Bund für
Umwelt und
Naturschutz
Deutschland

BUND
FRIENDS OF THE EARTH GERMANY

Challenges for a Sustainable Chemicals and Materials Policy

The Need for Transformation in the Global Context

In memory of Karl Otto Henseling

CONTENTS

EXECUTIVE SUMMARY

Over the past few years the use of natural resources and the production of chemicals have increased dramatically – and a further increase is forecast. Whereas earlier the main focus was on local effects on health and the environment, in the meantime it has become clear that current ways of dealing with natural resources, chemicals and products manufactured from chemicals are threatening the biosphere as a whole.

In 2009 and 2015 scientists introduced the concept of planetary boundaries [1]. 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" – which scientists define as chemicals humans have introduced into the environment that were not present previously – six of these boundaries relate to the use of resources as well as the use of chemicals and 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 growth is accelerating. No reversal of the trend is in sight. Humanity has already left the safe operating space.

What contribution can a sustainable chemicals policy make? Until now quantifying the planetary boundary for "novel entities" has not been successful. This is also due to the fact that the variety of substances with varying effects is increasing. We are only gradually ascertaining what consequences this diversity of substances is having on, for example, sensitive ecosystems. Many of these chemicals have been stable in the environment for centuries. The examples of chlorofluorocarbons (CFCs) 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 they 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 – acting on ecosystems and on human health must be taken into consideration. The global dimension of materials 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 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 policy. Examples: Persistent substances should not enter the environment and substantially fewer toxic chemicals should be produced. Where possible, fewer chemicals should generally be used. If a chemical or product is still used, this should be done as efficiently as possible – in other words, with a high level of benefit. At the same time, making the remaining materials flows part of a recycling loop, optimally as a closed-loop cycle, should be considered. The statutory regulations for chemicals, product and waste legislation must share a common basis and be closely coordinated with each other.

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 current chemicals policy and, similarly to environmental protection, requires a comprehensive transformation of economic activity and consumer behavior. 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 preventive 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.

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 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 sustainable material flow management with special emphasis on sufficiency as a solution approach.

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 national working group had already coined this term as early as 1983. In the first issue of the information bulletin service "Chemie und Umwelt" on chemicals and the environment published by FoE Germany, the Öko-Institut and the German Association of Citizen's Initiatives (BBU) it says:

> *It is almost beyond belief that regulation of the use of chemicals does not represent a separate and independent political policy area despite serious environmental problems. It goes without saying that there is economic policy, social policy, agricultural policy – but no chemicals policy.*

Chemicals policy exists today: catastrophes such as the Seveso disaster in 1976, the Bhopal disaster in 1984 and the Sandoz chemical spill in Schweizerhalle, Switzerland, in 1986 all triggered discussion of chemicals policy in the political arena. In the meantime, European and German legislation have been passed to protect against the risks posed by chemicals. On the one hand, the results are notable: Many chemical manufacturers have safer production practices. With the Responsible Care Initiative the chemicals industry is committed to its responsibility for the safety of its production and products. Laws were also improved: For the first time, the EU regulation for Registration, Evaluation, Authorization and Restriction of Chemicals (REACH) requires companies manufacturing or importing chemical substances into the European Union to provide evidence that all their chemicals are safe for humans and the environment (this applies to annual production volume exceeding one ton). Among other things, Germany's Federal Pollution Control Act (*Bundesimmissionsschutzgesetz*) regulates the manufacture and handling of chemicals in industrial plants. On the other hand, the exposure of people and the environment to chemicals continues to be a problem.

In Western industrial countries the concentrations of some harmful substances in humans and the environment have declined; environmental protection technology and some legal provisions are having an effect. Nevertheless, modern chemical analyses reveal that there are more and more problematic chemical substances in the environment and make clear in this way that considerable need for action continues to be required. Both the micropollutants strategy of FoE Germany (July 2017) [2] as well as that of the German Federal Environment Agency (Umweltbundesamt – UBA) (April 2018) [3] show how necessary it is to adopt measures against the wide range of chemicals in environmental media.

The complexity of substances is also increasing in consumer products. Transparency about the ingredients products contain remains poor. The same applies to many modern products such as electronic devices, or cars, which today are made from a large number of complex materials and building blocks. This makes recycling difficult or even impossible. Many valuable raw materials are lost in this way. The rapid increase in global materials flows poses new challenges to chemicals policy. New approaches which are considered viable into the future such as Power-to-X [1] or the use of renewable resources are the subject of controversy regarding their feasibility and their true contribution to greater sustainability, while their consequences have not yet been conclusively determined.

After looking back over more than 50 years of debate on chemicals (Chapter 2) we turn our attention to the key basic principles of a sustainable chemicals policy (Chapter 3) and then to the global dimension of chemicals policy (Chapter 4). Within the EU, REACH is the central legal norm for chemicals safety and features substantial advances and several weaknesses (Chapter 5). In Chapter 6 we discuss the significance of persistence and other hazards related to chemical substances before discussing quantitative aspects of sustainable materials flow management in Chapter 7. Finally, we present the guiding principles and recommendations of FoE Germany for a sustainable chemicals and materials policy (Chapter 8).

1 Power-to-X (PtX) processes utilize (renewable) energy to create liquid or gaseous chemical energy sources from carbon dioxide (CO_2) and hydrogen (H2).

2 LOOKING BACK ON OVER 50 YEARS OF DEBATE ON CHEMICALS

The debate about chemicals has changed. In the mid-20th century the permeation of our life with chemicals was still just beginning, as was the chemicals policy debate. This changed in early 1962 when Rachel Carson published her book "Silent Spring" in the United States [4]. In her book the biologist presented facts about the use and effects of pesticides. That is now over 50 years ago, but many of the questions she raised are still so valid today that the Academy of Sciences Leopoldina gave its recently published discussion paper on pesticides almost the same title: "The Sleeping Spring" [5].

That chemicals can have an effect on our health and the environment mainly became apparent to people due to accidents at industrial plants as well as bad experiences with the use of products (e.g., formaldehyde in particle boards or chlorinated solvents in drinking water). Until the 1990s the risks posed by chemical factories and the elimination of dangerous waste dominated debate on the topic. Chemicals and chemical products are widely regarded as generally hazardous.

As early as the 1960s and 1970s, resistance of people to the dangers of chemicals grew. Environmental protection groups and local initiatives fought against the effects of such environmental pollution and for clean production, use and disposal of chemicals, as well as for a safer life in an increasingly chemical world.

At the beginning of the 1980s, experts from FoE Germany began their first fundamental consideration of this subject. In 1983, FoE Germany's National Working Group on Environmental Chemicals and Toxicology coined the term chemical policy. In 1984, FoE Germany's tenth position paper entitled "Chemicals policy – FoE Germany calls for a new policy area" ("Chemiepolitik – der BUND fordert einen neuen Politikbereich") was published [6]. This includes the following three principles of chemical policy:

- A minimization requirement should apply both to the extraction of raw materials from the environment and to the introduction of substances into the environment (sufficiency).
- In the case of the recycling principle, the return of products or the recovery of substances should be given priority.
- It is important to develop an ecological design for substances. This means that – as far as possible – chemicals should be used that can be incorporated into natural material cycles when released.

Further publications from the working group followed [7-9]. Ten years later, the working group looked more closely at the consequences of increasing chlorine use in chemical production. In February 1994 the 24th FoE Germany position paper "Chlorine chemistry – an era is coming to an end" *("Chlorchemie – eine Ära geht zu Ende")* followed [10].

In 1999, the German Federal Environment Agency also described fields of action and criteria for a precautionary and sustainable chemicals policy [11]. In it, among others, the following environmental action goals are named:

- Regardless of their toxicity, the irreversible entry into the environment of persistent and/or bioaccumulating contaminants should be completely avoided.
- If retrieval is impossible in practice because of their wide distribution and/or low exchange (minimization requirement), an increase in the input of materials into the environment is to be avoided independently of currently known effects and other intrinsic[2] properties.

These guidelines are still fully current.

The debate has evolved since then. Today, it no longer concentrates only on chlorine chemistry but, for example, on chemicals that have a detrimental effect on the hormone system (endocrine disruptors), that persist in the environment over long periods of time (persistent), or that accumulate in living organisms (see Chapter 6). The protection of biodiversity is now a central protection objective alongside the protection of human health. Furthermore, the risks of increasing exposure[3] of humans and the environment to products and waste containing synthetic chemicals have become more prominent.

Chemicals policy today goes far beyond national tasks. The interconnectedness of global trade and threats to the Earth system through global warming, biodiversity loss and also the growing volume of synthetic chemicals demonstrate that a sustainable chemicals and materials policy is needed worldwide (see Chapter 4). This challenge is also reflected in the United Nations "Sustainable Development Goals" (SDGs) [12]. This ap-

2 Intrinsic properties are properties that are inherent to the object itself and make it what it is.

3 Exposure refers to the extent to which humans or the environment are exposed to substances.

plies in particular to the twelfth of these goals, which refers to sustainable production and sustainable consumption (SDG 12).

In the past 20 years, it has also increasingly been recognized that the best way to reduce the burden on humans and the environment is to analyze and control materials flows, as environmental pressures are increasingly being created through resource extraction, the products themselves, and the waste after the end of their useful life. As early as 1998, the Committee of Inquiry of the German National Parliament "Protection of Humans and the Environment" formulated five basic rules that must be observed for sustainable future-oriented development (see Section 7.1). Today, chemicals policy is closely linked to product and waste policy. The circular economy is thus also a chemicals policy challenge.

3 GUIDING PRINCIPLES OF A SUSTAINABLE CHEMICALS AND MATERIALS POLICY

The difficulty in finding guidance for a sustainable chemicals and materials policy is that it must be carefully weighed . It is important to design the use and production of chemicals in such a way that negative consequences are avoided as far as possible. This is especially true for the use of problematic substances that can enter the body or the environment. However, non-synthetic substances or processes are not always preferable. These can have significant disadvantages in terms of energy consumption, resource consumption, effectiveness or health effects. A sustainable chemicals and materials policy thus goes beyond a mere chemicals policy. It covers the entire life cycle of products and the materials used. It also considers the exchange of problematic substances, the closure of cycles and the significant reduction in the use of substances and energy. Achieving the Sustainable Development Goals (SDGs) formulated by the United Nations in 2015 (see above) 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 characterize a sustainable chemicals policy: the precautionary principle and sustainability.

3.1 The precautionary principle

As early as 1986, the Federal Government published guidelines on the precautionary principle [13]. According to this, precautionary environmental action encompasses all areas

- that protect against concrete environmental hazards ("hazard control"),
- that prevent or reduce risks to the environment (" risk prevention"),
- that proactively shape our future environment, in particular through the protection and development of natural resources ("provision for the future").

The precautionary approach is based, on the one hand, on the limitations of knowledge of the environment and the effects of substances, on the other hand, on the need to protect future scope of action.

In the international area, this guiding principle is also reflected in numerous documents and contracts. In 2000, the European Commission published a Communication on the precautionary principle [14]. Agenda item 21 Chap. 35 (3) of the UNDP Conference in Rio de Janeiro in 1992 stated:

Given the danger of irreversible environmental damage, a lack of absolute scientific certainty should not serve as an excuse for postponing measures that are intrinsically justified. For actions related to complex systems that are not yet fully understood and where the consequences of disruptions cannot yet be predicted, a precautionary approach could serve as the starting point.

The 1992 International Convention for the Protection of the Marine Environment of the North-East Atlantic Ocean (OSPAR) [15] described this in 1992 in the following way:

> *Parties shall... take all possible measures to prevent and eliminate pollution, and take all necessary steps to protect the maritime area against the adverse effects of human activities in order to protect human health, maintain marine ecosystems and, where feasible, restore degraded maritime zones.*
>
> *The parties to the contract adopt the following principles:*
>
> - *the precautionary principle, according to which preventive measures are taken where there are reasonable grounds for concern that substances or energy directly or indirectly introduced into the marine environment are leading to hazards to human health, to damage to living resources and marine ecosystems, to adverse effects on the environment, or to interference with other legally permitted use of marine resources, even if there is no conclusive evidence of a causal link between the inputs and their effects.*

- *the polluter pays principle, according to which the costs of measures to prevent, control and reduce pollution are to be borne by the polluter.*

According to the precautionary principle, action must therefore be taken as soon as there are "reasonable grounds for concern", that is, when exposure to non-natural, persistent and mobile substances is high. Although the precautionary principle has found its way into numerous national, European and international regulations and should be a binding guiding principle, it is rarely implemented effectively in the context of chemicals policy. The publications of the European Environment Agency "Late Lessons from Early Warnings" (EEA 2001 [16] and 2013 [17]) mention numerous examples of too little attention to the precautionary principle (for example PCB, DDT, CFC, bisphenol A).

