in the form of agglomerates or aggregates. Bulk form is understood to be the form of the same substance to which this definition as nanoform does not apply because of its larger particle size.

Because nanomaterials enable diverse new technical applications, their economic importance is increasing. They are being produced in ever greater quantities. This is also associated with an increasing exposure of humans and the environment to such materials. However, while the effects and exposure potential of most substances are determined by their chemical composition only, in the case of nanomaterials, physicochemical properties such as particle size, shape, surface chemistry and surface charge also have a considerable influence on behaviour and effects in the human organism and in the environment. Coarse-grained particles are often not bioavailable, whereas nanomaterials, due to their small size, can penetrate cells and spread more rapidly in the environment [150].

New testing strategies are therefore needed to assess the risks of nanomaterials. Within the framework of the Test Guidelines Programme of the Organisation for Economic Development and Cooperation (OECD), appropriate test methods for nanomaterials are a focus.

In recent years, the European Chemicals Agency (ECHA) has published guidance documents on how companies should register nanomaterials. In its Regulation (EU) No. 2018/1881 adopted in December 2018, the EU Commission limited itself to adapting only the REACH annexes with regard to nanomaterials and specifying in them which data companies must submit, but did not adapt the REACH Regulation itself and add nanomaterials to the core text. According to this, since 01.01.2020, companies have to provide additional information for nanoforms of substances

[13] For the number size distribution of at least 50 %, see EU Commission Recommendation of 18 October 2011 [149] (see also [147] resp. [3]).

of which they manufacture or import more than one tonne per year into the EU. Since both bulk forms and nanoforms are merely different forms of one and the same substance, the substance in question only has to be registered once in accordance with the so-called OSOR principle (OSOR = one substance – one registration); however, if one or more nanoforms occur, an existing registration of the substance in question must be updated and supplemented with additional information on the respective nanoforms. In principle, each nanoform must be described individually if its deviation from other nanoforms goes beyond the usual variations from batch to batch of a particular manufacturing process. Essential points such as specific testing requirements and separate exposure considerations for this update of the registration dossier are mentioned in this regulation. It should be considered whether, within the framework of the upcoming REACH revision (see chapter 5), the provisions on nanomaterials should not be incorporated into the core text of the regulation, which does not yet recognise the term "nano". Then, for example, the quantity threshold for including a nanoform in a registration dossier could also be lowered, which at one tonne per year is clearly too high for these materials active in low concentrations. Scientific findings on the grouping of different nanoforms should also be implemented [151] and then the quantity thresholds should refer to the sum.

In addition, another EU regulation (No. 2020/878) prescribes modified requirements for the preparation of the safety data sheet according to Annex II of the REACH Regulation, according to which additional information on the nanoform or the different nanoforms of a substance or mixture must be included in its safety data sheet mandatorily if the substance in the nanoform has hazardous properties [152]. Since the examination of nanomaterials requires special adaptations of the test methods, an adaptation of the Test Methods Regulation is also necessary, which is about to be finalised [153].[14]

[14] *The current version of the test methods specified under the REACH Regulation can be found in [154].*

The discussion about the special properties of nanomaterials has now expanded to include the question of what potential risks are associated with other novel materials ("advanced materials"). These are understood to be an extremely heterogeneous field of very different substances and mixtures that do not occur naturally, but are intentionally developed and manufactured so that special functionalities such as superconductivity, optical and magnetic features can be developed with them. They are specifically designed and manufactured at the atomic or molecular level to best meet functional requirements of a particular application. Composite materials as well as substances with biological functionalities (e.g. bio-nano, biomaterials for cell culture or vectors for targeted drug delivery) are also included. A uniform definition of novel materials does not yet exist, nor does a uniform assessment of potential risks to the environment and health. As with nanomaterials, the material risks are often not derived from the chemical composition alone. The potential risks and hazards for humans, the environment and society associated with them should therefore be identified and assessed at an early stage, if possible with foresight already during their development. In addition, resource availability (for example in the case of special alloys) and lack of recycling (for example in the case of composite materials) must often be included in the assessment (see section 7.4). It is necessary to identify priorities among the existing diversity of these materials that require closer examination of potential risks [155]. Particular attention should be paid to materials that are no longer covered by the REACH substance definition (examples: biologically functionalised materials, multifunctional multi-component systems). From the point of view of occupational and consumer protection, there is also a need for a risk assessment of fibre-reinforced materials that can release hazardous fibres during processing [156]. The particular risks of bio-persistent fibres have so far been insufficiently regulated in chemicals legislation.

In order to prevent potential risks from being identified too late, participatory, forward-looking and critical monitoring of rapid technological development and consideration of the associated environmental and social impacts is just as necessary as the development of "safe by design" concepts as a new focus of safety research. Applying the precautionary principle, regulatory measures are also appropriate in some fields of application.

6.8 Combination effects

In chemical assessment, it is common to determine and evaluate the effect and expected concentrations of individual substances. In practice, however, substances are often used as mixtures of substances. The EU Regulation on Classification, Labelling and Packaging of Substances and Mixtures (CLP Regulation) [95] contains rules on how mixtures are to be classified and labelled. However, a risk assessment of mixtures is only carried out in exceptional cases. Existing risks are therefore often underestimated, as the components of a mixture of substances can influence each other and amplify or weaken their effects. Since experimental testing of a mixture is usually not carried out for animal protection reasons and because of the high expense involved (commercially produced preparations rarely have an unchanging composition), other suitable methods are needed to assess combination effects. One possibility is the calculation from the toxicities of the components by concentration addition ([157], [158]).

Based on the Council's conclusions in 2009, the EU Commission presented a report in 2012 [159] to what extent the existing legal acts sufficiently take into account the toxicity of mixtures. It states:

> *"Current EU legislation does not provide for a comprehensive and integrated assessment of cumulative effects of different chemicals taking into account different routes of exposure. In the case where a mixture of concern is identified and where such a mixture contains chemical substances regulated under different pieces of EU legislation, no mechanism currently exists for promoting an integrated and co-ordinated assessment across the different pieces of legislation."*

In the EU Chemicals Strategy for Sustainability published in 2020 (see chapter 5) [70] the EU Commission announces the creation of a consistent legal framework for combination effects. Specifically, it is planned to introduce a so-called Mixture Assessment Factor (MAF) in the chemical safety assessment under REACH. The procedure is also to be used in other relevant legislation (for example, on water, food additives, toys, food contact materials, detergents and cosmetics). In the view of FoE Germany and other environmental associations, the MAF would be a pragmatic solution to adequately reduce the risks of such effects. The factor should be high enough to significantly raise the existing level of protection for the environment and health. In view of the large number of substances from different sources that are detected in the body and in the environment, as well as the gaps in knowledge regarding the effects of as yet unknown substances, an MAF of 100 would be appropriate.

In the case of agricultural pesticides, the need for a practicable and at the same time safe procedure is particularly high, as pointed out by the National Academy of Sciences Leopoldina, among others [7]. In this context, combination effects must be taken into account both when setting maximum residue limits in food and in ecological risk assessment. The European Food Safety Authority (EFSA) has published a draft guidance document on the assessment of combined exposure to multiple active substances in products to be evaluated by EFSA [160]. When assessing pesticides, not only the effects of the components contained in the preparations must be considered, but also the fact that more and more frequently several preparations are applied simultaneously as tank mixtures. Furthermore, it must be considered that during a vegetation period often several applications of pesticides take place (spray sequences), which influence each other. In fruit growing, for example, there are often more than 20 sprays per year.

While mixtures of chemicals from one source can still be adequately assessed using scientific methods, there is still a lack of reliable exposure scenarios for the assessment of multiple exposures to chemicals from different sources. In reality, humans and the environment are exposed to many different substances from different sources. The World Wide Fund for Nature's (WWF) examination of blood samples from EU parliamentarians in 2004 showed that on average 41 out of 100 chemicals were detectable in their blood [161]. Consequently, the EU's Human Biomonitoring Programme (HBM4EU) also aims to develop methods for taking multiple exposures to chemicals into account in risk assessment.

The forecasting possibilities are even smaller if the influences of non-substance environmental stressors such as temperature, noise, electromagnetic radiation and drought on the toxicity of substances are also taken into account. This shows once again how necessary it is to integrate the precautionary principle more strongly into risk assessment and management in order to really approach the goal of a "non-toxic environment" proclaimed by the EU [162]. Safety factors for the transfer of model results to reality therefore remain necessary even with a significantly improved data situation.

6.9 Micro-pollutants in water bodies

Recently, there have been increasing findings that sensitive species of invertebrate groups in flowing waters disappear at concentrations of micro-pollutants that are lower than the results of laboratory tests would suggest. This means that established environmental quality standards, which are usually based on the results of laboratory tests, are not able to protect such species sufficiently. A plausible explanation for this is that most studies on the effects of substances on aquatic organisms only record the effect of the individual substance. In water bodies, however, numerous compounds usually have an effect on flora and fauna at the same time. The FoE Germany's micro-pollutant strategy lists, among other things, as necessary measures [4]: more extensive wastewater treatment (fourth purification stage) and more consistent consideration of environmental risks in the approval of pharmaceuticals. To avoid water pollution with active pharmaceutical ingredients, it may be necessary to treat wastewater from point sources such as hospitals separately [103].

The German Federal Government is also concerned with the issue of micro-pollutants. In 2022, the Federal Trace Substances Centre (although the term micro-pollutant is actually more meaningful, the term trace substances was used here) was established at the German Environment Agency.[15] According to the procedure established there, in a first step a panel of experts assesses whether it is a priority trace substance for which there is an acute need for action to reduce it. In the second step, a "round table" is then set up for this trace substance, which decides on reduction measures. Work on this procedure has been ongoing since 2016. So far, only three round tables have been concluded, which could only agree on less ambitious reduction measures.

This procedure of the German Federal Government's dialogue on trace substances is inadequate in three respects:

1. Too few trace substances are dealt with because the selection by the expert panel is slow and too narrow standards are applied. Regulations for hundreds or even thousands of micro-pollutants in water bodies would be necessary.
2. The "round tables" jointly propose measures. Due to the extensive consensus principle, in practice

[15] *Cf. https://www.umwelt-bundesamt.de/das-spurenstoffzentrum-des-bundes*

the industry representatives involved have a right of veto. The measures developed in this way are not sufficient to achieve the necessary reductions.
3. So far, the whole procedure has been based on voluntariness, although clear regulations via ordinances or laws are actually needed.

In order to enforce effective measures for the reduction of micro-pollutants, measures are also needed that have an effect beyond pure environmental law.

One of the trace substances dealt with in a "round table" was the analgetic diclofenac. The measures developed there will not be sufficient to achieve the necessary reduction of releases into water bodies. An advertising ban on diclofenac or a prescription requirement would immediately lead to a significant reduction, since the majority of the inputs are made via painkilling gels whose effect is controversial, and most of which are washed off during the next bath and enter the water bodies. However, a ban on advertising or a prescription requirement would require corresponding regulations in pharmaceutical law.

Recent research also shows that persistent substances can also be transformation products that arise through incomplete degradation, for example in wastewater treatment or the environment. These are usually of unknown structure and effect. Their avoidance must be given greater consideration in the future micro-pollutant strategy.

The requirements for the further development of substance evaluation derived from chapter 6 are compiled in section 9.3.

7. Material flow management

If sustainable chemistry is to be concretely implemented, it requires comprehensive material flow management, which is an integral part of a circular economy. This begins with the extraction and processing of raw materials and ends with the recycling and disposal of waste. However, circular economy also means a paradigm shift with regard to material cycles, in that it requires the value chain to be circular in its entirety.