Precautionary action always involves reducing theoretically possible and reasonably foreseeable – and not (as in the case of hazard control) merely sufficiently likely – environmental damage. This means that even before the harmfulness threshold has been reached, the suspicion of harmful effects should be investigated and appropriate measures taken as precautionary action. So the following has to be considered:

- Precaution means that a suspicion of harmful effects should be investigated and appropriate measures taken even before the harmfulness level has been reached.
- Precautionary action requires maintaining an adequate safety margin in placing the harmfulness threshold.
- Precautionary actions are required if, in the case of delayed risks, later damage cannot be ruled out with sufficient probability.
- Precautionary action can already require risk reduction if causal, empirical or statistical causation relationships are not yet completely known or proven.
- Precautionary action commences with environmental pollution that is in itself harmless, but becomes harmful or preventable when combined with other stressors.

Compliance with legal limit values which serve only to protect against hazards does not satisfactorily satisfy the principle of precautionary action [18, 19]. The precautionary principle is linked to the formulation of concrete environmental quality and action objectives. It is also linked to the minimization requirement, which aims at a general improvement of the environmental situation[4]. Consequently, limit values should not be understood as maximum values that can be exploited. New scientific findings can also lead to lower limit values.

It is therefore important, even for substances that are currently considered to be unproblematic, to reduce the quantities of substances released into the environment. This applies in particular to substances for which delayed and unknown effects cannot be ruled out (see Section 6.1) – even if such substances occur naturally (from biogenic or geogenic sources) in the environment. A reduction in the quantities of substances is also necessary, as they require additional resources, including energy and water, for their use.

The OSPAR Convention – like the EU Treaties and the Federal Government's environmental policy – also refers to the polluter-pays principle. According to this, the costs of preventing and eliminating environmental damage are borne by the polluter. In many cases, the specific polluters cannot be unequivocally identified, so that costs are passed on to the general public. However, the polluter-pays principle also establishes fee systems (in Germany, for example, the sewage fee). However, this option is rarely used by lawmakers.

3.2 Sustainability

With the 1992 United Nations Conference on Environment and Development in Rio de Janeiro, the international community declared sustainable development a binding goal of global environmental and chemicals policies. Since then, sustainability has been anchored in numerous national and international documents as a guiding principle. Sustainability means meeting the needs of today's generation without compromising the opportunities of future generations. Thus, both intragenerational (within a generation) and intergenerational (between generations) justice needs to be achieved. Sustainable development is often divided into ecology, economics and social issues, with the ecological aspects describing the navigational channel within which economic and socially just development should take place [20]. Many people in politics and business talk about sustainability without acting in accordance with it. The scope for action is getting narrower; current global development blatantly contradicts the requirements for a sustainable development which still leaves room for maneuver.

In 2001, the Federal Government appointed the Sustainable Development Council as an advisory body for sustainable policy [21]. The German Federal Environment Agency's publications

4 According to Article 191 (1) TFEU, improving the quality of the environment is an EU objective.

"Nachhaltiges Deutschland" [22, 23] and the studies by FoE Germany entitled "Zukunftsfähiges Deutschland" (BUND) entitled "Zukunftsfähiges Deutschland" (both: „Sustainable Germany") [24, 25] showed in several areas of action what fundamental course needs to be followed to attain a sustainability policy. In practical politics and in business, however, sustainability is still subject to the preservation of economic growth. The erroneous belief in achieving "green growth" solely through efficiency gains continues to prevail. However, sustainability in industrialized Europe also requires a fundamental change in economic policy and a political strategy for significant changes in consumer behavior ("sufficiency").

In terms of chemical policy, sustainability primarily means avoiding irreversible damage to the ecosystem. To achieve this, a holistic view of materials flows is needed. In science and politics, the concept of "Green chemistry" has been established over the last 20 years, referring to the products (chemicals) and their production (in particular reducing waste and energy consumption, use of renewable resources, occupational safety, less use of toxic adjuvants). The 12 "Green Chemistry" criteria [26] published by Anastas and Warner in 1998 and the Best Available Techniques (BAT) in Annex III of the EU Industrial Emissions Directive 2010/75/EU [27] specify the benchmarks for sustainability of chemistry.

The term "sustainable chemistry" was used for the first time almost simultaneously by the German Chemical Society (GDCh) and the OECD with a meaning other than "green chemistry." "Sustainable chemistry" means aligning the production, use and disposal of chemicals with the rules of sustainability.[5] According to current understanding, this also includes starting from the functions which chemical substances are to meet, alternative business models and service-oriented thinking, ethics, social and economic aspects, and consideration of whole substance, material and product flows, which are not considered in "green chemistry."

Sustainability and precautionary action largely cover the same issues in their orientation, with sustainability focusing more on global and long-term effects, and precaution focusing more on knowledge deficits. Without optimal environmental precaution, sustainable development is not possible.

4 CHEMICALS AND MATERIALS POLICY IS A PLANETARY ISSUE

Chemical safety and the effects of chemicals have become a global issue.

4.1 Global exposure to chemicals

Safety and environmental standards for the manufacture and use of chemicals in many developing and emerging countries are still as low in many places as they used to be in Germany and the EU. This often has dramatic consequences in these countries: In many cases poor occupational safety, the emission of wastewater and exhaust air as well as the disposal of industrial waste severely burden health and the environment. The export of these risks is not without consequences for Europe either: Here prohibited chemicals and pesticides are reintroduced via textiles, plastics or as impurities (contaminants), as well as in food.

Global materials flows (trade in raw materials, chemicals and finished products) have multiplied over the last 20 years. In addition, European chemical companies have shifted their production to developing and emerging countries. In doing so, they do not always adhere to European safety standards, and thus transfer the associated risks elsewhere. There are also double standards: Products that may no longer be sold in some countries because of those countries' higher environmental standards are migrating to the global South or East.

The same is true of waste. Large quantities are being exported from Europe and the US (often illegally) to the countries of the global South or East. They are processed and disposed of there under in part dramatic environmental and working conditions, often by unskilled workers. Not only old electrical appliances but also whole ships are typical examples. Internationally, the Basel Convention (1989) aims at preventing the illegal export of hazardous waste.

All this is not inevitable. The industrialized countries must not shirk their responsibility for these problems. Industrialized countries are directly or indirectly responsible for many environmental problems in emerging and developing countries. A new global chemicals and materials policy with binding international agreements is needed.

5 On Germany's initiative, the International Sustainable Chemistry Collaborative Center (ISC3) was set up to promote a transformation to sustainable chemistry, https://www.isc3.org/en/home.html.

A good overview of global exposure to chemicals is provided by the new "Global Chemicals Outlook II" [28] of the United Nations Environment Program (UNEP): It is particularly alarming that, according to a WHO estimate, mishandling chemicals costs 1.6 million lives worldwide each year. This shows: Chemical pollution is a risk that is frequently underestimated.

4.2 Planetary boundaries

In 2009 researchers from the Stockholm Resilience Center[6],[7] attracted worldwide attention with the publication of "A safe operating space for humanity." They presented an approach which had the purpose of describing the stability of our planet and defining the planetary boundaries of what Earth can withstand [29].

For the past 10,000 years or so, Earth has been in a remarkably stable state of climate known as the Holocene epoch in geology. This state is characterized by stable temperatures, availability of fresh water, and thousands of years of unchanged biogeochemical cycles. This has made human development to our current way of life possible. The stable climatic phase rendered possible the transition from hunters and gatherers to sedentary farmers with domesticated animals and plants (the Neolithic) – the basis of our current way of life.

However, at the latest with the beginning of the industrial revolution, humans have intervened more and more in biogeochemical cycles and have thus influenced environmental conditions globally. Since the 1950s, science has documented an intensified acceleration of human (anthropogenic) interventions in the Earth system – the so-called "great acceleration" [30-32]. This is reflected, among other things, in climate change, decreasing biodiversity and a nitrogen cycle thrown out of joint. Figure 1 illustrates the great acceleration caused by human activity on the basis of numerous ecological and socioeconomic parameters.

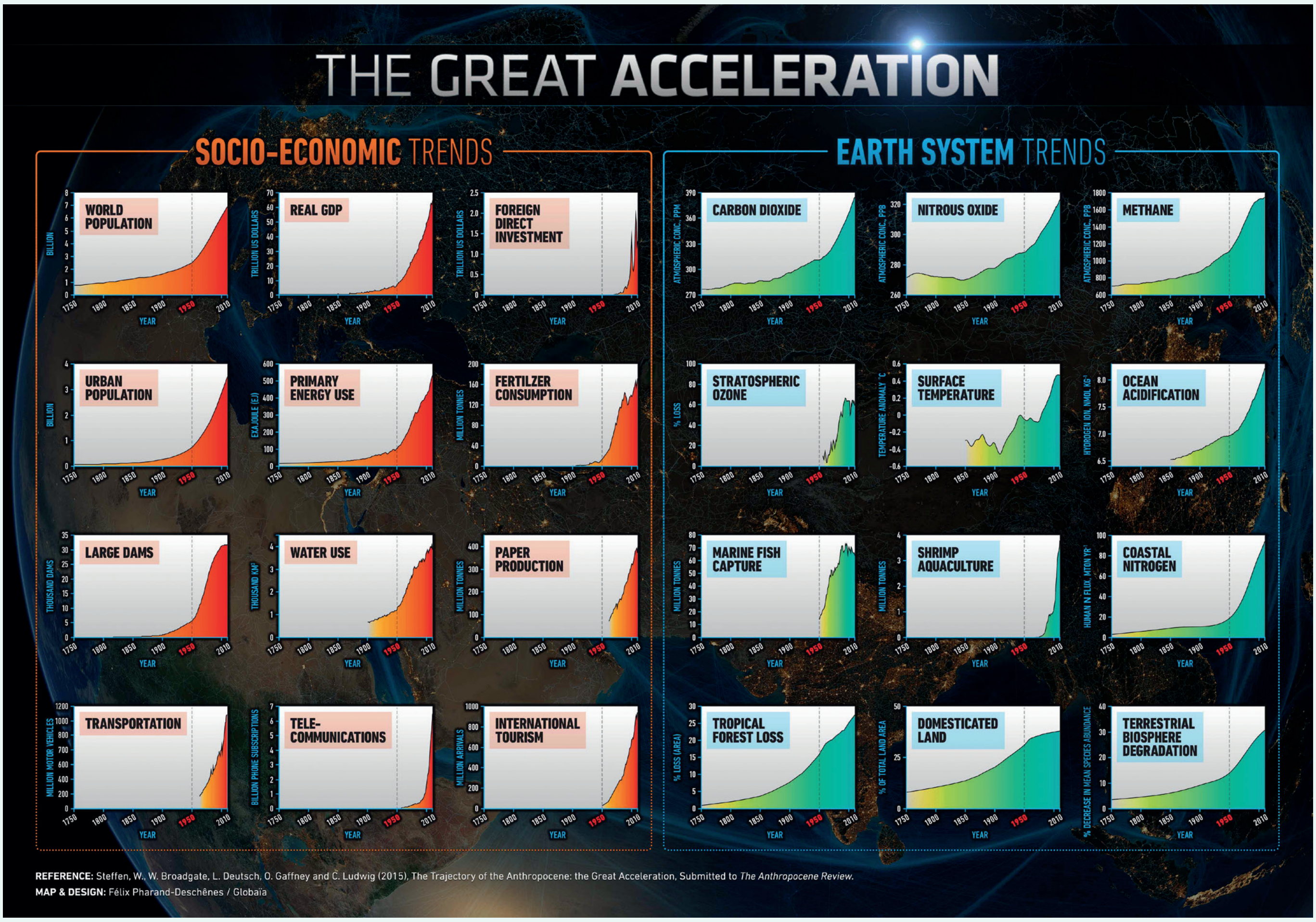

Figure 1: "The great acceleration": Trends in some environmental and socioeconomic parameters over the past 250 years [30]

6 The Stockholm Resilience Center is part of the University of Stockholm, conducts research on global problems and defines itself as a mediator among science, politics, and society. https://www.stockholmresilience.org/.

7 Resilience: The ability of an ecosystem to return to its original state after a disturbance.

In addition, people have released persistent chemicals, radionuclides, and plastics into the environment that can be detected in living organisms and sediments today and will continue to be in the future. The large-scale use of concrete and bricks also creates anthropogenic rock layers. The exploitation of mineral resources often leads to lifeless, deserted landscapes and results in the mobilization of pollutants. Based on these observations, the scientific community is now discussing the start of a new geological epoch: the Anthropocene [31, 33, 34].

According to Steffen and Rockström [1], human activities have reached a level that could seriously disturb the stability of the systems that hold Earth in its Holocene state. Scientists emphasize nine processes that are decisive for the stability of the Holocene Earth system. These influence global interactions between land, oceans, atmosphere, and the biosphere, which together represent the environmental conditions upon which our societies are based. The working group identified variables indicating the resilience of the nine processes they identified (Figure 2).