7.1 Basic rules of the Enquete Commission

The Enquete Commission of the German Bundestag "Protection of People and the Environment – Objectives and Framework Conditions for Sustainable Future Development" [163] formulated five basic rules as early as 1998 with regard to different raw materials. The first two rules set the framework for a sustainable resource strategy:

"1. *The rate of depletion of renewable resources should not exceed their rate of regeneration. This corresponds to the demand for the maintenance of ecological performance, i.e. (at least) for the preservation of the ecological real capital defined by the functions.*
2. *Non-renewable resources shall only be used to the extent that a physically and functionally equivalent substitute is created in the form of renewable resources or higher productivity of renewable as well as non-renewable resources.*"

It is important to set clear priorities for resource management as well as to find tools to implement them ([164], [165]).

In order to be able to set such priorities, indicators are needed for the effects on the environment of the extraction and use of energetic and material resources [166]. This is because both energy and material inputs are closely related in production and use. Suitable indicators are the "cumulative energy demand" (CED) [167] the "cumulative resource demand" (CRD) [168] and the greenhouse gas emissions (GHG) that can be derived from them. The CED records the energy input for the production of goods from material extraction to the finished product, the energy input in the use phase including maintenance, as well as the energy input for recycling, disposal, etc. The CED includes all energy inputs required for the production and use of goods. The CRD includes all raw materials used for the production and transport of a product, including energy raw materials, but not substances and materials such as excavation material that occur during extraction without being used economically. The CRD also does not cover the extent of water use in the production of chemicals and other substances – an increasing problem in view of the water shortage caused by climate change, e.g. on the Rhine. Through CED, CRD and associated GHG emissions, one gets an impression of the connection between extraction and processing of a certain resource, the associated energy and raw material input and the effect on the climate. It would make sense to include these key figures in the so-called BAT reference documents when describing the "best available techniques" (BAT) in the context of the EU Seville process.[16]

However, these three indicators only cover a part of the environmental impacts resulting from the use of resources. The criticality of individual raw materials, i.e. their economic, ecological and social relevance, is not covered by any of these indicators. Other negative effects such as eutrophication, acidification or the toxic effects of emissions are not taken into account, nor are the consequences for biodiversity. These and other indicators are indispensable for a comprehensive environmental assessment of products and processes. Currently, such an assessment fails due to both data availability and methodological ambiguity that still exist.

In recent years, many industrialised countries have succeeded in decoupling not only CO_2 emissions but

[16] *Annex III of the EU Directive 2010/75/EU on industrial emissions contains the criteria to determine what the "best available techniques" (BAT) are for an industrial process. The EU's "best available techniques" correspond to the "state of the art" technology level in Germany. In the EU Seville process, the BAT reference documents ("best available techniques reference documents" – BREFs) are developed for individual industrial sectors.*

also energy consumption from the growth rate of gross domestic product (GDP). Energy efficiency has thus increased. However, the savings are partially offset by economic growth (rebound effect). With regard to raw material consumption, however, no significant decoupling has yet occurred. A significant reversal is needed here in order to achieve the sustainability goals and the goals of the Paris Climate Agreement.

In the meantime, the European raw materials industry itself is giving impulses to use resources sparingly. The focus is on the threat to the availability of raw materials from a geostrategic perspective. The discussion has intensified since the beginning of Russia's war of aggression against Ukraine. Increasingly, attempts are being made to reduce dependence on raw materials from Russia and the People's Republic of China ([169], [170]). From the combination of these considerations, priorities can be developed for a German and European policy of resource conservation, which should be oriented towards the natural availability of resources, the environmental impact associated with their extraction, and geopolitical as well as social criteria.

The third and fourth sustainability rules of the Enquete Commission take into account potential damage in the environmental media and point to problems that are difficult to recognise but all the more critical in the mismanagement of ecosystems due to (harmful-)substance inputs that may become significant over several human generations, as in the case of chlorofluorocarbons (CFCs), per- and polyfluorinated alkyl substances (PFAS) or polychlorinated biphenyls (PCBs).

"3. Substance inputs into the environment should be oriented towards the carrying capacity of the environmental media, whereby all functions are to be taken into account, not least also the "silent" and more sensitive regulatory function.

4. The timing of anthropogenic inputs or interventions in the environment must be balanced with the timing of natural processes relevant to the environmental response capacity."

The fifth rule emphasises the importance of preserving human health:

"5. Hazards and unacceptable risks to human health from anthropogenic impacts shall be avoided."

When applying these rules, particular consideration must also be given to the combined effects of different substances in mixtures, the special risks of nanomaterials, micro-pollutants and endocrine effects (see chapter 6).

Considering that the Enquete Commission of the German Bundestag formulated these rules for the sustainable use of materials more than 20 years ago and that numerous experts, such as those of the Club of Rome, had already pointed out the need for a change in material flow management many years earlier, the balance of political efforts to date is unfortunately very sobering.

7.2 Principles of sustainable material flow management

Sustainable material flow management is based on guiding principles.
One of these is the circular economy in conjunction with the waste hierarchy, which defines the order of priorities as: Avoidance, reuse, recycling, recovery and disposal. Another model is based on the material cycles and technical solutions of nature (bionics), which are characterised by the fact that they work spatially and temporally limited with high effectiveness and efficiency with locally available materials.
Sustainable material flow management must incorporate these guiding principles, but must go beyond them. It requires a paradigm shift away from linear

economic methods towards a circular economy along the entire value-added network and including the entire product life cycle (cf. recommendations of the German Environment Agency [171]). It is essential that primary resources are actually saved and that the systems as a whole are energy- and resource-saving.

Energy is needed to keep material flows going. Sustainable processes are therefore characterised by high energy efficiency. This goes hand in hand with the lowest possible increase in entropy. Entropy[17] is often described as "lost energy" that can no longer be used in processes and is therefore "lost". However, it also arises in mixing processes, i. e. in dissipative processes[18]. Entropy is of particular importance when substances are distributed in products or in the environment in such a way that they cannot be recovered or can only be recovered at very high energy demand and cost. Thus, the lowest possible entropy production is an indicator of sustainable processes ([172], [53]).

Sustainable chemical production also means generating as little waste as possible in the production of a substance – over the entire manufacturing pathway including precursors along the supply chain. Despite great progress in the low-waste synthesis of chemical products, there are still synthesis routes that generate more waste than products. In the production of active pharmaceutical ingredients, even an average of 25 kg of non-usable by-products are "produced" per kg of product, which have to be disposed of [38].
A globalised, energy-intensive society oriented towards high material throughputs with short product lifetimes and a great diversity of materials within individual products and material flows requires a lot of energy and "produces" enormous amounts of entropy, which leads to high losses and costs of a material, energetic and economic nature. This is one of the reasons why it is important to keep material flows at all levels as low and as simple as possible in their composition.

To achieve more sustainability in the management of material flows, three strategies complement each other ([173], [174]):

- **Efficiency** is directed towards a more productive use of energy and resources. A product or service should be created with less energy and material input. This applies, for example, to the efficiency of power plants as well as to material savings in the manufacture of products. In the past, however, some efficiency gains have been offset by increased consumption (rebound effect). Currently, resource efficiency is related to the value added achieved in the GDP (gross domestic product) indicator. This means that price changes that have nothing to do with material consumption are also reflected in the indicator. Furthermore, important aspects are not included in this indicator, such as the state of natural resources.
- **Consistency** refers to the compatibility of nature and technology. This includes, among other things, the development of materials and products for closed material cycles. Products are to be used for as long as possible. Where reuse is not possible, the waste should be recycled as fully as possible or incorporated into natural biogeochemical processes [65]. In this context, sinks for the uptake of substances such as the atmosphere, soil and oceans must also be considered as limited resilient resources.
- **Sufficiency** addresses consumption and lifestyles, not only by individuals, but by society as a whole. Sufficiency can be characterised by the terms deceleration, unbundling, decommercialization and decluttering [175]. Sufficiency is not only directed at consumers but also at producers with the question of what is really needed [176]. This does not mean ascetic renunciation, but answers to the question of the right measure and the more conscious use of limited resources [177].

While efficiency and consistency are generally accepted by the population, sufficiency strategies are

[17] Entropy is a thermodynamic measure of energy that can no longer be used and can be considered analogously at the material level (often presented strikingly as the degree of 'disorder'). It is an indicator of sustainability.

[18] Dissipation: Dispersion / distribution of particles in a system.

met with reservations. However, the initiative "unpacked shops", among others, shows that some consumers are already trying to reduce their material consumption. The spread of car sharing and the increasing popularity of the bicycle also show that consumer behaviour is beginning to change. The car is no longer seen as a status symbol, especially among the younger generation. Ultimately, suitable political framework conditions are needed. Sufficiency will only prevail if favourable conditions for the waste of energy, material and labour are eliminated.

An often overlooked aspect of material flow management is environmental justice. For example, jobs in waste management are often poorly paid and harmful to health, even in Europe. The extraction of raw materials often takes place under very poor working and environmental conditions. In the countries supplying raw materials, mining deserts and monocultures are created (see section 4.1), as well as negative health and ecological consequences such as drinking water pollution and increased cancer rates among people living near petrochemical plants.

7.3 Necessary trend reversal in chemical production

Since 1950, chemical production worldwide has increased 50-fold. It could – according to some forecasts – triple again by 2050 ([38], [178]). Production volumes, use, sales and the variety of chemicals are constantly increasing, with less growth in Europe than in emerging countries. Already today, the chemical industry consumes about 10 % of the world's energy and is the third largest industrial sector in terms of CO_2 emissions ([179], [180]). Mineral oil demand is increasing faster than in other industrial sectors. In Germany, which is home to a quarter of the European chemical industry, primary energy consumption for the production of chemical and pharmaceutical products amounted to 33.5 % of manufacturing consumption in 2019 – more than all other sectors [181]. The increase in production inevitably leads to increasing global exposure to chemicals.

The chemical industry uses fossil raw materials not only to cover its energy needs but also as basic materials for its production. Currently, mineral oil and gas dominate as the material basis for chemical production with around 90 %. In addition, large quantities of water are used. In terms of sustainability and climate protection, this cannot be sustainable, as carbon-containing (organic) chemicals from mineral oil ultimately contribute to the emission of greenhouse gases when they are converted to carbon dioxide (CO_2) during disposal or biodegradation [182]. It is true that the chemical industry is making considerable efforts in its own interest by coupling production at its sites to use energy efficiently and generate little waste. Particularly in the case of basic materials, the potential for optimisation is therefore low.

If we want to curb the demand for fossil raw materials in chemical production and stop and reverse the use of increasingly diverse substances, there are three fields of action:

- A sustainable raw material base for chemical production: The synthesis of chemical base materials from carbon dioxide and (green) hydrogen, the use of biomass and also "chemical recycling" from plastic waste are the main alternatives being discussed ([183], [184]).
  Synthesis from carbon dioxide and hydrogen (PtX process) could play an important role, but today it still requires a lot of (renewable) energy to convert the inert CO_2 into organic chemicals. The energy requirement can perhaps be reduced in the future by new processes such as non-thermal plasma catalysis [185]. It is particularly costly to filter carbon dioxide directly from the air (direct air capture) as soon as there is no longer enough CO_2 from combustion and other technical processes. According to a study by the chemical industry, the energy demand of the chemical industry would increase

by a factor of 11 if fossil fuels were to be completely replaced at today's level [186].

The use of biomass can only be expanded to a limited extent. Competition with food production and other agricultural uses, as well as the need to preserve natural areas, quickly make it clear that biological materials may open up many new interesting synthesis paths, but they cannot replace the fossil base materials for the chemical industry ([187] – [190]).

The use of plastic waste through "chemical recycling" is discussed as a third option. "Chemical recycling" or chemical utilisation only leads to meaningful results if processes such as pyrolysis or gasification produce products that are suitable as base materials for chemical synthesis and material losses and energy consumption are not too great. At present, this is still doubtful, since many toxic by-products can also be produced and using the products for energy generation has no advantages over direct incineration. As a rule, "chemical recycling" is much less environmentally friendly than mechanical recycling of plastic waste. "Chemical recycling" will also only be able to replace the fossil basis of today's chemical production to a small extent. It consumes a lot of energy. A study by the Öko-Institut [191] estimates that pyrolysis requires about nine times as much energy as mechanical recycling.

There is therefore no way around a reduction in chemical production if the sustainability goals are to be achieved. In its scenarios, however, the chemical industry currently still assumes that it will at least maintain the volume of its production [186].

- The chemical industry needs to move from the current linear production to a circular production mode [192]. One goal is to close the carbon cycles as far as possible. Special efforts here concern plastic production, which is particularly high in terms of volume (see section 7.4.4). Some calculations predict that the increase in quantities of plastic waste over the next 20 years will be far greater than the successes in increasing the recycling rate [193]. Only a bundle of political, economic and technical measures can break this trend [194].
- But not only for plastics, but also for various process chemicals sold to commercial customers, the chemical industry has to develop take-back and reprocessing systems. In a guideline of the "Sustainability Initiative of the German Chemical Industry", practical tips are given, especially for medium-sized companies, on how they can implement elements of the circular economy in their companies [195].
- The products of the chemical industry must become more sustainable. This concerns an implementation of the principles of sustainable chemistry, in particular also a switch to sustainable chemicals (see chapter 8). In addition, the products of the chemical industry should be less complex and more durable and repairable. They should contain fewer hazardous substances (additives) (see section 7.4 and section 7.4.5).

Reducing chemical production to a level that is tolerable for the Earth system also requires political guidelines. These include global caps on chemical and plastic production comparable to the caps on climate gas emissions [50]. There is still considerable untapped potential for increasing resource efficiency, particularly in the use phase of chemicals. Sufficiency, i.e. limiting consumption and demands to what is necessary, must also be a central starting point of transformation of chemical industry. The diverse disposable materials and single-use items in today's economy do not represent a sustainable path and must be avoided in the future. Chemicals should only be used where a long-term benefit can be achieved through them that clearly outweighs the negative environmental impacts (see chapter 8). Sometimes classic materials such as wood also offer a suitable functional and sustainable solution.

7.4 Circular economy

Today's management of materials is characterised by linear processes: Raw materials are used to manufacture chemicals and products that are disposed of as waste after their use phase. This form of economic activity leads to a squandering of resources and is not sustainable. Instead, there is a need for a circular economy along the entire value-added networks and including the complete product life cycle.

A circular economy pursues the goal of closing material cycles as completely as possible, reducing resource consumption in absolute terms and making an important overall contribution to sustainable development and, in particular, to climate neutrality, the protection of biodiversity and the overall preservation of the natural foundations of life [196]. Circular economy also helps to reduce dependence on imported raw materials and thus to decouple resource consumption from economic growth and to secure the material production bases in a sustainable manner. Thus, the approach of circular economy is much more comprehensive than the understanding of "circular economy", which has so far primarily focused on the recycling and management of waste.

At the global level, this is reiterated in Resolution 11 of the UNEA 5.2 (United Nations Environmental Assembly) in March 2022 that a circular economy is essential for sustainable production and consumption (SDG 12) [197]. The EU Commission has declared a circular economy to be a central element of its "Green Deal" [198]. In a Communication of March 2022, the Commission announces measures to make circular products the norm, e.g. for textiles and construction products [199]. Some Member States have also presented strategies and plans for the transformation to a circular economy, e.g. the Netherlands and Austria (cf. also recommendations by the German Environment Agency [171]). Concrete, ambitious targets must be set, such as in Austria an increase in resource productivity by 50 % by 2030 [200].

Material cycles begin with the extraction and processing of raw materials and lead through the product and waste phases to reuse or recycling. Sustainable, circular material flow management therefore also includes product design requirements (recyclable, easily separable material mixtures, dismountable components, etc.). In this way, the reuse of products and product components is made possible. If this is not possible, the substances contained in the products should be recovered as completely as possible (mechanical recycling). Progress to date has been limited. The global consumption of primary resources is growing faster than the gains from reuse and recycling. For example, the share of recycling has tended to fall from 9.1 % to 8.6 % from 2018 to 2020 [201]. However, it is an illusion that material cycles can be 100 % closed ([202], [203]). The following obstacles make complete recycling an illusion:

- During the life cycle of a product, energy and material are lost. Entropy increases, especially when different components are mixed. Recovery is then only possible with a high energy input and not completely.
- Consumers do not get rid of their used products completely, i.e. a proportion ends up in mixed waste.
- Products can contain hazardous substances as components that can only be separated with great effort.
- Recycling companies often do not have complete substance information. This is especially true for imported products.
- Material streams that are scheduled for recycling often have changing compositions, which complicates the process management during recycling.
- Secondary raw materials must compete with primary raw materials on the market and be accepted by customers. This often does not succeed without state support.

Although a 100 % closed material cycle cannot be achieved, the potentials of a circular economy are far from being exhausted. Wang et al. propose to link the circularity of chemical use with the "essential uses" concept (see chapter 5) and to consistently minimise material losses in the life cycle [204]. Important factors for a circular economy include process design (e.g. linking materials and energy flows of thermodynamically high-quality with suitable downstream processes, low dissipative losses). Material flows should be kept at a high purity level for as long as possible. The more the material flows are mixed with each other, the fewer recovery routes are open.

7.4.1 Conflicting goals

There is often a conflict of objectives in product design, manufacture and use between energy and resource efficiency and optimal functionality, whereby the entire life cycle from raw material extraction to product manufacture to reuse / recycling and final disposal must be considered in order to find an optimal balance. For example, an energy- and resource-efficiently manufactured product cannot be sustainable if the addition of additives means that it is not possible to recycle the materials after use. In general, such difficulties of material recycling show that waste avoidance in terms of longer-term use must have priority and is the ecologically best form of material flow management.

The goals of the circular economy (as long as possible use through repair and reuse and as much material recycling as possible) and chemical safety (as little contamination of secondary raw materials with hazardous chemicals as possible) can also conflict with each other. Substances do not lose their hazard potential when they become waste; however, they are then no longer subject to the requirements of the EU chemicals regulation REACH. The interfaces between the regimes of chemicals, product and waste law must therefore be designed in such a way that

(i) the requirements are as equal as possible,
(ii) secondary materials are safe for humans and the environment, and
(iii) recycling is not unreasonably impeded [205].

With regard to the desirable durability (longevity) of a product, it should be noted that the chemicals it contains must be sufficiently stable. Otherwise, a conflict of objectives arises between the short life of the chemical and the longevity of the product, and resource efficiency will be impaired. It must be weighed up whether, for example, the longevity of the product offers advantages through the addition of an oxidation inhibitor, even if this impairs the material recycling of the product.

The goal of a recycling-oriented material flow management is also missed if hazardous ingredients contained in the original products are carried over into secondary raw materials and new products via recycling processes. This can be heavy metal stabilisers in PVC or halogenated flame retardants in other plastics. If such "interfering substances" cannot be separated, it makes sense to divert such contaminated products and dispose them of in an environmentally sound manner as waste instead of recycling them into secondary raw materials. For example, the recycling of PFAS-coated paper leads to the carry-over and spread of these problematic substances [81]. Under controlled conditions, a less demanding application for the secondary raw material produced from the contaminated waste (for example, fence posts instead of children's toys) can be considered in individual cases ("downcycling").

These problems can only be solved if the requirements for transparency in the product chain are significantly expanded in the EU chemicals regulation REACH, in product legislation and in waste legislation (see chapter 5).

7.4.2 Raw material extraction and processing

The use of raw materials has increased dramatically in the past century and – according to several forecasts – will continue to increase in the coming decades ([206], [207]) (see Fig. 4). Total consumption has now exceeded 100 Gt per year [201]. Reaching or exceeding global pollution boundaries (see section 4.2) is foreseeable. In order to comply with these, FoE Germany believes that resource consumption must be reduced by a factor of about 10. An international agreement to cap the use of raw materials as well as a European and a national resource protection law should therefore be sought.

The extraction and processing of raw materials causes side effects. For example, the mining of raw materials, especially metals, often releases toxic substances. The respective material flows can increase many times over compared to natural cycles. When phosphate is extracted, uranium and cadmium are partly mobilized; when neodymium, which is used for magnets, in CD players and in smartphones, is mined, the radioactive metals thorium and actinium are released. Moreover, the extraction of high-purity metals is often associated with a great expenditure of energy and a huge increase in entropy.

Rare earths as well as cobalt, tantalum, gallium, antimony and lithium are examples of "critical" metals. They are economically important for Europe, but there are significant supply risks [208]. Such raw materials often only occur in low concentrations in a few regions of the world. Their extraction and smelting are frequently associated with human rights violations and severe ecological damage. Recycling is currently too expensive in most cases, but would be urgently needed for a responsible handling of these materials [209]. The extraction of these critical metals also has social and political components. For

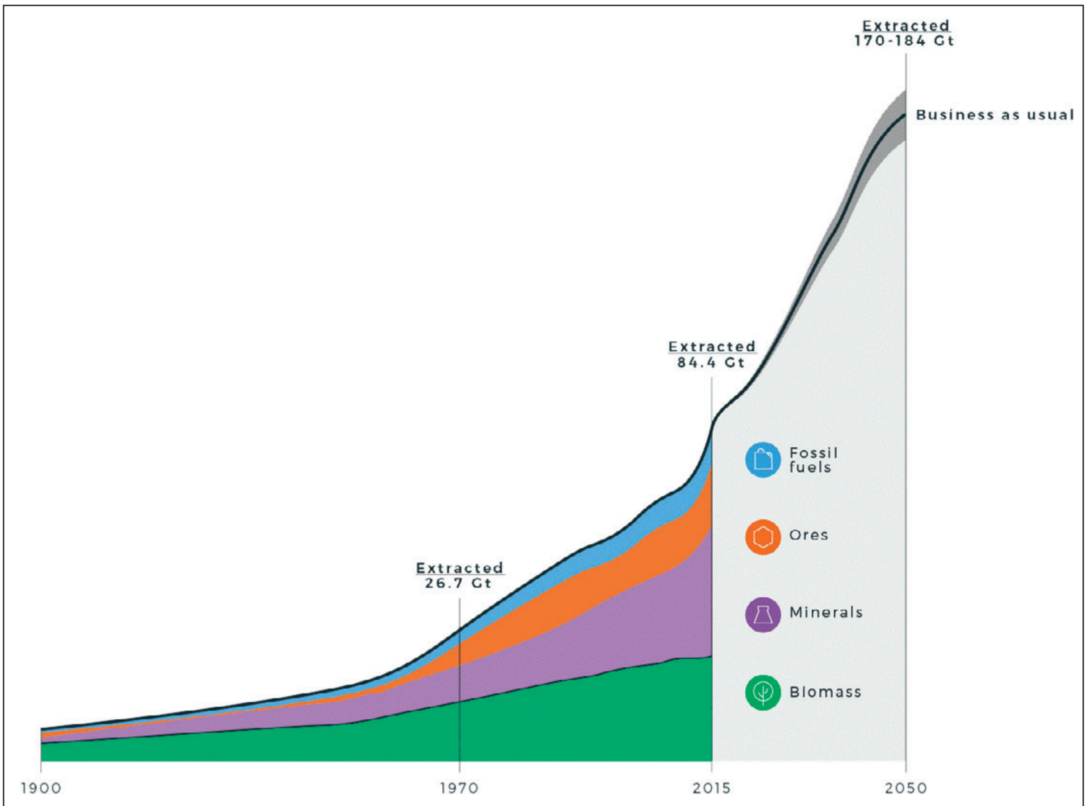

Figure 4: Global increase in raw material extraction [206]

example, the People's Republic of China uses its dominant position to make other countries dependent on it. In many countries, working conditions are dramatically poor; in some African countries, the yields from the extraction of raw materials are even used to finance wars or criminal gangs.