The dramatic nature of development is also illustrated by the new report "Transformation is feasible" [35] to the Club of Rome. In this case, four scenarios show that unrestrained economic growth is leading to missing sustainability goals and that only a major transformation will enable development that is viable into the future.

The fact that unlimited growth is destroying the limited system of the Earth and that a clear change in thinking and action is indispensable so that our children and grandchildren can still have a life worth living is also made clear by FoE Germany in its criticism of economic growth [36].

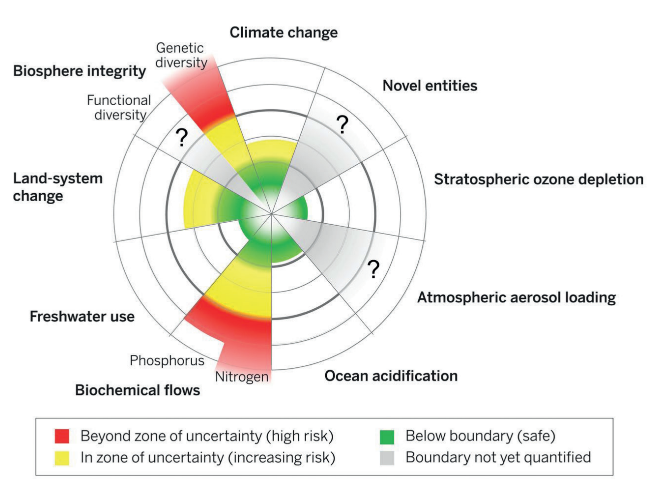

Figure 2: Planetary boundaries for nine global processes [1]

4.3 Planetary boundary: "Novel entities"

One of these planetary boundaries involves the "novel entities" defined by the authors as:

- new substances generated by human action,
- new forms of already existing substances,
- modified life forms (genetically modified organisms or synthetic biology products).

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

Scientists have formulated three criteria that "novel entities" must satisfy in order to have a global impact:

- They are persistent (stable in the environment for extended periods of time),
- mobile over long distances such as climatic zones or continents and correspondingly widespread, and
- able to affect important processes of the Earth system or its subsystems.

By "novel entities" the authors understand, among other things, human-made chemicals that were previously unknown in nature (xenobiotics). But they can also be naturally occurring elements, such as metals, which are first mobilized by human activities and become a problem as a result.[8]

The authors are not yet in a position to quantify planetary boundaries for "novel entities." However, they see signs of stress or even overload, and recommend precautionary action and further research. As an example from the past, the authors cite the chlorofluorocarbons (CFCs), which were initially considered harmless, before it was recognized that they destroy the stratospheric ozone layer. According to the authors, humankind has repeatedly experimented with the introduction of new substances with global effects (such as polychlorinated biphenyls (PCBs), brominated flame retardants, mobilized mercury or lead) without taking into account the risks evident from previous experiments. A great deal of time usually elapses before such interventions become subject to regulation [16,17].

8 The term "novel entities" should not be confused with "new chemicals" in the sense of chemicals legislation, which means substances that have not previously been marketed.

Steffen et al. (2015) argue that, given the variety of chemicals and the many unknown effects, it is difficult to pinpoint specific chemicals or groups of substances that have a destructive effect on the Earth system [1]. For some substances regulated, for example, by the Montreal Protocol or the Stockholm Convention (see below), such hazard profiles are known. Further descriptions of the hazardous properties are to be found in scientific discussions (Persson et al. 2013 [37], McLeod et al. 2014 [38] and Diamond et al. 2015) [39]. In any case, chemicals whose introduction into the environment and thus their potential effects are irreversible over extended periods of time, are potentially problematic. Steffen et al. (2015) therefore recommend a precautionary chemicals management with a focus on sustainable chemistry. Synergies with other areas such as occupational health and safety, increased willingness to learn from past mistakes, monitoring and scientific research can be used to identify global risks from chemicals as early as possible. The findings make it clear that today's chemicals policy must take a global approach, with action urgently required.

The problem of quantifying chemical pollution not only arises on a global scale, but also in operational practice. Recently, there have been suggestions concerning how companies using chemicals or products containing chemical ingredients can measure and reduce their "chemical footprint" [40]. These suggestions involve assessing and assigning a score based on management strategy, inventory of chemicals, identification of the "chemical footprint," strategies for reducing exposure to chemicals, and willingness to disclose data. The questions are aimed at replacing hazardous substances (such as "substances of very high concern" as defined by REACH) rather than reducing the volume of chemical products in use.

Further research is needed to scientifically encapsulate the issues involved in quantification of chemical pollution and to make them usable at the global, national and operational levels.

In their concept, the team of authors around Rockström and Steffen cite further planetary boundaries that are closely linked to the requirements of a sustainable chemicals policy:

- Biogeochemical materials flows: According to the authors, the global pollution limits of nitrogen and phosphorus have already been reached or exceeded.

- Climate change: Here, humanity has also already gone beyond the safe area within the planetary boundaries. The main causes of anthropogenic greenhouse gas emissions are the use of fossil fuels and emissions of other greenhouse gases.

- Acidification of the seas: This is strongly linked to climate change, since about 27 to 34 percent of CO_2 emissions are absorbed by the oceans and cause a reduction of their pH values. This makes it difficult for many marine animals to form their limestone skeletons. According to the authors, the load limits have not yet been reached.

- Ozone loss from the atmosphere: This could be kept within globally acceptable load limits by successful measures to ban ozone-depleting substances such as CFCs.

- Aerosols in the atmosphere: Due to the use of chemicals, the amount of aerosols (small droplets and particles) in the atmosphere has increased significantly. However, the authors could not define a load limit for these pollutants.

- Biodiversity (functional and genetic diversity): Biodiversity is falling dramatically. Insects, birds and other species are becoming extinct as a result of human activity. The load limits are clearly being exceeded. Species extinction has many causes, including, but not limited to, pollution of ecosystems by chemicals, in particular pesticides [5] and other anthropogenic inputs. The World Biodiversity Council IPBES (Intergovernmental Platform on Biodiversity and Ecosystem Services) sees a major reason for the high losses of biodiversity as lying – among other causes – in the extensive use of pesticides as well as in intensive agriculture and forestry [41].

Six of the nine planetary boundaries thus have a close relationship to sustainable chemicals policy. It is thus very important to find solutions in these areas in order to keep the Earth safe for humanity.

4.4 International solutions

It has long been recognized that too many chemicals threaten man and the environment. This is repeatedly emphasized officially by heads of state and government. In some cases, governments have also agreed upon concrete measures:

4.4.1 The commitment of the world community

In 1992, at the Rio de Janeiro Conference on Environment and Development (the Earth Summit), the global community recognized the environmental and human impact of chemicals and wastes as a global challenge. Chapters 19 and 20 of Agenda 21 call for sound management of chemicals and waste. Ten years later, in 2002, at the WSSD (World Summit on Sustainable Development, Rio+10), the international community agreed to minimize the harmful effects of chemicals in their manufacture and use by 2020.

4.4.2 Five global agreements

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

- The Montreal Protocol [42], 1987, prohibits substances responsible for ozone depletion. This first global agreement on chemicals is regarded as having been successful. The concentrations of chlorofluorocarbons (CFCs) and other ozone depleting substances in the atmosphere are slowly decreasing.

- The Basel Convention [43], 1989, regulates the transboundary shipments of hazardous wastes and seeks to prevent illegal exports. This is succeeding to a considerable extent, but does not prevent waste from continuing to be exported on a large scale from developed countries to countries of the South and East. In the Global Waste Management Outlook (GWMO), UNEP points out that only two out of the top 50 landfills are located in the industrialized countries [44], although the level of waste per capita is significantly higher there than in the developing countries.

- In the Rotterdam Convention [45], 1998, state parties undertake to obtain information on transboundary movements of hazardous chemicals (prior informed consent). The list of chemicals is being continually expanded, although consensus has still not been reached on some of the most dangerous substances, such as asbestos.

- The Stockholm Convention [46], 2001, prohibits or restricts the production and use of some persistent organic pollutants (POPs) and also minimizes the unintentionally produced POPs (such as polychlorinated dibenzodioxins and furans) as by-products in technical and thermal processes. Further substances have been identified and listed as POPs on an ongoing basis. The global burden seems to be gradually decreasing.

- The Minamata Convention [47], 2013, aimed at reducing mercury emissions globally, whether through the use of mercury in products and processes or by burning coal.

The Basel, Rotterdam and Stockholm Conventions form a joint secretariat. This should connect chemical and waste management in a meaningful way and exploit synergies.

In addition, there are a number of other multilateral chemicals-related agreements in the framework of UNECE, ILO (International Labour Organization), IMO (International Maritime Organization) and WHO (World Health Organization). The EU and Germany have ratified all these treaties.

4.4.3 The SAICM discussion framework

In 2006, the Strategic Approach to International Chemicals Management (SAICM) process [48] began to achieve the goal of minimizing the negative effects of chemicals and waste in a joint, cross-sectoral process of states with non-governmental organizations. SAICM is conceived as a platform that is designed to operate in a manner that complements other global and regional chemicals management tools. All parties involved recognize the importance of sound chemicals and waste management for sustainable development.

In this platform, global objectives and measures on chemicals policy are discussed and planned, but no legally binding decisions are made. The mandate ends in 2020. It is planned to renew and reaffirm the mandate of SAICM at the fifth International Conference on Chemicals Management (ICCM 5) in 2020. The following strategic goals are to be achieved:

- by appropriate measures avoid or minimize damage from chemicals during their life cycle and from waste,

- use the comprehensive knowledge available for informed decisions and measures worldwide,

- identify topics that require global action, prioritize them, and implement the necessary measures,

- provide innovative and sustainable solutions through forward thinking both to maximize the benefits of chemicals and to avoid risks to human health and the environment.

4.4.4 Globally accepted test, assessment and classification procedures

Another cornerstone of international chemicals management is the chemical program of the Organization for Economic Cooperation and Development (OECD) [49]. Above all, it provides scientifically validated testing and assessment procedures that are internationally accepted.

The OECD has also been involved in the development of the Globally Harmonized System (GHS) [50], which makes it possible to classify and label the hazards of chemicals globally. However, by the fall of 2018 120 countries still had not implemented the GHS, although this was already required by 2008. It is also alarming to note that in the EU 62 percent of the 345 million tons of chemicals manufactured and used in 2016 were harmful to health according to GHS [27]. This also indicates that sustainable chemistry is still a distant goal, even in the EU.

4.4.5 United Nations activities – Sustainable Development Goals

In 2015, the UN General Assembly adopted seventeen goals to be achieved by 2030 (called Sustainable Development Goals, SDGs) [12]. These include several environmental targets related to clean water, climate or the protection of terrestrial and marine ecosystems, and also encompass 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 policy. Target 12.4 refers directly to the decisions of 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, all stakeholders now agree that this goal will not be achieved in 2020. The limited progress has not been sufficient to really improve the situation. On the contrary: The rapid increase in chemical production more than compensates any success and progress made.

With regard to the significant health damage caused by chemicals, target 3.9 of the SDG 3 "Ensure healthy lives and promote well-being for all at all ages" is particularly relevant:

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

At the fourth United Nations Environmental Assembly (UNEA 4) in March 2019, the international community decided to intensify efforts on international management of chemicals and waste and to make significant progress by 2030 [51]. This resolution also recognizes – as was already the case with UNEA 2 in 2016 – sustainable chemistry as an important tool for safe chemicals management. In addition, the goal "Towards a Pollution-free Planet" was announced.

4.4.6 Despite all this: not enough!

Overall, international efforts do not do justice to the magnitude of the problem. The various measures and forums are fragmented and rarely coordinated. After being approved, resolutions often fail to be implemented. At their current pace, the problems will grow faster than the measures take effect. Global boundaries are being exceeded. As pointed out in UNEP's Global Chemicals Outlook II report, "business as usual" is not an appropriate solution. There are solutions; but a far more ambitious and coordinated approach is urgently needed. This also means that the industrialized countries should financially support developing countries more strongly with regard to implementing appropriate measures. There is a close link between poverty and the lack of opportunities for implementing effective management. In addition, the binding nature of international decisions must be increased. This includes formulating binding targets, establishing indicators for achieving them, and the obligation to report regularly on progress made in achieving the goals.

Even though there is currently no political will to do so, in view of the global challenges, attempts should be made to establish a Chemicals Framework Convention which would set globally binding standards for the production and use of chemicals.

The recommendations made by FoE Germany on international chemicals policy derived from this chapter are summarized in Section 8.1.