Some of these impacts can be reduced by an effective circular economy. For example, many metals can be recycled without serious loss of quality. The higher the metal content in the recycled scrap and the lower the complexity of the respective alloy, the lower the entropy production.

In its position paper "Resource protection means drastic reduction of resource consumption", FoE Germany has presented an analysis of the current use of raw materials and a strategy for more effective resource management [210]. With the Netzwerk Ressourcenwende (Resource Turnaround Network), FoE Germany, DNR and IÖW have established a consortium of actors from civil society and science in the German-speaking countries, which advocates a globally and intergenerationally equitable use of resources within the limits of ecological limits [211]. The network is guided by the principle of sufficiency. This means that it is looking for ways to reduce the often wasteful use of resources in the Global North to a socially and ecologically acceptable level.

7.4.3 Variety of ingredients and products

Modern products are usually diverse and complex. High-performance plastics, which are used for example in automotive engineering to reduce weight, contain a variety of additives and often consist of several different polymers. Even supposedly simple plastic films for food packaging are sometimes complex multi-layer plastics with additives that can no longer be separated. As long as there is no labelling obligation, the material composition remains unknown to consumers, commercial users and recyclers. The diversity of chemicals in products is increasingly becoming a problem that impedes the implementation of a circular economy. Kümmerer et al. therefore advocate measures to limit the diversity of substances, especially in consumer products [212].

Material recycling is very difficult, especially in the post-consumer sector. Complex composite products usually cannot be subjected to the intended recycling. Substances, materials and products originally produced with great effort in high purity are increasingly mixed and distributed worldwide across global markets, so that enormous efforts must be made in recycling aiming at avoidance of losses at the most diverse points of the supposed cycle. With a few exceptions (such as metallic scrap and glass, within limits also paper and cardboard), material recycling is therefore currently still mainly confined to production waste ([53], [65]). For scrap and glass, the EU Commission has defined criteria for the requirements that a waste must fulfil in order to be recycled [213]. An additional problem is posed by materials that contain – in some cases now banned – pollutants (example: stabilisers containing cadmium in PVC). During recycling, such pollutants may be unintentionally carried over into secondary raw materials.

Increasingly problematic is the diversity of building products. The material flow of construction products is by far the largest of all: 4.7 billion tonnes of mineral raw materials are "consumed" in the EU per year [214]. Even sand as a raw material is already experiencing shortages. However, building products are not only a quantitative problem. Some of them contain dangerous chemicals such as the flame retardant hexabromocyclododecane (HBCD[19]) or plasticisers. This can lead to significant health hazards in the indoor air. Facade paints often contain biocides that inhibit algae growth but can be washed out by the rain and seep into the groundwater. It is particularly unfortunate that according to a ruling of the European Court of Justice [215] just EU-law restricts transparency about ingredients: Apart from the CE

19 *Since 2017, new polystyrene insulation boards no longer contain HBCD.*

mark, no other environmental labels – such as the German "Blue Angel", which is helpful for consumers – may be affixed to the product.

The lack of transparency on ingredients in products means that trademarks also have difficulties avoiding harmful substances [216]. Consumers cannot consciously protect themselves from harmful substances [217] and pollutants remain in the product cycle. Extensive transparency of ingredients in products is a central element for a functioning, toxic-free circular economy [204]. Today, it must already be communicated in the supply chain if products contain more than 0.1 mass% of chemicals of very high concern (SVHC) (according to the EU REACH Regulation). However, this information does not allow companies and consumers to proactively identify other known pollutants, such as those cited in the SIN list (SIN: Substitute It Now) [218]. Different methods are discussed on how to improve transparency on product ingredients. These include chemical and digital tracers, electronic labelling, (digital) product passports, but also standardised materials with specified ingredients. In accordance with the EU Waste Framework Directive, ECHA has developed the SCIP database (Substances of Concern In articles as such or in complex objects (Products)) [88] which is intended to make substances of very high concern in products visible (see chapter 5). Furthermore, in March 2022, the EU Commission published a draft of the Ecodesign Regulation for sustainable products [220] which provides for the introduction of digital product passports (see section 7.4.5). There are also some industry initiatives, which, however, only provide incomplete ingredient information available to consumers. In the packaging sector, these include the HolyGrail project [221] and in the automotive industry the projects Catena-X [222] and the International Material Data System. The dissemination of ingredient information needs a clear identification of chemicals, for which international rules for uniform harmonised naming are required [223].

7.4.4 Plastics

Plastics are one of the major challenges of the 21st century. In the Global Plastics Outlook [224] the OECD presents figures on the production, use, waste and environmental impacts of plastics. The report states that "business as usual" is not sustainable and develops scenarios for dealing with plastics in type, scope and quantity. Plastics are extremely persistent (see also section 6.1) and are a touchstone for a functioning circular economy. Production worldwide doubled every 20 years and amounted to more than 400 Mt in 2015 [225]. In the EU, more than 25 million tonnes are collected annually as plastic waste, of which only about 30% is recycled in Germany. Approximately 7% of the collected plastic is exported [226]. Since the beginning of 2018, China has created a de facto import ban by abruptly increasing quality requirements. Since then, large flows of plastic waste have been sent to other countries in the East and South for "recycling". The decision of the Parties to the Basel Convention of 10 May 2019 is intended to prevent this practice in the future. Only unmixed, unpolluted plastic waste may in future be exported for recycling without the permission of the states concerned [227]. This means that the EU must also ensure the recycling and disposal of plastic waste in Europe. The export of plastic waste from Europe to the countries of the South and East must be prevented through consistent controls and the prosecution of violations of the Basel Convention. A large part of plastic waste is types of packaging plastics made of various different polymers. From these, pure plastic granulates can only be obtained – if at all – with a great deal of effort.

The EU Commission presented a plastics strategy in 2018 [198]. This contains proposals on how to increase the recycling rate and reduce environmental contamination. However, many of the proposals are not very concrete. The Commission relies more on voluntary action than on regulatory requirements. In particular, effective measures to reduce the consumption of plastics are lacking.

As a first implementation of the plastic strategy, the EU issued a directive on certain plastic products in 2019. This aims to reduce the input of single-use plastic products and fishing nets [228] . In addition to labelling and take-back obligations and extended producer responsibility, the package of measures also includes bans for eight product groups such as drinking straws, cotton buds and disposable plastic plates and has now been implemented in the member states. The effectiveness of the measures will only be assessed after six years. For microplastics (particle size smaller than 5 millimetres), the European Chemicals Agency ECHA has submitted a proposal for a restriction directive under REACH in 2019 [110], which led to a draft directive from the EU Commission in 2022 [111]. It is intended to lead to a far-reaching marketing ban on purposefully manufactured primary plastic particles. Microplastics are not only used in the cosmetic sector, but also to a greater extent in fertilisers and pesticides as well as in detergents and cleaning agents for the inclusion and controlled release of nutrients, active ingredients and fragrances.

The EU's plans so far are going in the right direction, but will not be enough. One study estimates that a reduction of plastic inputs into the environment by a factor of 27 is needed to avert further damage to the environment [229]. To achieve this, a bundle of regulatory, economic and voluntary measures must be developed and introduced. In particular, the use of single-use plastic packaging should be significantly reduced through bans, reusable packaging, and deposit and return regulations. Currently, about 40 kilograms of plastic packaging are produced per person in Germany, which then has to be disposed of as waste. Mechanical recycling must be expanded, which requires improved effective collection and sorting systems and – where possible – a renunciation of composite plastics. Since it often does not make ecological sense to clean, sort and pelletise mixed plastic waste and some types of plastic (e.g. tyres, resins) cannot be recycled, so-called "chemical recycling" is increasingly being discussed as an alternative [219]. This refers to processes such as depolymerisation, pyrolysis or gasification [230]. If products can be obtained that can be used as starting products for chemical syntheses, this could be an option (see section 7.3) [184]. However, using the products as fuels makes little sense – direct combustion is more advantageous here. In addition, it must be considered that, for example, toxic by-products and relevant material losses are produced during pyrolysis. It still needs to be examined whether these processes make ecological and economic sense. In any case, they require significantly more energy than mechanical recycling (a study by the Öko-Institut [231] assumes a nine-fold higher energy requirement) and therefore do not represent an alternative if the latter leads to good results. In view of the diversity of plastic types and the wide variety of additives, consideration should also be given to limiting this diversity through regulation in order to facilitate mechanical recycling.

"Bio" plastic is certainly not a solution in avoiding single-use plastic either. It is only slowly compostable at elevated temperatures. Furthermore, there are no suitable recycling logistics for these polymers ([232], [233]) From FoE Germany's point of view, biodegradable plastic offers no advantage in terms of disposal. Furthermore, the production of bio-based plastics requires plant raw materials and thus soil, fertilisers and pesticides. There is the danger of land competition with food production and, on the other hand, the conversion of extensively used land into intensively used land.

However, the plastic problem is not just a waste problem. What is needed is a significant reduction in production and consumption. If the manufacturing industry's plans to increase global production by 40% in the next ten years come to fruition, plastics will remain one of the biggest environmental problems despite improved recycling [225]. Once again, technical innovation and increased efficiency are not enough to solve the problem. A change in consumption is necessary (sufficiency). Plastic is a global problem. The UN Environment Assembly UNEA 5.2 decided in February 2022 to agree on a legally binding international plastic convention, which is to be negotiated by 2024 and should bring about a halt to plastic pollution by 2040 [64] (see section 4.4.3).

7.4.5 Product design

In cars, electrical appliances such as computers and other complex products, components are often glued together and cannot be replaced. Few products feature modular construction and are designed for longevity. Often products are designed in such a way that they are inexpensive but soon have to be replaced by a successor product (planned obsolescence) [234]. New acquisition is often cheaper than repair. The German Environment Agency has presented recommendations on how to extend the lifespan of household appliances and reduce resource consumption [235].

Ever faster product cycles, e.g. for mobile phones, textiles or furniture, make recycling more difficult. The German Electrical and Electronic Equipment Act (ElektroG) [236] specifies some criteria in § 4 "Product design" that are intended to facilitate the reuse of components; however, these provisions are hardly binding. The target collection rate of 65% since 2019 was clearly missed in 2020 with 44.1%. Of this, 75–85% was then recycled, which is in line with the targets [237].

The EU Ecodesign Directive [238] specifies maximum energy consumption values for energy-consuming products. This includes the manufacturing and use phases. Although the aim is also to reduce the demand for resources, the requirements in this regard do not yet go beyond an obligation to document. In several implementing regulations, for example for dishwashers and refrigerators, which were promulgated in 2019, the EU Commission has now set concrete requirements for reparability and recyclability [239]. The Ecodesign Directive will in future be replaced by the Regulation on Ecodesign for Sustainable Products, for which the legislative proposal was presented in March 2022 [220]. With this regulation, almost all product groups in the EU are to be covered in the future, e.g. also standards for furniture and textiles. In addition to energy efficiency, provisions on reparability, durability, chemicals that interfere with recycling, the proportion of recycled material, CO_2 emissions and the environmental footprint are planned. Furthermore, the regulation lays the foundation for a digital product passport [240]. However, it will be a long time before the standards are defined product group by product group. A resource-saving and circular economy-oriented product policy must be introduced consistently. The EU Commission and the German Federal Government should therefore be called upon to set the new Ecodesign Regulation into force quickly and also to formulate standards across product groups. This includes the right to repair: newly produced products should be compulsorily repairable, spare parts should be available over the entire service life and repairs should be more favourable from a fiscal point of view than new purchases [210]. A resource- and environmentally-friendly product design also means that, in the event of disposal, the individual modules are composed simply and without pollutants and can therefore be recycled.

Increasing internet trade is also involved in the increase in material flows. The COVID19 pandemic led to a considerable increase in e-commerce. Apart from the fact that mail-order goods are usually elaborately packaged, the number of returns is high: every sixth package is returned by customers. There are no reliable figures on the extent to which these returns are resold, given away to charitable organisations or disposed of as waste. The University of Bamberg investigated the extent of disposal/scrapping and found that for retailers, destroying returns is often the cheapest option [241]. The ZDF magazine "frontal 21" also documented a worryingly large extent of destruction of usable goods [242]. The German Federal Government reacted to this and in § 23 of the German Circular Economy Act (Kreislaufwirtschaftsgesetz – KrWG) [243] the provision is added that the usability of a product must be maintained when it is taken back. Nevertheless, according to Greenpeace's research, Amazon apparently continues to violate this provision and makes returned goods unfit for use [244].

This development underlines that, in addition to technical measures to increase efficiency and recycling, sufficiency is a decisive approach to reducing material flows and making them environmentally compatible in the sense of a circular economy.

7.5 Service models

One way to reduce chemicals and material flows is through business models such as chemical leasing. Traditionally, manufacturers of materials are interested in selling their products to their customers in large quantities. This swells a material flow more than necessary. However, if a supplier also offers a service such as cleaned workpieces, lubricated equipment or hygiene in addition to the substance, it is also in his interest to consume as little material as possible. This creates a win-win situation with economic advantages for both parties. Interest in "chemical leasing" is growing thanks to promotion, especially by the UN Industrial Development Organization (UNIDO) ([245], [246]) and the Austrian Ministry of the Environment [247], and steadily increasing.

However, there are obstacles that hinder a general dissemination: Some industry partners fear a loss of know-how or too much dependence on one supplier. In some cases, liability issues have not been clarified. It is urgent to develop solutions to overcome these obstacles. In order to avoid misuse of this business model, Moser et al. have developed five sustainability criteria for chemical leasing, which are backed by measurable indicators [248]:

- Reduction of adverse effects,
- improved handling and storage,
- no substitution by substances with higher risk,
- economic and social advantages,
- monitoring of the improvements.

The dissemination of such business models could also be promoted if they were included as "best available techniques" (BAT) in the so-called BAT reference documents ("Best available techniques reference documents" – BREFs, cf. footnote 16).

New business models are also needed to avoid waste, reuse products or recycle them in a high-quality way. Currently, it is still easier and cheaper for many traders to "dispose of" waste, which is why a circular economy is still a distant goal [44]. Without a circular economy, however, a sustainable transformation of the economy and society is not possible.

FoE Germany's recommendations on material flow management derived from chapter 7 are compiled in section 9.4.

8. Sustainable chemistry

How can chemistry contribute to sustainability? On the one hand, chemistry provides many tools that help to achieve the United Nations' Sustainable Development Goals (SDGs). We need chemicals for the generation and storage of renewable energies, clean water, hygiene and health, thermal insulation, mobility or corrosion protection. A "chemical-free world" is not conceivable and would not be desirable. On the other hand, chemicals can pose a danger to humans and the environment and jeopardise the achievement of the SDGs ([249], [250]).

Sustainable chemistry aims above all to avoid irreversible damage to human health and the environment. This can be achieved through

- chemical products that do not pose a hazard to humans or the environment,
- chemical production in a way that does not endanger people and the environment and saves energy and resources,
- material flow management that meets ecological criteria and respects planetary boundaries (see chapter 7),
- significant reduction in the amount of resources and material flows used through an orientation towards sufficiency and consistent recycling and waste avoidance.

Many ingredients of products enter the environment during their use phase as intended (such as pesticides, detergents) or are released unintentionally (e.g. through volatilisation, leaching or abrasion). They are therefore found in water, soil or (indoor) air. "End-of-pipe" systems such as wastewater treatment are helpful and necessary, but they have their limits. Measures to prevent health and environmental pollution are already necessary at the source. Chemicals therefore need an ecological molecular design; they should be "benign by design", i.e. have no undesirable effects and have a low stability in the environment before they decompose into harmless substances ([251], [252]). They should have a low temporal and spatial range, which puts their persistence and mobility in the foreground [253]. Some hazardous properties are inseparably linked to the function (e.g. flammability). However, hazardous properties unrelated to function should be avoided as far as possible. Many currently registered chemicals can only be handled safely if elaborate safety (risk reduction) measures are applied – a prerequisite that is often not given in small and medium-sized enterprises and outside industrialised countries. In its Chemicals Strategy for Sustainability, the EU Commission therefore calls for chemicals to be safe and sustainable [70]. In a technical report, the EU Joint Research Center developed criteria and indicators for this category of chemicals [254]. An essential step would be to register hazardous substances under REACH only for essential uses, and to make these subject to strict risk reduction measures [83]. In addition to the material properties, the energy and resources required for raw material extraction and production are important criteria for assessing the sustainability of a chemical. Furthermore, the necessity and extent of the use of a chemical are important assessment criteria. The German Environment Agency has published a decision-making aid in the form of a "Guidance document for sustainable chemicals" [255]. Sustainable chemical production means, among other things, high energy and resource efficiency, state-of-the-art sewage and exhaust air treatment, and inherently safe production processes.[256]. This requires innovative changes, e.g. the use of (bio)catalytic processes, syntheses at low temperatures and pressures, a high safety level of industrial plants, the use of microreactors and, last but not least, a change in the raw material base of chemical production towards renewable feedstocks (see section 7.3).

Products of the chemical and related industries are used because they fulfil a certain purpose or provide a certain function. This function must always be the starting point for sustainability considerations [257]. The first question is: Is this purpose or function necessary and, if so, how can it best be achieved? Consideration of non-chemical alternatives and alternative business models, such as services or leasing of chemicals, is important. Business models should not focus exclusively on economic goals. Only when it is clear that a chemical compound is needed for the purpose does the question arise as to which chemical compound can best fulfil this purpose and how this can be realised in the most sustainable way. The consideration here goes far beyond pure chemical synthesis. The entire life cycle from raw material extraction to the end of use, taking into account possible ways of recovery, must be considered.

In order to successfully introduce an innovation or an alternative product offering, the inclusion of social and societal improvements is inevitable. At all levels, innovations must be developed that are responsible, trustworthy, transparent and traceable. This also includes that sustainable chemistry must meet the requirements of gender equity (see box "Gender and chemicals").

To achieve the 17 Sustainable Development Goals (SDGs) of the United Nations, chemical industry practices must be guided by general sustainability principles such as sufficiency, consistency, efficiency and resilience. Together with attention to the planetary boundaries and the precautionary principle, this can create new economic opportunities while delivering societal benefits.

Gender and chemicals

Gender inequalities are omnipresent in our society and also influence the world of chemistry. Physiological differences between men and women often lead to different reactions to chemical stresses. Women in particular go through phases of life when the body is particularly vulnerable (such as pregnancy, lactation and menopause) and may pass on enriched chemicals to the next generation ([258], [259]). Different social gender roles and norms lead to different exposures. For example, men are more often affected by poisoning in (industrial) workplaces: Chemical-related deaths are about twice as frequent as in women ([260]). In contrast, women are more exposed to contaminated indoor air in the home and at work. In the medical sector and in the textile industry, they make up the majority of employees [261]. They use more household chemicals, detergents, cleaning agents and cosmetics ([260], [262], [263]). Different gender roles in the countries of the South lead to different exposures of women and men, e. g. to agricultural and construction chemicals [261]. Failure to address these gender issues can result in negative impacts on human health and the environment. There is a clear lack of data differentiating by gender ("gender data gap") [264]. It is also a concern that data on the health effects of chemicals in medicine and toxicology are collected particularly on adult men and too little on women and children, leading to disregard of other physiological responses in women [265]. In addition, there is a lack of research evidence on the effects of chemicals on trans or inter people.

Sustainable chemicals management therefore requires examining the effects of measures in a "Gender Impact Assessment" (GIA) in order to identify negative impacts on gender and to be able to take gender-responsive measures [266] – because a sustainable substance policy must also mean that

- no gender suffers from toxic chemicals and structural inequalities in chemistry,
- all genders are seen as agents of change,
- all genders benefit from sustainable chemistry ([264], [267]).

Sustainable chemistry also means, above all, avoiding at least irreversible damage to human health and ecosystems ([249], [250]). This can be achieved by

- chemical products that do not have hazardous properties that pollute the environment and health,
- chemical production that is carried out in such a way that it does not pose a risk to people or the environment and is efficient in terms of energy and resources,
- processing and recycling, which are taken into account from the very beginning,
- material flows that are managed in such a way that they do not exceed planetary boundaries and meet ecological criteria.

The International Collaborative Center for Sustainable Chemistry (ISC3) has listed the key characteristics of sustainable chemistry [268]:

"1. **HOLISTIC:** Guiding the chemical science and the chemical sector towards contributing to Sustainability in agreement with sustainability principles and general understanding and appreciating potential interdependencies including long-distance interactions and temporal gaps between the chemical and other sectors.

2. **PRECAUTIONARY:** Avoiding transfer of problems and costs into other domains, spheres and regions at the outset, preventing future legacies and taking care of the legacies of the past including linked responsibilities.

3. **SYSTEMS THINKING:** Securing its interdisciplinary, multidisciplinary and transdisciplinary character including a strong disciplinary basis but taking into account other fields to meet Sustainability to its full extent. Application as for industrial practice including strategic and business planning, education, risk assessment and others including the social and economical spheres by all stakeholders.

4. ETHICAL AND SOCIAL RESPONSIBILITY: Adhering to value to all inhabitants of plant earth, the human rights, and welfare of all live, justice, the interest of vulnerable groups and promoting fair, inclusive, critical, and emancipatory approaches in all its fields including education, science, and technology.

5. **COLLABORATION AND TRANSPARENCY:** Fostering exchange, collaboration, and right to know of all stakeholders for improving the sustainability of business models, services, processes and products and linked decisions including ecological, social, and economic development on all levels. Avoiding all "green washing" and "sustainability washing" by full transparency in all scientific and business activities towards all stakeholders, and civil society.

6. **SUSTAINABLE AND RESPONSIBLE INNOVATION:** Transforming fully the chemical and allied industries from the molecular to the macroscopic levels of products, processes, functions and services in a proactive perspective towards sustainability including continuous trustworthy, transparent and traceable monitoring.

7. **SOUND CHEMICALS MANAGEMENT:** Supporting the sound management of chemicals and waste throughout their whole life cycle avoiding toxicity, persistency and bio-accumulation and other harm of chemical substances, materials, processes, products and services to humans and the environment.

8. **CIRCULARITY:** Accounting for the opportunities and limitations of a circular economy including reducing total substance flows, material flows, product flows, and connected energy flows at all spatial and temporal scales and dimensions especially with respect to volume and complexity.