5 THE EU CHEMICALS REGULATION REACH

With the Chemicals Regulation REACH [52] at the end of 2006, the EU agreed on the most advanced chemicals law in the world. With REACH, the EU decisively strengthened the idea of risk prevention: It is no longer the duty of authorities or society, but manufacturers and importers that are now obliged to demonstrate that their substances and mixtures can be used without risks to health and the environment. For this purpose, they must submit the required safety data in the form of registration dossiers. The marketing of chemicals is subject to the principle "no data, no market."

One of the main objectives of REACH is to collect substances of very high concern (SVHC) in a so-called candidate list and to gradually replace them with less harmful or sustainable substances or processes. In order to strengthen the legally anchored principle of substitution, SVHCs are subject to authorization and should only be permitted to be used with a special permit.

REACH undoubtedly constitutes great progress, even though the regulations still have major deficiencies [53]: In particular, criticism emphasizes the poor quality of the registration dossiers submitted. Regular spot checks by the European Chemicals Agency (ECHA) and a study carried out by the German Federal Institute for Risk Assessment (BfR) on behalf of the German Federal Environment Agency [54] show that a very high per-

centage of registrations does not meet the legal requirements of the REACH regulation. The reason is often lack of safety data on the hazardous properties of substances that are essential for an adequate risk assessment.

This also involves substances that are produced in large quantities and used in the production of countless consumer products for daily use. As research by FoE Germany revealed [55], companies operating on a global scale, among others from the oil-processing and plastics industry, have not or not completely fulfilled their legal registration obligations. The issue has sparked general debate in the European Commission, the European Council and the European Parliament.

The traditional approach of evaluating each chemical individually ("substance by substance") should also be criticized. This ignores the interaction of several substances (see Section 6.7) and has already led in several cases to inappropriate replacements with less well-studied substances having a similar hazard profile (example: bisphenol S is increasingly replacing bisphenol A). In addition, REACH also inadequately records intermediate products as well as articles[9] containing hazardous chemicals. The current version of the REACH regulations also fails to take into account the particular risks associated with nanomaterials or microplastics.

Furthermore, information transfer in the product chain (downstream and upstream) needs to be improved, because many companies often do not pass on essential, safety-related information [56]. Above all, this information does not reach the recycling companies that produce marketable products from waste. If product waste contains "Substances of Very High Concern" (SVHC), which are now no longer permitted, this further complicates recycling into secondary products. The provisions of the amended Waste Framework Directive [57] that ECHA should establish a database of products containing SVHC is a step towards more transparency.

REACH applies in principle to all chemicals. For special substance groups (for example, pesticides, pharmaceuticals, cosmetics), however, there are separate legal provisions. Although it makes sense that additional requirements exist, for example, for biocides, European legislation often lacks consistency. For example, it is contradictory that hazardous ingredients in medicines, cosmetics and food additives do not require classification and labeling while the risk assessment of cosmetics is limited to health despite their mostly environmentally exposed use.

The recommendations made by FoE Germany regarding REACH derived from this chapter are summarized in Section 8.2.

6 PERSISTENCE AND OTHER SUBSTANCE-RELATED PROPERTIES

6.1 Persistence as a central environmental problem

Substances that cause global problems tend to be persistent and can spread from the point of release through wind or water, or accumulate in organisms and in the food chain. Persistence is therefore a key feature that contributes significantly to human and environmental exposure to chemicals.

Conventional substance evaluation to date is based on comparing effect thresholds and predicted exposure. If the predicted or measured exposure (concentrations/dosages in respiratory air, in food, in the body or in the environment) is higher than the effect threshold, a risk is identified which needs to be reduced. This approach ignores that exposure and effects are uncoupled in persistent substances. As they accumulate and spread in the environment, effects can be transferred somewhere else. If adverse effects are observed at a later date, the substance can no longer be removed from the environment.

Even without a (as yet undetected) negative effect, persistent chemicals thus have a high hazard potential. They can stay in the environment for a long time, spread widely, accumulate in certain places and lead to completely unexpected interactions with various substances and organisms. This was impressively demonstrated in the example of chlorofluorocarbons (CFCs). In the case of persistent chemicals, the consequences of not knowing about unrecognized effects can thus be particularly serious.

Persistence is particularly critical if it occurs together with bioaccumulation (see Section 6.2) or mobility in the water cycle (see Section 6.3). Over the past 20 years, in the context of bioaccumulation, the issue of persistence has also moved into the foreground in the regulatory evaluation of chemicals: Under REACH, chemicals that are very persistent and strongly bioaccumulating are among the "substances of very high concern" even without a proven problematic effect.[10] These are the "very

9 Articles are products whose form and shape determine predominantly their function, not their chemical composition.

10 Substances that are persistent, bioaccumulating and toxic (PBT substances) are also considered substances of very high concern according to REACH.

persistent and very bioaccumulative" (vPvB) substances. Other EU legislation, such as the Plant Protection Regulation [58] and the Biocidal Products Regulation [59], also set stringent provisions for persistent and bioaccumulating substances, with the aim of phasing them out. At the international level, the Stockholm Convention regulates a number of persistent organic pollutants (POPs) (see Section 4.4).

Persistence also affects the groupings of substances that have not previously been in focus. For example, until recently, plastics in the environment have been considered at worst an aesthetic problem. In the meantime, however, plastics have become a serious problem, even if they are neither toxic nor bioaccumulating themselves.[11] The European Chemicals Agency ECHA states that an important feature of microplastics is their "extreme" persistence. Consequently, microplastics should be treated as non-threshold substances, much like PBT/vPvB substances, in whose case it is believed that any release into the environment involves risks [60].

Specifically added microplastics and those created by abrasion of plastic materials, textiles and vehicle tires, ultimately enter the environment in significant quantities. Many of them end up in the oceans. Marine organisms, especially plankton feeders, consume the persistent particles, starve despite full stomachs and cannot digest them. They then enter higher organisms such as fish and marine mammals via the food chain, and ultimately enter the human body too. A survey by five German federal states showed that plastic particles are also common in rivers and lakes [61]. The pollution of soils is also a very serious issue. Compost, fermentation residues from biogas plants and sewage sludge contain plastic residues, so that all agricultural soils today contain microplastics as well as residues of macroplastics [62].

Given that by far the largest part of plastic waste inputs are from sources in Asia and Africa [63] (partly from European plastic waste that has been exported there), the environmental problems caused by macro- and microplastic are likely to be even more serious in these regions.

The large quantities combined with the difficulty involved in their degradation make plastics one of today's most pressing global environmental problems. In addition, additives in plastics such as plasticizers, antioxidants, UV stabilizers and flame retardants often pose a serious environmental problem. Moreover, plastic particles in the environment – like many other small particles – can absorb, accumulate and transport pollutants out of the aqueous environment into the bodies of living organisms [64]. According to Australian studies, each week humans ingest an average of 5 g of microplastics [65]. Meanwhile, scientists at the Medical University of Vienna and the Austrian Federal Environment Agency have also detected plastic particles in human stool samples. First indications show that this may encourage inflammatory reactions in the intestine [66] (see also Section 7.4.4).

6.2 (Bio)accumulation

Persistent substances that bioaccumulate should be viewed very critically. They are often scarcely soluble in water and accumulate – mostly because of their lipid solubility – in living organisms. Some heavy metals such as mercury and cadmium are also bioaccumulating. Animals higher up in the food web are particularly at risk. The pollutants are passed along the food chain, so that the highest concentrations are found in animals such as seals, birds of prey, or humans. Consequently, these organisms are at greater risk of being exposed to harmful effects. Examples of such chemicals are flame retardants such as polybrominated diphenyl ethers (PBDE) and hexabromocyclododecane (HBCD), as well as polychlorinated biphenyls (PCB), which have been used, among other things, in transformers, hydraulic fluids and joint sealants.

For some time now, perfluorinated and polyfluorinated alkyl substances (PFCs) have come into focus. These substances, which are used in numerous products such as textiles and extinguishing foams, but also in coatings as well as in processes such as electroplating, are now ubiquitous and often toxic. Two representatives of this substance group – perfluorooctanesulfonate (PFOS) and perfluorooctanoic acid (PFOA) – have now been included as POPs in Annex A of the Stockholm Convention [67]. Thus, their use – except in the case of temporary exceptions – will be prohibited worldwide in the future. In addition to the current activities for the regulation of individual members of this substance group, abandoning this area of fluorine chemistry is necessary. In their "Zurich Statement on Future Actions on Perfluor- and Polyfluoroalkyl Substances (PFASs)," more than 50 well-known scientists are calling for new assessment approaches and determined regulatory measures for this group of substances [68].

In addition, metabolites of chemicals can also be found in high concentrations in organisms. Researchers in 2018 showed that the serum of Canadian polar bears contained many metabolites of halogenated substances. They concluded that the risks of bioaccumulation have obviously not been sufficiently considered [69].

11 However, some plastics contain toxic additives which, if not bound firmly, may escape during use or be released during the treatment or handling of waste.

Bioaccumulation is thus also a risk factor that is often underestimated in classical risk assessment and, especially in the case of persistent chemicals, endangers humans and the environment. The use of some 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 example, chlorofluorocarbons (CFCs) and hydrofluorocarbons (HFCs) accumulate in the atmosphere, damage the ozone layer, or contribute to the greenhouse effect.

6.3 Mobility

Persistent substances are particularly worrying, not only in connection with bioaccumulation. If they are water-soluble (polar), they can often easily seep into soils and sediments and be transported over long distances in the groundwater. If groundwater or bank filtrate is used for drinking water, water treatment can hardly remove such mobile substances by means of adsorption by activated carbon or other adsorbents.

The REACH chemicals regulation does not provide for systematic detection and evaluation of these hazardous characteristics. However, it is possible to classify substances as "Substances of Very High Concern" (SVHC) – if an "equivalent level of concern" exists. The ECHA Member States Committee has since identified a perfluorinated chemical (HFPO-DA) as the first SVHC for mobility and persistence [70]. The German Federal 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 – so-called "PMT substances" – or that are very persistent and very mobile – so-called "vPvM substances"[12]. There is a clear need for regulation here.

6.4 Indirect effects

When considering harmful effects on the environment, the focus has often been on toxicity, which is certainly important. It turns out, however, that some persistent substances tend to cause damage indirectly. Six examples are:

- Pesticides: Some of these harm living things not only through direct toxic effects, but also by changing agrarian biocommunities. If herbicides eliminate wild herbs, insects and thus birds are deprived of the basis of their existence. The extinction of insects and birds leads in turn to a depletion of biodiversity.

- CFCs: The destruction of the ozone layer by these substances causes increased short-wave UV radiation on Earth which harms living organisms. Chlorofluorocarbons (CFCs) also have a very high global warming potential, as do fluorocarbons (HFCs) and some other stable gases.

- Plastics: Most polymers are not toxic in the sense of having a direct toxic effect. Nevertheless, they harm living organisms because they make habitats inaccessible, block the stomachs of sea creatures or, as microparticles, invade cells, damage tissues and transport pollutants (see Section 6.1).

- Phosphate: The scarcity of this important natural nutrient was a key food security problem until industrialization. The widespread use of phosphorus as a fertilizer (in the course of the Great Acceleration – see Section 4.2) is now leading to massive overfertilization worldwide, causing eutrophication both in inland waterways and the oceans [71]. The consequences are depletion of the oxygen supply and endangering of aquatic ecosystems.

- Reactive nitrogen compounds (especially ammonia/ammonium, nitrates, nitrous oxide and nitrogen oxides): The anthropogenic multiplication of the natural input of reactive nitrogen compounds into the environment is leading to a variety of problems: These include toxic effects, for example, stemming from ammonia or nitrogen oxides. By being released into the atmosphere, ammonia and nitrate (from nitrogen oxides) cause overfertilization and degradation of agrarian ecosystems. Nitrate leads to groundwater pollution and overfertilization. Nitrous oxide (N2O) contributes to climate warming because it is a greenhouse gas. The United Nations Environment Council (UNEA) 4 obviously regards environmental overloading with reactive nitrogen as a problem, but without adopting concrete measures [72]. In May 2020, the International Nitrogen Initiative (INI) [73] will hold a conference in Berlin under the auspices of the German Federal Environment Agency. Measures will be discussed for reducing inputs to an extent that planetary boundaries for nitrogen (see Section 4.3) are met.

- Carbon dioxide (CO_2): This gas is also a persistent substance. The burning of fossil fuels for electricity, mobility, heat and other technical processes (such as production of chemicals, cement production) has released and is continuing to release huge amounts of CO_2, which are the primary cause of climate change.

12 PMT substances are persistent, mobile and toxic, vPvM substances are very persistent and very mobile; see also: German Federal Environment Agency (2018): https://www.umweltbundesamt.de/mobile-chemikalien.