9. **GREEN CHEMISTRY:** Meeting under sustainable chemistry application as many as possible of the 12 principles of green chemistry with hazard reduction at its core when chemicals are needed to deliver a service or function whenever and wherever this complies with sustainability.[20]

10. **LIFE CYCLE:** Application of the above-mentioned key characteristics for the whole lifecycle of products, processes, functions and services on all levels, e.g. from molecular to the macroscopic

[20] *With regard to the principles of green chemistry cf. [31].*

levels and all sectors in a pro-active perspective towards sustainability."

Sustainable chemistry focuses on the key interfaces between the use of chemicals and health, climate, nutrition, energy supply and resource consumption. It thus goes beyond the twelve principles of the "Green Chemistry" [31] and is oriented towards the functions that chemical substances should fulfil. This also includes social, economic and ethical aspects.

The German Environment Agency also identified the essential characteristics of sustainable chemicals management in 2021 [269]:

"1. *Preference should always be given to substances cause no harm to health and the environment.*
2. *Hazardous substances may only be used if absolutely in the interest of society and sustainable development and there are no alternatives. One example is considering the use of perfluorinated and polyfluorinated alkyl substances, which include perfluorooctanoic acid. Discussions at European level are in progress about applications where these substances are still absolutely essential.*
3. *The circular economy requires pollutant-free material flows. This means that the chemicals contained in the products must be known throughout the entire chain, they must be known to be harmless and raw materials are to be provided in a sustainable way. Substances of concern that are nevertheless contained in materials must be carefully managed or discharged in safe cycles as required. Any measures must take into account the resulting energy requirements.*
4. *Society must find a sustainable measure for its demand for chemicals if sustainable energy and resource consumption are to be achieved at all. Substituting hazardous substances with other substances is not enough. Since chemicals are part of our living environment and will also be needed in many ways in the future for sustainable solutions, the use of all synthetic chemicals must always be questioned and possible impacts on climate and biodiversity must be taken into account.*
5. *Chemicals must achieve climate neutrality throughout their life cycle. The chemical industry offers innovative solutions for generating energy from renewable sources and using non-fossil feedstocks in the future, as well as ways to become more energy efficient. Nevertheless, its high energy consumption and global growth make it a significant CO_2 emitter and thus a driver of climate change.*
6. *Clear criteria and indicators can make it visible to both industry and consumers the extent to which a product contributes to the specified sustainability aspects. These indicators are essential for weighing up opportunities and risks."*

How can the development of chemicals, products and their application areas be measured in terms of sustainable chemistry? This requires indicators that are aligned with the principles of sustainable chemistry, preferably at the global level (see box "Indicators for Sustainable Chemistry" on next page).

The ten characteristics of sustainable chemistry [268] illustrate that the transformation towards sustainable chemistry requires a fundamentally new approach. The starting point of the purpose or function of a product, production or service requires a holistic approach. This is also a particular challenge for the training of employees in chemical professions and overall for all professions employed in the chemical industry [273]. Cooperation in interdisciplinary teams must be promoted and encouraged in science as well as in industry and administration. Sustainability issues and inter-, multi- and transdisciplinary thinking must be inte-

Indicators for Sustainable Chemistry

The discussion on sustainable chemistry at the global level began in 2016 at the second UN Environment Assembly (UNEA 2), which mandated UNEP, among other things, to "to prepare a report... to assist the Strategic Approach to International Chemicals Management in considering the opportunities presented by sustainable chemistry, including linkages to sustainable consumption and production policies, and the possibilities that sustainable chemistry may offer of contributing to the achievement of the 2030 Agenda." [270]. A milestone on this path is the "Green and Sustainable Chemistry Framework Manual"[271], to which experts from industry, science, administration and environmental associations contributed. This publication and the above-mentioned discussion paper by ISC3 [268] are being discussed in a project commissioned by the German Environment Agency [272] for the development of sustainability indicators for international chemicals management. The criteria for indicators derived from this are documented in the following table.

Table: Criteria for the development of indicators linked to the key characteristics of sustainable chemistry (ISC3) and the Green and Sustainable Chemistry Framework (UNEP) (according to [272])

Sustainable chemistry as orientation and pacemaker for the Sound Management of Chemicals and Waste
H) Sustainability Systems thinking is the prerequisite to reach the goals of the Agenda 2030: Potential trade-offs can be identified and managed with systems thinking. Sectors dealing with chemical entities contribute to Sustainable Development in compliance with the respective SDG principles and the following sub-criteria (H1 – H5).
H1) Responsible innovation Development of sustainable solutions and safe and nonregrettable alternatives for chemicals of concern through cooperation on innovations, non-chemical alternatives, services like chemical leasing, or extended producer responsibility (EPR) mechanisms. Foster collaboration along the value chains to promote circularity.
H2) Inter- and multidisciplinarity, holistic approach Considering interfaces with other urgent issues (health, environment, climate, resources/waste/circularity, biodiversity, nutrition, etc.) throughout the entire life cycle of chemical entities, while avoiding shifting problems to other sectors and future legacies.
H3) Social responsibility Promoting and ensuring health and safety as well as fair, inclusive, and emancipatory labour conditions, complying with human rights and justice in all its fields including education and science. Reduce inequalities and distribute benefits equitably.

H4) Transparency and exchange of information
Enabling the right-to-know throughout the entire life cycle. Promoting knowledge exchange on all levels including all stakeholders (e. g. science, education, business, governments, administration, NGOs).

H5) Resource management and circularity
Sustainable management of resources, materials, and products (raw materials extraction, production, application, logistics, recycling, and end of life scenario) and energy, to enable circularity without contamination throughout the entire life cycle.

The identified indicators are to be presented and discussed at the International Conference on Chemicals ICCM5 in September 2023. The indicators should be as easy to identify as possible and the origin of the data should be transparent. In this sense, indicators are proposed for, among others

- a reduction in the use of hazardous chemicals and the resulting damage to health,
- a support of climate protection through production and products of the chemical industry,
- a renunciation of subsidies for fossil basic materials,
- sustainable management of nutrients (especially nitrogen),
- careful use of resources for the extraction of raw materials,
- an effective recycling of waste,
- measures taken by the chemical industry for more safety in production and of products.

This overview reflects the need to look at the use of chemicals from production to waste and to link it systemically with other issues that can only be solved globally.

grated into the professional training of chemists. To this end, the importance of chemical products in different sectors and in society – including economics and sustainability – must be communicated.

However, a recent example from the pharmaceutical industry (Roche Group) illustrates the difficulties in phasing out chemicals that have been classified as Substances of Very High Concern (SVHC) by the European Chemicals Agency [274]. The study identified 37 problematic substances in the company, but 27 had to be exempted from the ambitious phase-out target. The reasons given by the company for the exemptions included technical difficulties, such as a lack of test periods for new synthesis processes in ongoing production, a lack of alternative chemicals and the high regulatory obligations to provide proof of the harmlessness of an alternative manufacturing process as part of ongoing production approvals. Nevertheless, the company believes that it will be possible to phase out the problematic chemicals within 10 years. The long transition period in the industry underlines the central role of prospective assessment, so that chemicals are already identified as problematic before they enter the market. Technical progress and sustainability in chemistry are based on a consistent pursuit of the precautionary principle, so that risks are identified and avoided even before a product is ready for the market.

However, a sustainable path for chemistry can only be found if the intensity of chemical production and use worldwide does not continue to increase but decreases significantly (see section 7.3) [275].

FoE Germany's recommendations on sustainable chemistry derived from chapter 8 are compiled in section 9.5.

9. Guiding Principles for Chemicals and Materials Policy – Recommendations of FoE Germany (BUND)

A sustainable substance policy must increasingly focus on the persistence of substances and the quantity flows of materials from the cradle to reuse or disposal as waste. Chemicals and materials policy must therefore be guided by the following principles:

- Today, chemicals and materials policy is international. The burden of chemicals on the Earth system has reached alarming proportions. In some cases, the planetary boundaries have already been exceeded. This applies in particular to the boundary "new substances". In order to counteract this, the United Nations' Sustainable Development Goals (SDGs) must be taken seriously and binding measures must be taken to implement them.
- Chemicals and materials policy must be increasingly oriented towards the principles of precaution and sustainability. This means, in particular, that persistence must be regarded as a central hazard characteristic – also for substances that are transformed into persistent degradation products and for substances that, like plastics, are released into the environment in large quantities without exhibiting other hazard characteristics such as toxicity.
- Material flows must be slowed down and reduced regionally and globally, and resource consumption must be reduced overall. Above all, this means using fewer chemicals that cannot be used sustainably. This can be achieved through greater resource efficiency, recycling and sufficiency in the handling of substances and materials.
- Chemicals and materials policy is closely linked to resource and climate protection. Sustainable chemistry must help to significantly reduce resource consumption and greenhouse gas emissions. Challenges include finding suitable substances and processes for environmentally compatible mobility and climate-friendly and resource-efficient construction.
- Chemicals and materials policy is also linked to biodiversity protection. Pollution of the environment contributes significantly to the decline of biodiversity. Substance inputs into water, soil and air cause biodiversity losses, as does large-scale cultivation of biogenic raw materials and animal feed and the application of pesticides and fertilisers.
- Material policy and the circular economy must be linked. A reduction of material flows can only succeed if the waste hierarchy is consistently observed. This also means that the foundations of material, product and waste legislation must be integrated and complement each other.

Sustainable chemicals and materials policy addresses all actors:

- the state, which controls the behaviour of companies and consumers through concrete regulations and permits as well as indirect incentives such as taxes and levies with the aim of a sustainable economy and the safe handling of substances,
- the companies that live up to their responsibility in a global economy and provide sustainable products, and
- consumers who, taking into account technically correct information, align their lifestyle with the principles of sustainability and sufficiency in particular.

None of this is new. The most important basic features of sustainable chemical management were already described and illustrated in 1993 (see Fig. 5 on next page): According to this, "ecological design" is central. Such a design aims to use only chemicals and substances whose environmental impact is as low as possible. In other words, only substances should be used that are as non-persistent as possible, but are also not mobile or toxic and do not accumulate. And in order to reduce the overall exposure of humans and ecosystems, chemical consumption must be reduced by increasing efficiency and sufficiency, and used products must be returned to the economic cycle through repair, reuse or recycling (consistency).

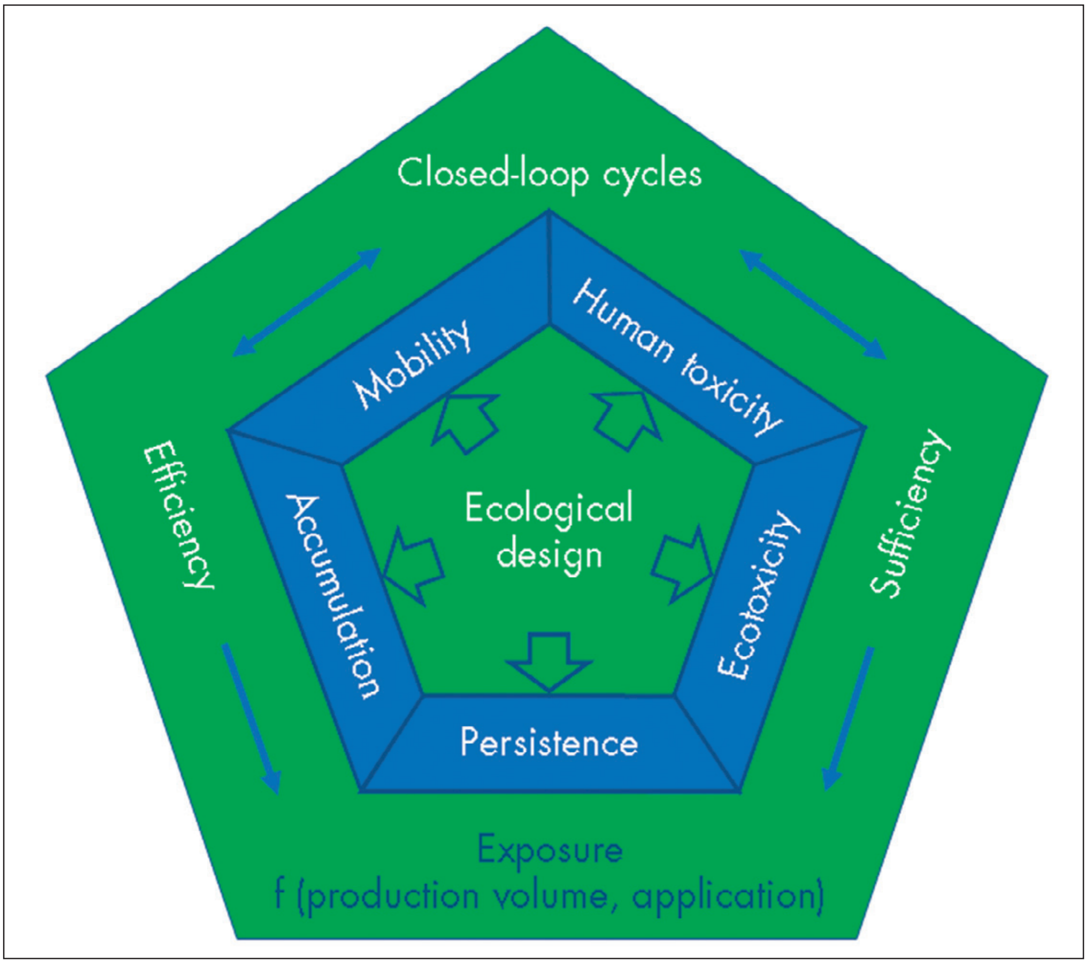

Figure 5: Minimising chemical risks by reducing exposure and effect (adapted from Friege [276])

FoE Germany calls for sustainable chemistry as well as a consistent implementation of a sustainable chemicals, resource and materials policy with special emphasis on the precautionary principle.

This means in detail:

9.1 Recommendations for the further development of international chemicals and materials policy

In view of the steadily increasing production of chemicals and the international spread of hazardous substances and waste, chemicals and materials policy today needs a global approach to ensure that planetary boundaries are not exceeded any further.

- Chemicals and materials policy must be linked to the United Nations' Sustainable Development Goals (SDGs), especially with respect to SDG 12 on sustainable production and use and SDG 3, which calls for action to address the health impacts of chemical exposure. The SDGs must be more than mere declarations of intent, but require the development of appropriate measures for their implementation.
- A global framework convention on the sustainable management of chemicals, materials, waste and resources is needed that provides for effective global restrictions on the production and use of chemicals in order to comply with planetary boundaries.

Such a convention should serve as an umbrella for existing international regulations and at the same time lead to an overarching strategy for the significant reduction of environmental impacts from chemicals and resources and include regulations for material flow management along the value chain. The "Strategic Approach to an International Chemicals Management" (SAICM) process can be further developed as the basis for such a framework convention. The measures adopted must become binding, and indicators for measuring the achievement of goals must be developed and defined. The implementation of a sustainable chemicals and waste management, taking into account the "polluter pays principle", must be accelerated considerably. The countries of the East and South must be supported in establishing their own chemical management systems.

- Consistent expansion and enforcement of the existing international chemicals conventions, in particular also to prevent illegal exports of hazardous waste (Basel Convention).
- The currently negotiated global plastics agreement must lead to an effective restriction on the production, use and waste volume of plastics. It should be integrated as an essential element under the umbrella of a future global framework convention on the sustainable management of chemicals, waste, materials and resources.
- The export of hazardous waste from the EU to developing and emerging countries in the South must be prevented through consistent controls and prosecution of violations of the Basel Convention.
- The fragmentation of international chemicals and waste management across numerous forums must be ended to enable a consistent approach. A Science Policy Panel on the management of chemicals and waste must be established in accordance with the decision of UNEA 5.2 (United Nations Environment Assembly) and equipped with comparable competencies and funding as the IPCC (Intergovernmental Panel on Climate Change) and IPBES (Intergovernmental Platform on Biodiversity and Ecosystem Services). When appointing members, particular attention should be paid to their independence so that no conflicts of interest arise.
- Develop international rules to reduce the complexity of global material flows to enable a circular economy. Global action plans to reduce environmental inputs of phosphorus and reactive nitrogen, and consistent enforcement and tightening of fertiliser regulations at national and EU level.

9.2 Recommendations for the further development of European chemicals policy

- In some essential points, this chemicals regulation must be further developed so that it can contribute more effectively to the implementation of the "Green Deal" and the EU "Chemicals Strategy for Sustainability". Inconsistencies between the various substance-related legal pieces must be eliminated.
- Consistent implementation of the precautionary principle to avoid previous mistakes when action was taken too late after the harmful effects were recognised.
- The further developments envisaged in the "Chemicals Strategy for Sustainability" must be implemented promptly in order to pursue the goal of a "toxic-free environment". They must not be watered down under any circumstances.
- In this sense, the EU Commission is called upon to present an ambitious draft of a REACH revision as soon as possible.
- Clearer and stricter requirements for (imported) products, intermediates, polymers and nanomaterials are needed.
- For chemicals that form by-products with other substances in the environment as intended, these transformation products shall be identified, investigated and evaluated.
- Efficient, more numerous checks ("compliance checks") of registration dossiers at EU level and stricter obligations to implement and update them

correctly are necessary. In serious cases, registrations must be invalidated and the marketing and use of the substances concerned must be banned in accordance with the REACH principle of "no data, no market".

- In addition to dossier evaluations, products must also be increasingly checked for REACH conformity. Strong sanctions and fines are needed to guarantee pollutant-free products and a level playing field. This requires harmonising the enforcement of all national enforcement authorities of the EU member states and equipping them with the necessary resources.
- The European Chemicals Agency (ECHA) shall disclose all substances for which complete toxicological and ecotoxicological data are not available, as well as the names of companies and other registrants that do not promptly correct inadequate or incorrect dossiers.
- Clearer requirements are needed for the transfer of information in the product chain up to the recycling companies to create transparency about the material composition of products and prevent potential risks.
- A joint assessment of substance groups ("grouping") must be carried out in order to accelerate the regulation of substances of concern and to avoid inappropriate substitutions by structurally similar substances. Per- and polyfluorinated alkyl substances (PFAS) can serve as a model for other substance groups, e. g. plasticisers.
- Substances with hazardous properties may no longer be used in applications close to the consumer (consistent application of the "generic risk approach") or enter material cycles for recycling. For substances of concern, the hazard-based assessment is the basis for restrictions and bans. Only essential uses are to be allowed for a limited period of time.
- Substances that are persistent, mobile and toxic (PMT) or very persistent and very mobile (vPvM) are to be included among the substances of very high concern (SVHC), just like endocrine disruptors. The criteria for classification and labelling in the CLP Regulation should be expanded accordingly.
- The assessment across several legal regulations is to be simplified by applying the principle of "one substance – one assessment".
- There must be a reduction in the use of pesticides and biocides through changes in agricultural practices or reduced use of biocides. Medicines that are harmful to the environment must be made prescription-only.
- The polluter pays principle must be more clearly anchored and levies introduced on (internet) trade in substances of concern and products containing them. Revenues generated by this should flow into the financing of surveillance.

9.3 Recommendations for the further development of substance evaluation and chemicals management

In addition to toxicity and ecotoxicity, accumulation, mobility in the water cycle and especially persistence are key hazard characteristics in substance assessment. Particular attention must be paid to indirect effects, combination effects and the assessment of nanomaterials and endocrine disruptors. The persistence of substances deserves special attention, as it has been shown that many long-lasting substances lead to delayed damage in the environment that was not suspected when these substances were introduced. Therefore, the following measures in particular are necessary:

- Prevention of the irreversible input of synthetic persistent substances into the environment.
  Measures for ecologically sound retrieval and remediation of existing contamination with persistent materials such as plastics, applying the polluter-pays principle.
- Prevention of the irreversible input of synthetic bioaccumulating substances into the environment.
- Prevention of the irreversible input of synthetic highly mobile stable substances into the water cycle.

- Prevention of the exposure of humans and the environment to synthetic endocrine disruptors.
- Phase out of the production and use of particularly critical groups of substances. The per- and polyfluorinated alkyl substances (PFAS) are to be phased out as completely as possible by 2030.
- Consideration of combination effects of substances in substance mixtures and in combined use of several products. The "Mixture assessment factor" (MAF) provided for in the Chemicals Strategy for Sustainability, must be implemented expeditiously.
- Further development and introduction of adapted testing and evaluation strategies to assess the particular risks of nanomaterials.
  Development of a control and regulation system to follow the developments of this technology and to ensure safe handling of these materials.
- Implementation of provisions on nanomaterials in the core text of REACH (e.g. lower quantity thresholds for data requirements).
- Testing and evaluation strategies of bio-persistent fibres.
- Participatory, critical monitoring of the development of "Advanced Materials".
  Prioritisation of potentially hazardous products and development of "safe by design" concepts.
- Implementation of an effective micro-pollutant strategy. Introduction of cross-legislative measures to reduce the input of trace substances into water bodies, including the expansion of wastewater treatment plants with the fourth purification stage.
- Minimisation of inputs into the environment of substances that are produced in large quantities and not used in closed cycles such as detergents, plastic products, lubricants, cosmetics, pharmaceuticals and other products for daily use.

9.4 Recommendations for sustainable material flow management

Starting with the extraction of raw materials to the recycling and disposal of waste, material flows and the consumption of resources and water must be reduced (minimisation requirement). The current consumption of energy and resources is not sustainable; too much entropy is created. This can be changed by meeting the following requirements:

- A circular product design that is capable of circular economy is needed. Already during the development and design of products, requirements of sustainable material flow management must be considered. To this end, the educational objectives and the curricula of design courses should be examined and, if necessary, reformed (see also section 9.6).
- The use of chemicals that are hazardous to the environment and health must be limited to essential applications. Hazardous substances must be removed from material cycles.
- Legal regulations on the transparency of deliberately added ingredients (including critical impurities) are needed for products in all sectors. These must be easily and comprehensibly accessible to all actors (e.g. supply chain, civil society, recyclers). Global standards on product transparency are necessary.
- A trend reversal in chemical production is needed: a significant reduction in production volumes is necessary. For this, chemical consumption must be reduced through higher efficiency and more sufficiency. The (significantly reduced) raw material base must change in the medium term: To this end, sustainable ways of providing raw materials in a regenerative way must be developed. Concrete reduction targets for the use of chemicals and resources must be formulated.
- Processes are to be designed in such a way that they have a high energy efficiency and few losses due to an increase in entropy, for example through fine distribution in products and thus subsequently in the environment (dissipation).
- In the manufacture of substances and products, the use of chemicals must be kept as low as possible along the entire value chain up to the finished product.
- A comparative assessment of the cumulative energy and resource use (CED, CRD) and greenhouse gas

(GHG) emissions of products and processes is necessary and should be considered in the EU Seville process – i. e. in the EU BREFs.