All these problems can no longer be solved with old instruments such as conventional risk assessment by calculating an exposure-effect comparison.

6.5 Endocrine effects

Different substances can interact with the hormonal (endocrine) system of humans or animals (endocrine disruptors, ED). They simulate or block hormones or influence their action, formation, transport and degradation. Low fertility, drastically decreasing sperm counts, genital abnormalities, increased occurrence of various types of hormone-dependent cancers (such as breast and prostate cancer) are described in the literature as possible consequences of exposure [74].

The multiple disorders resulting from hormonally active substances can occur at very low concentrations in early stages of development (for example, in embryos and fetuses) and cause significant, often irreversible human health problems or have negative population-dynamic effects on organisms in the environment. Since the effects can be more pronounced at low doses than at higher doses ("non-monotonic dose responses") [75] and the point in time when exposure occurs has a decisive influence, the traditional risk assessment procedure often leads to false conclusions. Consequently, regulatory measures based on the precautionary principle are important, especially for consumer-oriented and open-use applications.

Substances that are harmful to hormones are often bulk chemicals such as bisphenols used in polycarbonate plastics and interior coatings of cans, softeners (phthalates), which are still found in floor coverings, imitation leather, shoes and, despite legal restrictions, in every fifth toy [76], flame retardants in upholstered furniture, all the way to agricultural pesticides and antimicrobial cleaning agents. The World Health Organization (WHO) has listed more than 800 endocrine-disrupting chemicals [77]. It also lists many other suspicious substances that still need to be tested for their harmful endocrine effects.

Attempts to update an existing EU Common Strategy on endocrine active substances from 1999 on the basis of new scientific evidence and concrete action to tackle the problem have not been successful [78]. A study commissioned by the Petitions Committee of the European Parliament outlines the evidence available, makes recommendations for effective protection against endocrine disruptors, and identifies the associated health effects and costs [79].

In 2017 and 2018, the EU Commission issued two regulations [80,81] that lay down scientific criteria for the definition of endocrine-disrupting properties in pesticides and biocides, which could also be applied in other substance groups. However, this definition sets the bar very high and requires comprehensive testing. Presumably, this means that only a few substances will be identified as endocrine disruptors. A category of substances where there is reasonable suspicion of hormonal effects (analogous to carcinogenic and mutagenic substances) is not provided for. The present criteria are therefore obviously insufficiently guided by the precautionary principle. In addition, the standardization of testing methods that reliably determine the occurrence of endocrine effects is still incomplete.

Exposure of humans and the environment to endocrine disrupting substances should therefore be prevented and, as a precautionary measure, also reduced as far as possible in the case of suspected ED.

6.6 Nanomaterials and other novel materials

Nanomaterials contain particles whose size is 1 to 100 nanometers in at least one dimension[13]. The particles may be present unbound or as an agglomerate or aggregate.

Because nanomaterials make possible a variety of new technological applications, their economic importance is increasing and they are being produced on an ever-increasing scale. This is also associated with an increasing burden placed on people and the environment through such materials. However, while the effects and exposure potential of most substances result from their chemical composition, nanomaterials also have significant physico-chemical properties such as particle size, shape, surface chemistry and surface charge which substantially influence behavior and effects in the human organism and in the environment. Coarse particles are often not bioavailable, while nanomaterials, because of their small size, can penetrate cells and spread more rapidly in the environment [82].

Consequently, new testing strategies are needed for assessing the risks of nanomaterials. The Test Guidelines Programme of the Organisation for Economic Co-operation and Development (OECD) focuses on suitable test methods for nanomaterials.

Until now, the word "nano" has never been mentioned in the EU's REACH chemicals regulation. Instead, in recent years, the European Chemicals Agency ECHA has published guidelines on

13 Number size distribution at least 50%, see recommendation of the EU Commission of 18 October 2011, https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32011H0696&from=EN.

how companies should register nanomaterials. So far, however, these guidelines have no adequate legal basis. In principle, it would make sense to adapt the existing regulation text. However, in its proposal submitted in April 2018 after years of delay, the European Commission limited itself to adapting only the REACH annexes relating to nanomaterials, and in them to define what data companies would be required to submit from January 2020. With the agreement of the Member States, this Regulation [83] was published on December 3, 2018. According to this regulation, companies must provide additional information on nanoforms of substances of which they produce or import into the EU more than one ton per year. Essential points such as specific test requirements and the company's own estimation on exposure are included. It remains to be seen what data the manufacturers will present on January 1, 2020. Apart from this, amendments to the Test Methods Regulation [84] are still pending. This is important because testing of nanomaterials requires special adaptations of test procedures.

Meanwhile, discussion of the special properties of nanomaterials has been broadened to include the question of which potential risks are associated with other advanced materials. This is an extremely heterogeneous field involving extremely diverse substances and mixtures, which have in common that they can be used to develop special functionalities such as superconductivity, optical, and magnetic properties. Composite materials as well as substances with biological functionality (for example bio-nano) are also included. There is no single definition nor unified assessment of potential environmental and health risks. As with nanomaterials, the materials' risks often do not derive solely from the chemical composition of substances. In addition, resource availability (e.g. for special alloys) and potential of recyclability (for example, in the case of composite materials) are often required to be included in the assessment (see Section 7.4). Some materials lead to risks during processing (e.g. some fiber-reinforced materials). Special attention should be paid to those materials that are no longer covered by the substance concept of REACH (examples: biologically functionalized materials, multi-functional multi-component systems). In order to prevent that potential risks are not recognized in time, participatory, critical monitoring of the rapid technical development is just as necessary as the development of "safe by design" concepts and a new focus of safety research. Applying the precautionary principle, regulatory measures are also called for in some fields of application.

6.7 Combined effects

In the assessment of chemicals, it is usual to determine and evaluate the effect and expected concentrations of individual substances. In practice, however, substances are often used in the form of substance mixtures. The EU Regulation on Classification, Labeling and Packaging of Substances and Mixtures (CLP Regulation) [85] does lay down rules on how mixtures should be classified and labeled. However, a risk assessment of mixtures only takes place in exceptional cases. Existing risks are thus often underestimated, because the components of a substance mixture can influence each other and increase the strength of effects. Since experimental testing of a mixture is usually not carried out for reasons of animal welfare and because too much effort is involved (commercially produced preparations rarely have a fixed composition), other suitable methods for assessing combination effect, are needed. One possibility is the calculation of the toxicities of the components by concentration addition [86,87].

Based on Council conclusions in 2009, the EU Commission presented a report in 2012 [88] on the extent to which existing legislation takes sufficient account of 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 coordinated assessment across the different pieces of legislation.*

The REACH regulation currently does not systematically consider the toxicity of mixtures. In its "Strategic Plan 2019-2023" the European Chemicals Agency ECHA is now adopting the approach of assessing and regulating chemically related substances together by "grouping" these substances. Its aim is to avoid hazardous substances being replaced by others with similar properties. This would be a departure from the previous principle of evaluating "substance by substance" and also make possible a joint exposure assessment. However, this is not a measure for evaluating the additive effect of mixtures.

In the case of agricultural pesticides, the preparations are tested and evaluated, but not the more frequently used tank mixtures and the multiple applications of pesticides during a growing season ("spraying sequences") [5]. Recent publications suggest that compound toxicities will gain more attention in pesticide assessment in the future [89]. The establishment of maximum residue levels of pesticide active substances in food is currently still based on the evaluation of individual substances, often leading to an underestimation of the risk. The European Food Safety Authority (EFSA) is currently discussing a guideline draft for assessing combined exposure to multiple active substances.

Although it is still possible to adequately evaluate chemical mixtures from a single source using scientific methods, there is a lack of reliable exposure scenarios for evaluating multiple instances of exposure to chemicals from various sources. In reality, humans and the environment are exposed to many different substances from different sources. The 2003 World Wildlife Fund for Nature (WWF) blood samples from EU parliamentarians showed that an average of 41 of 100 chemicals studied were detectable in their blood [90]. Consequently, the EU's Human Biomonitoring Program (HBM4EU) aims at developing methods in which multiple exposure to chemicals can be considered in risk assessment.

The prognosis possibility is even lower if the effects of non-material noxious environmental factors such as temperature, noise, electromagnetic radiation and drought on the toxicity of substances are taken into account. This shows once again how necessary it is to incorporate the precautionary principle into risk assessment and management, in order to truly approach the EU's non-toxic environment target [91]. Consideration of uncertainty factors when transferring model results to reality thus remains necessary, even with significantly improved data.

6.8 Micropollutants in waters

There has been increasing recent evidence that sensitive species of invertebrate groups in running waters disappear when these waters have micropollutants at concentration levels lower than can be anticipated from laboratory studies. That is, once specified, environmental quality standards that are usually based on results of laboratory tests are not sufficient to protect such species. A plausible explanation for this is that most studies on the effects of substances on aquatic organisms only record the effects of an individual substance. In water, however, it is usual for several compounds to act on flora and fauna concurrently. The micro-pollutant strategy of FoE Germany [2] cites as necessary, among other things, more extensive purification of wastewater as well as more rigorous consideration of environmental risks in drug approval. In order to avoid water pollution stemming from active ingredients in pharmaceuticals, it is necessary to treat wastewater from localized sources such as hospitals separately. These are measures that the German Federal Environment Agency recommends, too [3].

Recent research has shown that also transformation products resulting from incomplete degradation generated, for example, by wastewater treatment or in the environment can be persistent. These substances are mostly of unknown structure and effect. In the future, their avoidance must increasingly be taken into account in any micropollutant strategy.

6.9 The outlook: sustainable chemicals

A sustainable chemicals and materials policy focuses more strongly on the environmental inputs of persistent substances and materials and aims at reducing them. Chemicals suitable as substitutes should be neither persistent nor bioaccumulating nor highly mobile. They should be controllable in their field of application and be as readily degradable as possible.

As many ingredients of products in the course of their correct intended use phase (such as pesticides, drugs, detergents, cosmetics) or unintentionally (such as outgassing, leaching or abrasion) escape into the environment and are found in water, soil and (indoor) air, these chemicals need an ecological molecule design. This means they should be "benign by design." End-of-pipe systems, such as wastewater treatment, are reaching their limits in the reduction of inputs.

For a chemical to be termed sustainable, it must meet several conditions: As far as possible, such chemicals should have no undesirable effects and have low stability in the environment, i.e. they need to be broken down as soon as possible after their possible entry into the environment. They should also have a short range in terms of time and space ("short-range chemicals"). The development of sustainable chemicals is also necessary because many substances that are registered under the EU's REACH regulation can only be used safely if elaborate and sometimes expensive safety precautions and measures to reduce exposure are adhered to – a requirement that is not easily met by small and medium-sized companies or companies outside the EU.

The recommendations for further development of substance evaluation derived from this chapter are summarized in Section 8.3.

7 MATERIALS FLOW MANAGEMENT

If sustainable chemistry is to be concretely implemented, comprehensive materials flow management is required. This already starts with the extraction and collection of raw materials and ends with the recycling and disposal of waste.

7.1 Basic principles of the Committee of Inquiry

In 1998 the Committee of Inquiry (Enquete-Kommission) of the German National Parliament "Protection of Humans and the Environment – Objectives and Framework for Sustainable Future Development" [92] formulated five basic rules with regard to different raw materials. The first two rules establish a framework for a sustainable resource strategy:

1. The rate of degradation of renewable resources should not exceed their regeneration rate. This corresponds to the requirement of maintenance of ecological capacity, that is (at least) preservation of ecological real capital defined by its functions.

2. Non-renewable resources should only be used to the extent that a physically and functionally equivalent replacement in the form of renewable resources or higher productivity of renewable and non-renewable resources is created."

It is important to set clear priorities for resource management and to identify tools to implement them [93, 94].

In order to be able to set such priorities, indicators of the environmental impact of the extraction and use of energy and material resources are needed [95]. Because both energy and material costs are closely related in production and application. The indicators used are "cumulative energy demand" (CED) [96], "cumulative raw material demand" (CRMD) [97], and greenhouse gas (GHG) emissions deriving from these two forms of demand. CED is used to determine the energy required for manufacturing goods from raw material extraction all the way to the finished product, energy demand during the useful life of the goods including maintenance as well as the energy demand for recycling, disposal, etc. The CRMD covers all raw materials used for the production and transport of a product, including the energy raw materials, but not substances and materials such as excavation material, which are produced without being economically exploited. CED, CRMD and related GHG emissions give an idea of the relationship between extraction and processing of a particular resource, the associated energy and resource costs, and the impact on the climate. It would be useful to include these figures in the description of best available techniques (BAT) as defined in the Seville Process[14] in the so-called "best available techniques reference documents" (BREFs).

However, these three indicators cover only part of the environmental impact of resource use. Thus, the criticality of individual raw materials, that is their economic, ecological and social relevance, is not covered by any of these indicators. Further negative effects such as eutrophication, acidification or the toxic effects of emissions are thus ignored, as are the consequences for biodiversity. These and other indicators are indispensable for a comprehensive environmental assessment of products and processes. At present, such an assessment fails in terms of both data availability and unresolved methodological ambiguity.

In recent years, many industrialized countries have succeeded in uncoupling not only CO_2 emissions but also energy consumption from the growth rate of gross domestic product (GDP). Thus, energy efficiency has increased. However, part of these savings are canceled out by economic growth. In terms of raw material consumption, however, no significant uncoupling has yet occurred. A significant reversal is needed here to achieve the sustainability goals and the goals of the Paris Agreement.

The European raw materials industry itself is now introducing initiatives for using resources sparingly. The threat to the availability of raw materials from a geostrategic point of view is the focus here. By combining these considerations, priorities can be developed for a German and European resource conservation policy based on the natural availability of resources, the environmental impact of their extraction, and geopolitical and social criteria.

The Third and Fourth Sustainability Guidelines of the Commission of Inquiry take into account potential damage in the environmental media and highlight elusive, but all the more critical, problems with mismanagement of ecosystems due to (pollutant) inputs, which may become important over several generations of human beings, as was the case with chlorofluorocarbons (CFCs) or polychlorinated biphenyls (PCBs).

3. Inputs into the environment should be based on the resilience of the environmental media, with all functions taken into account, not least the 'silent' and more sensitive control function.

4. The time scale of anthropogenic inputs or environmental interventions must be in a balanced relationship to the time taken by the natural processes relevant to the ability of the environment to react."

The fifth rule emphasizes the importance of protecting human health:

5. "Threats and excessive risks to human health caused by anthropogenic influences must be avoided."

The application of these rules must also take into account, in particular, the combined effects of different substances in mixtures, the particular risks of nanomaterials, micropollutants, and endocrine effects (see Chapter 6).

14 In accordance with Industrial Emissions Directive 2010/75/EU, the state of the art is determined specifically for each industry sector respectively.

Considering that the Committee of Inquiry of the German National Parliament had already formulated these rules for the sustainable handling of raw materials more than 20 years ago and many experts such as those of the Club of Rome had already pointed out the necessity of reorienting raw materials flow management many years prior to that, the balance of the political efforts until now has been regrettably very sobering.

7.2 Principles of ecological materials flow management

Ecological materials flow management is based on guiding principles. One of these is the circular economy in combination with the waste hierarchy, which sets the priorities: Avoidance, reuse, recycling, recovery and elimination. Another guiding principle is based on the material cycles and technical solutions of nature (bionics), which are characterized by the fact that they work with spatially and temporally limited locally available substances with high effectiveness and efficiency.

In order to maintain materials flows, energy is needed. Sustainable processes are therefore characterized by high energy efficiency. This is accompanied by the lowest possible increase in entropy. Entropy[15] is often described as "lost energy," which is no longer usable in processes and is thus "lost." However, it also arises in mixing processes, i.e., in dissipative processes.[16] 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 great expense. Thus, the lowest possible entropy production is an indicator of sustainable processes [98].

However, sustainable chemical production also means generating as little waste as possible during the production of a substance – along the entire manufacturing route including the input products in the supply chain. Despite great progress in the low-waste synthesis of chemical products, there are still synthetic routes in which more waste is generated than products. In the manufacture of active pharmaceutical ingredients, per kg of product an average of 25 kg of unusable byproducts are "produced" and must be disposed of [28].

A globalized, high material throughput and energy intensive society with short product lifetimes and a large variety of materials within individual products and material flows requires a great deal of energy and "produces" vast amounts of entropy, resulting in high losses and material, energy-related and economic costs. It is essential to keep material flows as low and their constituent components as simple as possible.

The combination of three complementary strategies help achieve more sustainability in the management of materials flows [99, 100]:

Efficiency is oriented towards more productive use of energy and resources. Products and services should be created with less use of energy and materials. This involves, for example, the efficiency of power plants as well as savings in materials in the manufacture of products. However, some efficiency gains have in the past been offset by increased consumption. This is called the "rebound effect."

Consistency refers to the compatibility of nature and technology. This includes, among other things, the development of closed-loop material cycles by fully recycling waste or through materials flows that are not harmful to nature that can easily be integrated into natural biogeochemical processes. At the same time, sinks such as the atmosphere, the soil and the oceans, which absorb substances, must be regarded as resources with only limited capacity for resilience.

Sufficiency focuses on consumption and lifestyle in relation not only to individual people but also to society as a whole. Sufficiency can be characterized by the terms "deceleration," "unbundling," "decommercialization" and "decluttering" [101]. Sufficiency does not mean ascetic austerity, but poses the question of the right amount and more conscious use of limited resources [102].

While efficiency and consistency are generally accepted in the population, sufficiency strategies are met with reservations. However, the "unpacked shops" initiative shows that some consumers are already trying to reduce their material consumption. The spread of car-sharing and the increasing popularity of the bicycle show that consumer behavior is beginning to change. Today, the car is no longer regarded as a status symbol, especially in the younger generation. Ultimately, a suitable political framework is needed. Sufficiency will only succeed when incentives for the waste of energy, materials and labor are stopped.

A frequently overlooked aspect of material flow management is environmental justice. For example, in Europe, too, jobs in waste management are often poorly paid and harmful to health.

15 Entropy is a thermodynamic quantity indicating the unavailability of thermal energy and can be regarded analogously at the material level (often simply described as a degree of "disorder"). It is an indicator of sustainability.

16 Dissipation: Dispersion/distribution of particles in a system.

The extraction of raw materials often takes place under very poor working and environmental conditions. Mining deserts and monocultures are emerging in countries that supply raw materials. The hunger of industrialized countries for raw materials deprives entire regions of their development opportunities.

7.3 A necessary trend reversal in the production of chemicals

The worldwide problem of chemicals is not only a matter of the hazardous properties of substances, but is also a problem of ever-increasing global chemical production in quantity, sales revenue and diversity: Sales revenue doubled in the decade from 2000 to 2010. For the period 2017 to 2030, the Global Chemicals Outlook II report of the United Nations Environment Program (UNEP) predicts a further doubling from $US 5 trillion to $US 10 trillion [28], with the most marked increase anticipated in emerging economies. Already today the chemical industry consumes about 10 percent of global energy needs and is the third largest industrial sector in terms of CO_2 emissions [103]. Although emerging and developing economies have some catching up to do, a reversal of the trend is needed, which also requires action in industrialized countries. The increase in production will inevitably bring about increasing harmful effects from chemicals around the world.

At present, fossil resources (especially oil and gas) predominate, accounting around 90 percent of the organic raw materials (feedstock) in chemical production. Oil consumption by the chemicals sector is now growing the most strongly in comparison with other areas [104]. In the sense of sustainability and climate protection this cannot be sustained in the future, because chemicals derived from oil which thus contain carbon ultimately contribute to the emission of greenhouse gases when they are converted into carbon dioxide (CO_2) [105]. These problems can only be solved if the trend towards increased production and use of a wider and wider range of substances is halted and reversed.

Achieving this will require global efforts to increase resource efficiency and recycling. While the chemicals industry already works relatively efficiently in its own interest by manufacturing its products in joint production, there is still considerable untapped potential in the user phase. Sufficiency, that is the restriction of consumption and demand, must also be a key element of a new chemicals and materials policy. In particular, the wide variety of disposable products in today's economy does not represent a sustainable approach and must be avoided in the future. Chemicals should only be used where they lead to long-term benefits that clearly outweigh negative environmental impacts. Sometimes, traditional materials such as wood also provide a suitable functional and sustainable solution.

Using oil and gas as an essential raw material ("feedstock") for the production of chemical products cannot be a sustainable solution in the long term. As a priority – especially for climate protection reasons – the use of fossil fuels must be stopped as soon as possible. In this respect, chemicals policy and energy policy are interlinked. In the medium term, the use of fossil raw materials for production can only be justified if there is consistent recycling of the products made from them.

Coal, as an alternative source of raw material compared to oil, would lead to an increase in CO_2 emissions and thus exacerbate the problem. The use of biomass is only expandable to a limited extent [106], if problems such as competition for land resulting from renewable raw materials or the deforestation of primary forests for the production of biomass (palm oil being a prominent example) are to be avoided. In any case, it makes sense to use nature's capacity for synthesizing by means of plants and microorganisms as intelligently and effectively as possible. Producing renewable resources through the reaction of carbon dioxide (CO_2) with hydrogen (H_2) – Power-to-X – could be a long-term solution, but a more detailed assessment of the environmental impact is still needed. There is still a need for clarification because of the high energy expenditure and the need to filter out CO_2 from the air or to capture it from combustion and fermentation processes and then temporarily store it.

7.4 Sustainable chemistry in the circular economy

Material cycles start with the extraction and processing of raw materials and pass through the product and waste phase to reuse or recycling. Consequently, sustainable material flows management also includes requirements on product design (recyclable, easily separable material mixtures, easy to dismantle, etc.) and process design (for example, linking thermodynamically high-grade material and energy flows with suitable downstream processes, low dissipative losses). Material flows should be maintained at a high level of purity as long as possible. Even small impurities can often only be removed with high resource outlay and "entropy production." The more the material flows are mixed with each other, the fewer ways of recycling are available.

7.4.1 Conflicts of goals

In product design, manufacture and use, there is often a conflict of goals when striving to arrive at an optimum balance between energy and resource efficiency and optimal functionality, with the entire life cycle from raw material extraction through product manufacture to recycling being taken into consideration. For example, an energy and resource efficient product cannot be sustainable if the addition of additives makes it impossible to recycle materials after use. In general,

such difficulties in materials recycling show that waste prevention must take precedence over longer-term use, and that it is the ecologically best form of material flows management.

In addition, the objectives of the circular economy (as much material recycling as possible) and chemical safety (the lowest possible contamination by pollutants from secondary raw materials) may conflict. Substances do not lose their hazard potential when they become waste; however, they are then no longer subject to the requirements of the EU REACH regulation. The interfaces between substance, product and waste legislation should therefore be designed in such a way that (i) the requirements are as similar as possible, (ii) secondary materials are safe for humans and the environment and (iii) material recycling is not unreasonably impeded.

With regard to the desirable durability (longevity) of a product, it should be noted that the chemicals contained in it must be sufficiently stable. Otherwise, there will be a trade-off between chemical longevity (persistence) and longevity of the product, and resource efficiency will be compromised.

The goal of recycling-oriented material flows management is not achieved even then, if hazardous substances are inserted into recycling processes. These may be heavy metal stabilizers in PVC or flame-retardant halogenated additives in other plastics. If such contaminants cannot be separated, secondary raw materials of this kind should be removed and disposed of in an environmentally sound manner. Under controlled conditions, less demanding applications for secondary raw materials (such as fence posts instead of children's toys) may be considered in individual cases (downcycling).

These problems can only be solved if the requirements for transparency in the product chain in the EU chemicals regulation REACH, product legislation, and waste legislation are significantly extended. Recycling companies usually do not have sufficient information about the material composition of the waste delivered to them.

7.4.2 Raw material extraction and processing

The use of raw materials has increased dramatically over the past century and will continue to increase over the coming decades [107,108] (see Figure 3). Reaching or exceeding planetary boundaries (see Section 4.2) is anticipated. An international agreement to cap the use of raw materials should therefore be sought.