- Material resources are to be used sparingly. During raw material extraction, inputs into the environment through mobilisation of the raw material and its by-products are to be avoided.
- Measures are needed to promote and expand the recycling of critical raw materials such as lithium, cobalt, neodymium or tantalum.
- Extraction and consumption of resources must be drastically reduced in order to comply with planetary boundaries.
- An international agreement in the context of a framework convention on the sustainable management of chemicals, materials and resources to cap the global extraction of raw materials is necessary.
- A European and a German resource protection law with ambitious targets are necessary.
- There is a need to promote sustainable consumption and sustainable public procurement. Consumers need more information and advice to be able to adapt their consumption behaviour and lifestyle to the requirements of sustainability (sufficiency). This also requires economic incentives to steer consumer behaviour.
- Legal regulations are necessary to largely prevent the destruction of usable goods in mint condition.
- Recycling rates must be at least doubled in the next 10 years. The use of recycled materials must be strengthened. Secondary materials in anthropogenic storage must be used as far as possible. Among other things, government incentives for the use of products made from secondary raw materials are necessary.
- The recyclability and long service life of products must be enforced through effective measures, i. e. legal requirements, targets and consumer information. Examples:
  - Consumers can access easily understandable, comparable information via eco-labels and the digital product passport;
  - Requirements to reduce the complexity of ingredients in products must be formulated and enforced;
  - Non-recyclable composites should be avoided unless they have clear advantages in terms of functionality and energy efficiency;
  - The use of additives in plastics and of non-removable alloy components in metals must be minimised;
  - Impurities that restrict the use as a secondary raw material are to be avoided as early as possible in the production chain;
  - Ease of repair can be achieved through modular construction; and
  - Products are to be designed to have the longest possible service life and a right to repair is to be made mandatory.
- The international convention currently being negotiated to prevent inputs of plastic into the environment, especially the ocean, must include ambitious global commitments.
- The EU plastic strategy to reduce plastic emissions (bans on use, deposit regulations, expansion of sorting and collection systems, etc.) must be consistently developed further and tightened up. The decision of the Basel Convention to make it more difficult to export polluted, non-sorted plastic waste must be implemented.
- Ecologically high-quality recycling is to be promoted. The waste hierarchy must be consistently observed: Avoidance has priority over reuse, recycling, recovery and disposal. The interface between chemicals and waste legislation must be improved. This will make it easier to recycle materials from waste either materially or chemically.
- For products and processes, non-chemical solutions are to be preferred as long as they have no disadvantages in terms of functionality, energy and resource efficiency.
- More incentives are needed for the use and further development of resource-saving service models such as chemical leasing.

9.5 Recommendations for sustainable chemistry

Sustainable chemistry means that chemical production and use are aligned with the UN Sustainable Development Goals (SDGs) along the entire value chain networks. It is to contribute to compliance with the planetary boundaries. Therefore, the following measures in particular are required:

- Before using chemicals, the purpose and function should be checked to see if and to what extent it is necessary to use chemicals.
- Development of sustainable chemicals with high benefits and at the same time low undesirable effects and short temporal and spatial ranges ("short-range chemicals").
- Substitution of hazardous chemicals with sustainable chemicals.
- Worldwide implementation of sustainable chemistry in accordance with the resolutions of the United Nations Environment Assembly (UNEA 2, 4 and 5).
- Observance of the 10 characteristics of sustainable chemistry developed by ISC3 (International Sustainable Chemistry Collaborative Centre).
- Measuring progress in the implementation of sustainable chemistry through globally agreed indicators.
- Measures of chemicals management should be accompanied by a "Gender Impact Assessment" (GIA).
- Monitoring of the population's exposure to environmental and chemical stressors (e.g. air and water quality) in order to identify and eliminate unfair burdens on poorer sections of the population.

9.6 Recommendations on research and education policy

Many scientific findings on the contamination and overburdening of the Earth system and with chemicals and materials are the results of the research of the past decades. Numerous questions are still open, many links are unknown. For the further development of a precautionary chemicals management and a sustainable chemicals and materials policy, there is still a clear need for research, which should be taken into account in particular within the framework of governmental research programmes. Furthermore, it is necessary to anchor sustainable chemistry and material flow management in degree courses as well as in education and training.

Recommendations for research:

- Strengthening the independence of research. Scientific research on substance-related risks must not be dependent on funding from industry. Conflicts of interest must be avoided.
- A research focus on how the input of chemicals into the environment can be prevented and reduced and how the transformation of chemical production towards a sustainable chemicals and materials policy can succeed should be established.
- Toxicological and ecotoxicological research in Germany must be ensured and expanded.
- Environmental research and toxicology should focus less on the details of the effects of already known pollutants, often already affected by production and/or use bans, and instead turn their attention to the gaps in knowledge of the numerous less-well studied substances and the combination effects. Persistent substances should receive special attention.
- Research programmes are needed in particular for the following eleven fields of action:
  i. Operationalisation of the planetary boundary "Novel Entities": development of indicators on exposure to chemicals at global, national and company level;
  ii. Development of indicators to measure progress in implementing measures in national and international chemicals management;
  iii. Development of criteria and procedures to implement the precautionary principle, especially with regard to persistent substances;
  iv. Development of criteria and procedures for the assessment of mobile chemicals in the water cycle;

v. Environmental and health impacts of nanomaterials and advanced materials;
vi. Environmental and health effects of endocrine disruptors;
vii. Indirect effects of substances and substance mixtures on biodiversity and biogeochemical cycles;
viii. Combination effects of substance mixtures and in the case of simultaneous or sequential application of different substances or products;
ix. Development of strategies and measures for the reduction of material flows and the sustainable use of products;
x. Development of technical possibilities, strategies and better logistics for recycling; and
xi. Development of strategies for the use of a renewable raw material base for chemical production.

However, gaps in knowledge and an existing need for research are no justification for lack of action in the sense of the recommendations mentioned in sections 9.1 to 9.5!

Recommendations on education:

- The subject of "sustainable chemistry" must be anchored in the education of chemists, process engineers and similar degree courses, and corresponding teaching materials must be developed.
- The topics of life cycle analysis, material flow management and circular economy must be included in the curriculum of all engineering courses and natural sciences.
- Degree courses and further training in toxicology and ecotoxicology must be consolidated and expanded.
- Education and training programmes for the responsible, sustainable use of materials and products must be expanded.
- Educational offers for pupils and citizens on the sustainable use of materials should be developed and expanded.
- Professional information on the sustainability of substances and products, developed and verified by independent experts, should be made available to the public.
- Access to information on the sustainability of substances and products by consumers and non-governmental organisations should be improved. Manufacturers must provide the relevant information in a verifiable manner.
- Textbook publishers should give more space to the area of sustainable chemicals and materials policy in new editions.
- Continuation of the BilRess programme – resource competence in education and training (cf. [277]).

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The political position of BUND/Friends of the Earth Germany in the BUND Positions

The world is facing immense ecological, social and societal challenges. BUND/Friends of the Earth Germany seeks and designs solutions that meet ecological and social sustainability criteria. As an environmental and nature conservation organisation, we fight in particular for compliance with the 1.5 °C upper limit in the climate crisis and for climate justice, for an end to the extinction of species, and for the protection and appreciation of nature and biological diversity. We campaign for truly sustainable agriculture without genetic engineering, an immediate nuclear phase-out, and a reduction in resource consumption. BUND / FoE Germany campaigns aim to end the domestic and global dumping of industrial and household waste, the littering and poisoning of our environment with pesticides, countless pollutants and microplastics, among other things. As Germany's largest sustainability NGO, BUND / FoE Germany is committed to social and ecological justice, the fight against poverty, human rights and democracy. Our experience has taught us that you cannot have one without the other.

These goals cannot be achieved if only the environmentally and socially sustainable possibilities for increasing the resource use efficiency are exhausted. For an absolute reduction of our resource extraction from the environment, we also need sufficiency: we must not only consume differently, but also less. A sustainable change in the lifestyle of all citizens is not an individual responsibility, but a common and societal one. To promote the common good, we need not only more rights of participation for civil society, but above all we need a favourable political framework. For example, BUND / FoE Germany has long been calling for energy conservation to reduce final energy consumption by at least half, so that the rest can be provided by renewable energies – studies by the German Environment Agency confirm these demands.

If the extinction of more and more species is to be stopped and our natural areas protected, then the consumption of land for more and more roads, commercial zones and residential areas must finally be stopped and agriculture must be made compatible with the environment and animal welfare. The consumption of raw materials must be drastically reduced in the course of this century, e. g. by a factor of 10 or more – a rapid and massive reduction would help to overcome the climate crisis, to stop the loss of biodiversity and to enable future generations in all countries to have equal development opportunities.

Our economic system must become leaner in terms of materials and energy. This is a great challenge, but it can be done. However, it will be impossible to accomplish this task if policy-makers continue to give priority to economic growth over the preservation of the basics of nature and human subsistence. Growth policy, whether succeeding in stimulating economic growth or not, is the driver of damage to nature and the environment – for example, through the expansion of infrastructure with excessive land consumption (airports, roads, river expansion), the promotion of export-oriented agriculture with far too many animals and much more. It demands and promotes low-wage sectors, income polarisation and a global predatory economy. Democratic decisions and citizen participation are restricted by regulations accelerating spatial planning and the weakening of citizen participation and their right to bring government decisions to court, all in order not to endanger the growth targets. Governments on all levels, inspired by neoliberal policies, have enacted such regulations believing this would accelerate economic growth.

The necessary socio-ecological transformation offers the chance for a good life within the planetary boundaries, under living and working conditions with more justice and community spirit and less determined by egoism, competition and exploitation. Many of our fellow citizens have recognised how necessary such a turn towards the good life is, not least in the pandemic crisis since 2020 and the militarisation of public discourses since the 2022 Russian invasion of Ukraine. Many working conditions and lifestyles will change and have to change, through new technologies as well as through a new, sustainable design and new, sustainable forms of well-remunerated and voluntary work. This requires not only new job profiles and qualifications, but also that status, pay and social security are improved in many areas of the economy and administration.

BUND / FoE Germany stands not only for ecological, but also for social, institutional and economic sustainability – that is why our positions always include approaches that contribute to social justice, good work and sustainable economic activity. In doing so, BUND / FoE Germany always looks beyond the horizon and develops perspectives together with the partner organisations in our international network, Friends of the Earth Europe and Friends of the Earth International, and other civil society organisations sharing our vision. BUND / FoE Germany is not linked to any political party and – proudly – financially independent from government funding, and does neither accept business donations, nor enters partnerships with commercial groups or entities. This gives us the freedom to choose the right partners among, for instance, consumer, development, feminist or peace NGOs, trade unions and religious organisations.

There are alternatives to a policy that is driving into a dead end at an ever increasing speed! BUND / FoE Germany presents such alternatives in the BUND Positions, which are developed by the 20 federal thematic working groups, refined by the BUND / FoE Germany Scientific Committee, and finally adopted by the Federal Board. Academic and non-academic expertise is brought together on an equal footing in the federal thematic working groups, and the draft Positions are jointly examined in the scientific advisory board by experts from 20 subject areas – BUND / FoE Germany has been practising the principles of inter- and transdisciplinary science for decades. Thus, all BUND Positions are based on socially robust and evidence based interdisciplinary scientific knowledge (not necessarily mainstream), providing the knowledge base for campaigning, public mobilisation, environmental education, political lobbying for political and social solutions to sustainability problems, and for managing high biodiversity value land owned or managed by BUND / FoE Germany. Each of these Positions, including the one presented here, is an important building block in the overall picture of the socio-ecological transformation towards a sustainable economy and way of life.

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Resolution of the BUND (Friends of the Earth Germany) Federal Executive Board of 24.03.2023

FoE Germany Federal Working Group on Environmental Chemicals/Toxicology

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