The extraction and processing of raw materials has side effects. For example, the mining of raw materials, especially of metals, often releases toxic substances. The resulting material flows can exceed natural cycles many times over. Uranium and cad-

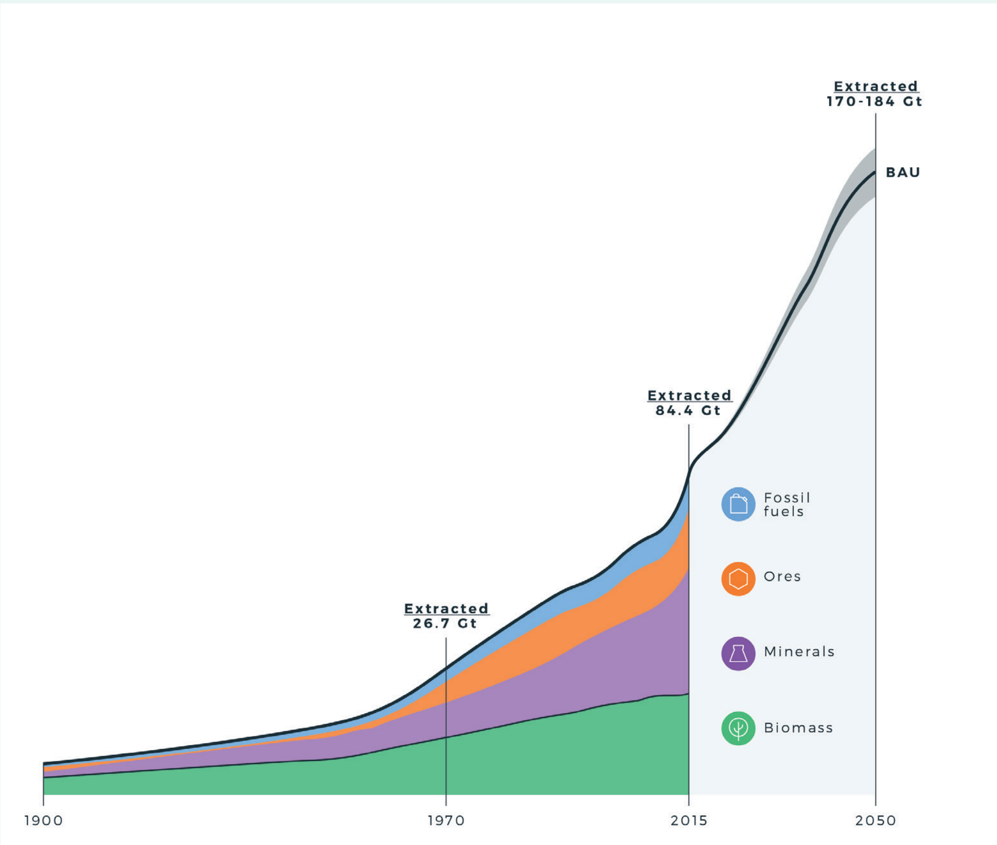

Figure 3: Worldwide increase in raw material extraction (de Wit et al, 2018) [107]

mium are sometimes mobilized in the extraction of phosphate, while the radioactive metals thorium and actinium are released during the mining of neodymium, which is used among other things for magnets, in CD players and in smartphones. In addition, the extraction of high-purity metals is often associated with great energy expenditure 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 significant for Europe and there are significant supply risks [109]. Such raw materials are often found only in low concentrations in a few regions of the world. Their extraction and smelting is usually associated with severe ecological damage. Recycling is currently too expensive, but is urgently needed for responsible use of these substances [110]. The extraction of these critical metals also has social components. It often takes place in countries where working conditions are dramatically poor. It is sometimes even used to fund wars.

The circular economy can reduce some of these effects. In this way, many metals can be recycled without serious loss of quality. The higher the metal content in the recycled scrap, the lower the entropy production.

In its background paper, “Ressourcenschutz ist mehr als Rohstoffeffizienz” (Resource Conservation is more than Resource Efficiency), FoE Germany presented an analysis of current resource use and a strategy for more effective resource conservation [111].

7.4.3 A wide range of ingredients and products

Modern products are usually diverse and complex. High-performance plastics, which are used for example in the automotive industry for weight reduction, contain a variety of additives and often consist of several polymers. Even supposedly simple films for food packaging are sometimes complex multi-layer plastics with additives that can no longer be separated.

Material recycling is very difficult, especially in the “post-consumer” sector. Complex composite products usually cannot be subjected to the desired recycling. Substances, materials and products originally manufactured with great effort at a high level of purity are increasingly being mixed and distributed globally across global markets, so that enormous effort must be made in recycling to avoid losses at the most diverse points of the supposed cycle. Apart from a few exceptions (such as scrap and glass and, within limits, paper and cardboard too), material recycling is currently mainly confined to production waste. For scrap and glass, the EU Commission has defined criteria defining which requirements waste must fulfill in order to be recycled [112]. An additional problem is represented by materials which contain – in some cases already banned – pollutants (example: cadmium-containing stabilizers in PVC). During recycling, such pollutants are carried over to secondary raw materials.

Increasingly problematic is the diversity of construction products. The material flow of construction products is by far the largest of all: 4.7 billion tons of mineral raw materials are “consumed” every year in the EU [113]. Even in the case of sand as a raw material, there are already shortages. However, construction products are not just a quantitative problem. Some of them contain dangerous chemicals such as the flame retardant hexabromocyclododecane (HBCD[17]) or plasticizers. This can lead to significant health-threatening loads on indoor air. Facade paint often contains biocides that inhibit algae growth, but are washed out in the rain and seep into the groundwater. It is particularly unfortunate that a new ruling of the European Court of Justice [114] limits transparency about ingredients: Apart from the CE label, no other – and for consumers helpful – eco-labels such as the “Blue Angel” may be applied to products.

7.4.4 The special case of plastics

Plastics are a special challenge for the circular economy (see also Section 6.1). More than 25 million tons of plastic waste are produced in the EU every year, of which only about 30% is recycled into new plastic. A large part of the plastic collected is exported. China has created a virtual import stop since the beginning of 2018 by abruptly increasing quality requirements. Since then, large streams of waste have been sent to other Eastern and Southern countries for “recycling.” The decision of the parties to the Basel Convention of May 10 2019 will prevent this practice in the future. Only unmixed, unpolluted plastic waste may be exported for recycling without authorization [115]. This means that the EU too must ensure the recovery and disposal of plastic waste in Europe. The export of plastic waste from Europe to developing and emerging countries should be prevented by consistent controls and the prosecution of violations of the Basel Convention. A large part of the plastic waste is packaging made of several materials, from which – if at all – pure plastic granules can be obtained only with great effort.

The European Commission presented a strategy for plastics in a circular economy in 2018 [116]. It contains suggestions on how to increase the recycling rate and reduce environmental contamination. However, many suggestions are not very concrete. And the Commission relies more on voluntary compliance

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

than regulatory control. In particular, there is a lack of effective measures to reduce the consumption of plastics.

As the first implementation of the plastic strategy, the Commission has proposed a directive on certain plastic products. Its aim is to reduce the input of one-way plastic products and fishnets [117]. In December 2018, the European Commission, the Council and the European Parliament reached agreement on this. In addition to labeling and product-return obligations, reduction targets for Member States and extended producer responsibility, the package also includes bans on drinking straws, cotton swabs and disposable tableware made of plastic. Since the effectiveness of the measures is going to be assessed only after six years, and the success of many measures depends on the participation of Member States and market participants, this directive is not expected to significantly reduce the input into the environment. For microplastics (particle size less than 5 millimeters), the European Chemicals Agency ECHA is currently preparing a restriction directive pursuant to the REACH regulation. This should lead to a far-reaching marketing ban on purpose-made plastic particles. Microplastics are used not only in the cosmetics sector, but to a much greater extent in fertilizers and pesticides, as well as in detergents and cleaners for the containment and controlled release of nutrients, active substances and fragrances [118].

Although the plans of the EU up until now are moving in the right direction, they will not be enough. A study estimates that reducing plastic inputs into the environment by a factor of 27 is necessary to prevent further damage to the environment [119]. To achieve this, a set of regulatory, economic and voluntary measures must be developed and implemented. In particular, the use of one way plastic packaging is to be reduced through bans, as well as imposed deposits, and levies. Currently, every German "produces" about 40 kilograms of plastic packaging waste per year. Recycling needs to be expanded, which requires improved effective collection and sorting systems and, where possible, no composite plastics. Bioplastics are certainly not a solution for preventing disposable plastic. It is slowly compostable only at high temperatures. In addition, there are no suitable recycling systems for these polymers [120, 121].

However, the plastics problem is not a sheer waste problem. On the contrary, significant reductions in production and consumption are needed. If the manufacturing industry's plans to increase world production by 40 percent over the next decade are realized, plastics will remain one of the biggest environmental problems, despite improved recycling [122]. Once again, it is clear that technical innovation and increased efficiency are not sufficient as solutions. A change in consumption is necessary (sufficiency). Plastic is a worldwide problem. In two resolutions of the UN Environment Council UNEA 4 in March 2019, countries are called upon to take effective action against the plastics problem [123]. However, these decisions lack binding power. In order to combat global pollution by plastics, the EU should aim for a legally binding international convention.

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. Only a few products feature a modular design approach and are designed for longevity. Frequently, products are designed to be reasonably priced, but to soon need replacement by a successor product (planned obsolescence) [124]. New purchases are often less expensive than repairs. The German Federal Environment Agency has made recommendations on how to extend the life of household appliances and reduce resource consumption [125].

Ever faster product cycles such as in the case of mobile phones, textiles or furniture complicate the cycle. Although the German Electrical and Electronic Equipment Act (ElektroG) specifies some criteria in § 4 "Product Design" intended to facilitate the reuse of components, these provisions are hardly binding and the targeted return rate of 85 per cent by 2019 has clearly been missed.

The EU Ecodesign Directive [126] sets maximum energy consumption for energy-using products. Here, the manufacturing and use phase is included. Although the need for resources should also be reduced, the requirements for this do not go beyond the obligation to provide documentation. In several regulations on implementation, for example for dishwashers and refrigerators, which were published in the Official Journal in October and December 2019, the EU Commission now sets concrete requirements for ease of repair and recyclability, an important first step [127]. In many other areas, such regulations are still missing.

The increase in material flows also involves higher levels of e-commerce. Apart from the fact that shipped goods are usually elaborately packed, the number of returns is high: Every sixth parcel is returned by customers. There are no reliable figures on the extent to which these returns are resold, given away to charitable organizations or disposed of as waste. The University of Bamberg estimates the extent of disposal/scrapping as being 3.9 percent [128]; the ZDF TV news magazine "frontal 21" documented a worryingly high degree of destruction of usable goods [129]. The Federal Ministry of Environment (BMU) is considering a legal regulation to restrict this destruction of resources (as of: June 2019).

This development underlines that in addition to technical measures to increase efficiency, sufficiency is also a decisive approach to reducing material flows and making them environmentally compatible.

7.5 Service models

One way to reduce substance and material flows is through business concepts such as "chemical leasing." Traditionally, manufacturers are interested in selling their product to their customers in bulk or in large numbers. This inflates the flow of materials more than is necessary. However, if a supplier offers a service such as cleaned workpieces, lubricated equipment or hygiene in addition to the substance, it is also in his interest to use as little material as possible. This creates a win-win situation that has economic benefits for both sides. Interest in "chemical leasing" is steadily increasing thanks to the support of the UN Organization for Industrial Development (UNIDO) [130] and the Austrian Ministry of the Environment.

However, there are obstacles that hinder general adoption of this approach: Some industry partners fear know-how losses or too great a dependence on a single supplier. In some cases, liability issues have not been clarified. There is urgent need to develop solutions to overcome these barriers. In order to prevent misuse of this business model, the German Federal Environmental Agency [131] has developed five sustainability criteria for chemical leasing, which are defined by measurable indicators: (1) reduction of adverse effects, (2) improved handling and storage, (3) no substitution by higher risk substances, (4) economic and social benefits, (5) monitoring of improvements.

Dissemination of such business concepts could also be beneficial if they were included in the so-called Best Available Techniques Reference Documents (BREFs) under the Seville Process as Best Available Techniques (BAT).

New business concepts are also needed to avoid waste, reuse products or to recycle them as valuable products. At present, it is still easier and cheaper for many traders to "dispose of" waste, which is why a circular economy is still a distant goal [32].

The recommendations of FoE Germany for material flows management derived from this chapter are summarized in Section 8.4.

8 GUIDING PRINCIPLES FOR CHEMICALS AND MATERIALS POLICY – RECOMMENDATIONS BY FRIENDS OF THE EARTH GERMANY

A sustainable chemicals and materials policy must focus increasingly on the persistence of substances and the flow of substances and materials from the very beginning to reuse. Chemicals and materials policy must therefore be based on the following guiding principles:

- Chemicalss policy is international today. The pollution of the Earth system with chemicals has reached a critical level. In part, planetary boundaries have already been exceeded. In order to counteract this, the United Nations Sustainable Development Goals must be taken seriously and binding measures must be taken to implement them.

- Chemicals and materials policy must increasingly focus on the principles of precaution and sustainability. This means, in particular, regarding persistence as a key hazard – including substances that are converted into persistent degradation products, and substances such as plastics that are introduced into the environment in large quantities although they exhibit no other hazardous features such as toxicity.

- Material flows must be slowed down and reduced both regionally and globally. Above all, this means using fewer non-sustainable chemicals. 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 use and greenhouse gas emissions. Challenges include finding suitable substances and processes for environmentally friendly mobility and climate-friendly and resource-efficient construction.

- Chemicals and materials policy and the circular economy must be linked. A reduction of material flows can only succeed if the waste hierarchy is systematically considered. This also means that the legal foundations of substance, product and waste law must be integrated and complement each other.

Sustainable chemicals and materials policy is everybody's business:

- the state, which controls the behavior of companies and consumers through concrete regulations and authorizations, as well as through indirect incentives such as taxes and levies, with the aim of establishing a sustainable economy and safe handling of substances;

- the companies that live up to their responsibilities in a global economy and provide sustainable products, as well as

- consumers who, on the basis of correct specialized information, orient their lifestyle to the principles of sustainability.

None of this is new. The most important principles of sustainable chemical management were already described and illustrated in 1993 (see Fig. 4): After these, "ecological design" is the central issue. Such design aims at using only chemicals and substances whose environmental impact is as low as possible. Thus, only substances should be used that are as non-persistent as possible but are also neither mobile nor toxic and also do not accumulate. To reduce the overall exposure of humans and ecosystems, the consumption of chemicals should be reduced by increased efficiency and greater sufficiency as well as by returning products into the circular economy through reuse or recycling (consistency).

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

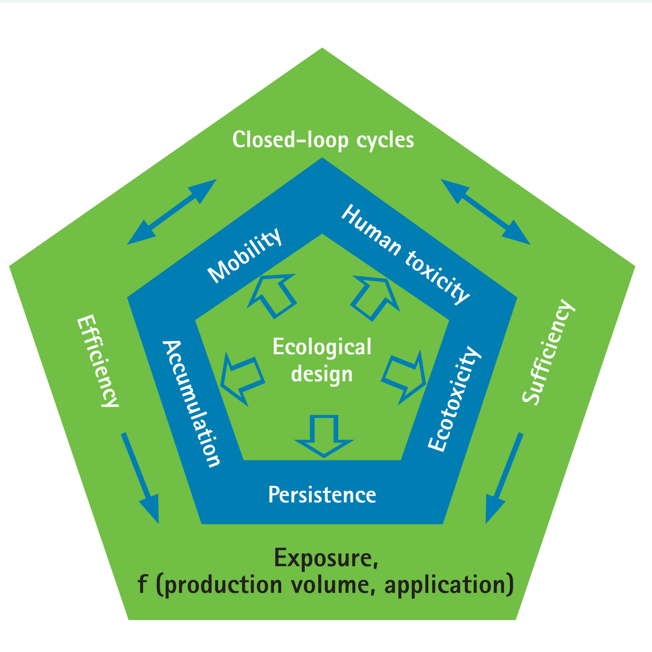

Figure 4: Minimizing the risks of substances by reducing exposure and effects (according to Friege [132])

This means in detail:

8.1 Recommendations for the further development of an international chemicals policy

In view of the ever-increasing production of chemicals and the global spread of hazardous substances and wastes, chemicals policy today requires a global approach so that planetary boundaries are not exceeded.

- Linking of chemicals and materials policy with the United Nations Sustainable Development Goals (SDG), in particular SDG 12 on sustainable production and use and SDG 3, which calls for measures for dealing with the health consequences of exposure to chemicals. The SDGs must be more than a mere declaration of intent. They require the development of appropriate measures for their implementation.

- Worldwide implementation of sustainable chemistry in accordance with the decisions of the United Nations Environment Assembly (UNEA 2 and 4).

- Further development of the "Strategic Approach to an International Chemicals Management (SAICM)". The measures adopted must be more binding; indicators for measuring the achievement of the objectives must be developed and defined. The implementation of sustainable chemicals and waste management, taking into account the "polluter pays" principle, should be significantly accelerated. The countries of the East and South must be supported in setting up effective chemicals management systems on their own.

- Consistent expansion and enforcement of international chemical conventions, in particular to prevent illegal exports of hazardous waste (Basel Convention).

- Prevention of the export of hazardous waste from the EU to developing and emerging countries through consistent controls and prosecution of violations of the Basel Convention.

- Stopping of the fragmentation of international chemicals and waste management into numerous forums, in order to ensure a consistent approach.

- Medium-term development of a legally binding Chemical Framework Convention, which sets globally valid principles of sustainable chemicals, waste and material flows management.

- Development of international rules to reduce the complexity of global material flows in order to enable an effective circular economy.

- Formulation of global action plans to reduce environmental inputs of phosphorus and reactive nitrogen, and consistent enforcement and tightening of fertilizer regulations at national and EU level.

8.2 Recommendations for the further development of REACH

REACH is a significant step forward in chemicals management. However, in some key aspects this chemicals regulation needs to be developed further to make it more effective and better able to achieve its goals. Inconsistencies among the various substance-related legal regulations must be eliminated.

- Consistent implementation of the precautionary principle in order to avoid earlier errors, when the reaction came too late after harmful effects were already recognized.

- Clearer and stricter requirements for (import) products, intermediates, polymers and nanomaterials.

- Efficient, more comprehensive compliance checks on registration dossiers at EU level, as well as stricter requirements for their correct implementation and updating. In serious cases, registrations must be canceled and marketing and use of the substances involved prohibited in accordance with the REACH principle "no data, no market."

- Identification by the European Chemicals Agency (ECHA) of all substances for which complete toxicological and ecotoxicological data are not submitted and disclosure of the names of companies and other registrants which do not promptly correct non compliant registration dossiers.

- Clearer information transfer requirements in the product chain to create transparency about potential risks.

- Joint assessment of substance groups ("grouping") to assess their risks more effectively and efficiently and to avoid inappropriate substitution by structurally similar substances.

- Further development of the criteria for substances of very high concern (SVHCs) to identify those substances that are persistent, mobile and toxic (PMT) or very persistent and very mobile (vPvM), as well as basic classification of endocrine disruptors as SVHCs.

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

Besides toxicity and ecotoxicity, bioaccumulation, mobility in the water cycle and, in particular, persistence are key characteristics in substance evaluation. Particular attention should be paid to indirect effects, combination effects and the evaluation of nanomaterials, endocrine disruptors and micropollutants. Consequently, persistence deserves special attention as it has been shown that many long-lasting substances lead to delayed damages in the environment that were unsuspected when these substances were introduced.

- Prevention of the irreversible entry of synthetic persistent substances into the environment. Measures for ecologically compatible retrieval and removal of existing contamination by persistent materials such as plastics using the polluter-pays principle.

- Prevention of the irreversible entry of synthetic bioaccumulating substances into the environment.

- Prevention of the irreversible entry of synthetic highly mobile stable substances into the water cycle.

- Prevention of human and environmental exposure to endocrine disruptors.

- Cessation of production and use of particularly critical groups of substances such as perfluorinated chemicals (PFCs).

- Consideration of combination effects of substances in mixtures and in combined use of several substances.

- Development and introduction of appropriate testing and assessment strategies for assessing the specific risks of nanomaterials.

- Participatory, critical monitoring of the technical development of "advanced materials" and development of relating "safe by design" concepts.

- Implementation of the proposals of the FoE Germany micropollutant strategy, in particular with regard to the environmental assessment of medicinal products and the upgrading of sewage treatment plants for the reduction of water inputs (keyword: "fourth purification stage").

- Minimization of inputs of substances into the environment that are produced in large quantities and are not used in closed systems such as detergents, plastic products, lubricants, everyday products, cosmetics and pharmaceuticals.

- Development of sustainable chemicals with high benefits and at the same time few undesirable effects and spatially and temporally limited range of action ("short-range chemicals").

8.4 Recommendations for sustainable materials flow management

From the extraction of raw materials to the recycling and disposal of waste, material flows must be reduced (minimization requirement). Current consumption of energy and resources is not sustainable; there is too much entropy generation. This can be changed by meeting the following requirements:

- Already during the development and design of products, issues of sustainable material flow management must be considered. For this purpose, the educational goals and criteria of design curricula must also be examined and, if necessary, reformed (see also Section 8.5).

- A trend reversal in the production of chemicals is needed: A significant reduction in production volumes is necessary. For this purpose, the consumption of chemicals must be reduced by higher efficiency and more sufficiency. The (significantly reduced) raw material base must change in the medium term: For this purpose, sustainable ways of regenerative supply of raw materials need to be further developed and evaluated.

- Processes must be designed in such a way that they have high energy efficiency and little loss due to entropy increase, for example through dispersion in products and subsequently in the environment (dissipation).

- In the production of substances and products, the use of chemicals along the entire supply chain all the way to the finished product must be kept as low as possible.

- A comparative assessment of the cumulative energy demand and cumulative raw material demand (CED, CRMD) as well as greenhouse gas (GHG) emissions of products and processes is necessary and must be given consideration in the Seville Process – in other words in the Best Available Techniques (BAT) reference documents, the so-called BREFs.

- Material resources should be used sparingly. When extracting raw materials, entry into the environment through mobilization of the raw materials and their sub-components should be avoided.

- Measures to promote and expand the recycling of critical raw materials such as lithium, cobalt, neodymium or tantalum are needed.

- An international agreement on global capping of raw material extraction should be sought.

- Consumers need more information and advice to be able to adapt their consumption behavior and lifestyle to sustainability requirements (sufficiency). This also requires economic incentives to regulate consumer behavior.

- Legal regulations are necessary to prevent the destruction of as-new, usable goods as much as possible.

- The recyclability and long service life of products must be enforced through effective measures such as legal requirements, specification of targets and consumer information. Examples:
  - Non-recyclable composite materials should be avoided, provided that they have no clear advantages in terms of functionality and energy efficiency;
  - The use of additives in plastics and non-removable alloying constituents in metals should be minimized;
  - Impurities that restrict materials' use as secondary raw materials should already be avoided in the production chain;
  - Ease of repair should be achieved through modular design; and
  - Products should be designed to last as long as possible.

- An international convention to prevent the entry of plastic into the environment, especially into the sea, should be sought.

- The EU's plastics strategy for reducing plastics emissions (bans on use, refundable deposits, expansion of sorting and collection systems, etc.) must be rigorously developed and made more stringent. The Basel Convention to make the export of contaminated, mixed plastic waste more difficult must be implemented.

- The waste hierarchy must be strictly observed: avoidance takes precedence over reuse, recycling, recovery and disposal. The interface between chemicals and waste legislation must be improved. This will make it easier to utilize waste substances materially or chemically.

- For products and processes, non-chemical solutions are preferable, provided that they have no disadvantages in terms of functionality, energy efficiency, or resource efficiency.

- The use and development of resource-saving service models such as chemical leasing requires more incentives.

8.5 Recommendations for research and education policy

Many scientific findings on the contamination and overloading of the Earth with substances are the result of research

in recent decades. Numerous questions are still open, many links unknown. The continued development of a precautionary chemicals management and a sustainable chemicals policy requires further research, which should be a focus, in particular, within the framework of public research programs. In addition, it is necessary to embed sustainable chemistry and materials flow management in degree programs as well as in training and in-service education.

Research recommendations:

- Strengthening of the independence of research. Scientific research on substance risks should not be dependent on industry funding. Conflicts of interest should be avoided.

- An area of research focused on how to prevent and reduce the input of chemicals into the environment and how to transform chemical production towards sustainable chemicals policy needs to 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 known pollutants, which are often already the subject of production and/or use bans, but should address the knowledge gaps concerning the many less well-studied substances and combination effects. Persistent substances should be given special attention.

- Research programs are needed in particular for the following eleven fields of action:

  - operationalization of the planetary boundary "novel entities" and development of indicators for exposure to chemicals at the global, national and company level;

  - development of indicators for measuring progress in implementing national and international chemicals management measures;

  - development of criteria and procedures for the implementation of the precautionary principle, in particular with regard to persistent substances;

  - development of criteria and procedures for the evaluation of substances which are mobile in the water cycle;

  - investigation of environmental and health effects of nanomaterials and advanced materials;

  - investigation of environmental and health effects of endocrine disruptors;

  - study of indirect effects of substances and mixtures on biocoenosis and geochemical cycles;

  - study of combination effects of mixtures and simultaneous or sequential use of different substances or products;

  - development of technical possibilities, strategies and better logistics for recycling;

  - development of strategies for using a regenerative raw materials base for chemical production.

However, knowledge gaps and existing research needs are not a justification for lack of action in the sense of the recommendations mentioned under 8.1 to 8.4!

Recommendations for education:

- "Sustainable chemistry" must be incorporated into the education of chemists, process engineers and similar degree programs as a teaching subject.

- The topics of life cycle analysis, materials flow management and the circular economy should be included in the curriculum of all engineering courses and scientific subjects.

- Degree programs and training courses in toxicology and ecotoxicology must be consolidated and expanded.

- Training and further education offers for a responsible, sustainable handling of substances and products should be expanded.

- Courses on the sustainable handling of substances should be developed and expanded for students and members of the public.

- Well-founded information on the sustainability of materials and products, prepared and checked by independent experts, should be provided.

- Access for consumers and organizations to information on the sustainability of substances and products should be improved. Manufacturers must provide the relevant information in a verifiable manner.

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FRIENDS OF THE EARTH GERMANY

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

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Graphic: Mahmure Alp / Noun Project

Layout: dieprojektoren.de

Dezember 2019

The full version of this FoE Germany position paper with further supportive arguments, detailed demands, and full documentation can be downloaded at
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