PLANETARY BOUNDARIES FOR CHEMICAL POLLUTION

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Introduction

Rockström et al.[1] presented 10 anthropogenic impacts of global relevance, including climate change, biodiversity loss, anthropogenic changes of the nitrogen and phosphorous cycles, stratospheric ozone depletion, ocean acidification, global freshwater use, change in land use, atmospheric aerosol loading, and chemical pollution. They proposed that humanity may be within a safe operating space as long as the magnitude of these impacts is below certain thresholds that represent tipping points of the global system. An example is the concentration of carbon dioxide (CO_2) that should remain below 350 ppm to prevent the global system from moving rapidly into a much warmer climate. Rockström et al. defined planetary boundaries for most of the 10 anthropogenic impacts and suggested that these boundaries should be used in environmental policy and decision-making. However, for chemical pollution Rockström et al. did not define a boundary, but stated that this boundary remains to be determined. In the context of chemicals assessment at the international level, the planetary boundaries concept is important because it makes it possible to explicitly address the global aspects of chemical pollution. Chemical pollution is a global impact for several reasons. First, there are chemicals with the potential to be distributed around the globe, in particular chlorofluorocarbons (CFCs) and Persistent Organic Pollutants (POPs). Secondly, chemical technology and chemical products are used in similar ways in almost all regions of the world so that even short-lived chemicals are present in many regions although they do not undergo environmental long-range transport. In addition, there is extensive global trade in chemicals and chemical wastes that leads to discharges and widespread distribution of numerous chemicals, be it as chemical products or as components of finished consumer goods, such as towels with nonylphenol ethoxylate[2], or as components of waste, such as polybrominated diphenyl ethers present in electronic waste[3]. This global nature of the chemical pollution problem is illustrated by the fact that the new UNEP Global Environmental Outlook (GEO-5) will, for the first time, include a chapter on chemicals and wastes.[4]

In this context, the planetary boundary concept stimulates discussions among scientists from different fields, such as environmental chemistry, ecotoxicology, ecology, chemical engineering, environmental systems analysis, and life-cycle assessment, regarding the possibilities to define boundaries for chemical pollution on a global, regional or local basis. To foster this discussion, the International Panel on Chemical Pollution, IPCP, held a workshop on “In Search of Planetary Boundaries for Chemical Pollution” in April 2012.

Concept and discussion

Application of the planetary boundary concept requires that the impact of an anthropogenic stressor on an ecosystem can be described and quantified by a control variable such as the CO_2 concentration in the troposphere in the case of global warming, see Figure 1A. Not for all systems and stressors it is clear if the response variable shows the step-like behavior shown in Figure 1. Such a step-like behavior occurs if there is a tipping point of the system where transition of the system into a qualitatively different stage is triggered, such as a much more rapid global warming at CO_2 concentrations above a certain value. In such a case, the tipping point is marked by a threshold, but the scientific knowledge about this threshold is always surrounded by uncertainty (Figure 1B). The planetary boundary can then be set as a level somewhere below the threshold (Figure 1C). It is important to note that the boundary is a limit value that is set on the basis of a political decision and has a normative component. The threshold, in contrast, is a property of the natural system reflecting the existence of a tipping point.

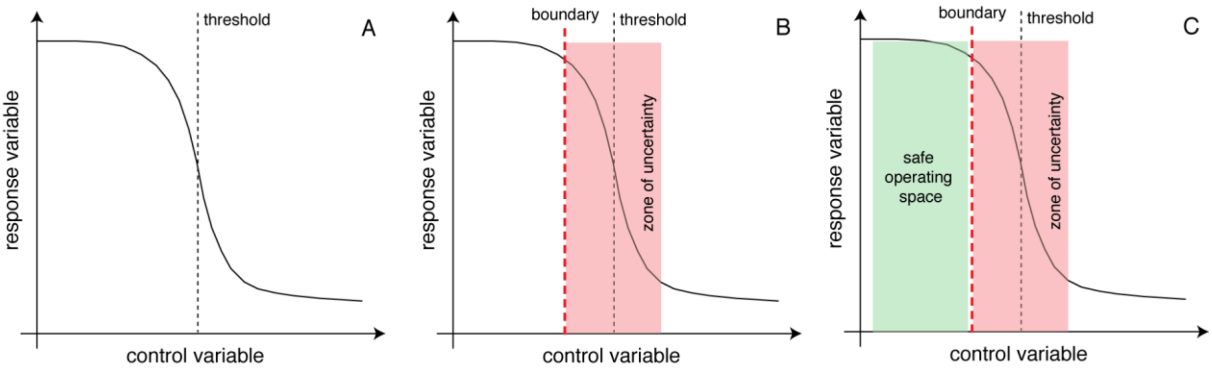

Figure 1: Conceptual visualization of the relationship between response variable and control variable, position of the threshold that marks the tipping point of the system, the boundary set at the lower end of the uncertainty range around the threshold, and the safe operating space below the boundary.

The distance between the planetary boundary and the threshold depends on the uncertainty that surrounds the scientific knowledge about the threshold. If the uncertainty is high, a larger distance between the threshold and the boundary is advisable. The domain below the boundary can be considered a "safe operating space". We acknowledge the possibility that for chemical pollution at the global level there might not be a tipping-point and that a planetary boundary in that case would have to be defined without a threshold; it might also be necessary to define different boundaries for different groups of chemicals (see Rockström et al.[5] and below).

Application of the planetary boundary concept to chemical pollution is not straightforward for several reasons. First, there is a very large number of chemicals (more than 100 000) that enter the environment as the consequence of human activity. These include various pesticides, biocides, pharmaceuticals, (several hundreds of active substances in each category), chemicals in personal care products and cosmetics, several tens of thousands of industrial chemicals (such as solvents, plastic softeners, flame retardants, dyestuffs, paints, impregnation materials, antioxidants and many more), and unintentionally produced substances such as polycyclic aromatic hydrocarbons and polyhalogenated dibenzodioxins and -furans. In addition, many of these chemicals lead to transformation products that are formed in the environment before complete mineralization is reached. Further there are numerous chemical species of metals such as arsenic, lead, cadmium and mercury and many more, and other elements, including radioisotopes. Many of these substances may be present at the same time and form complicated mixtures.

Secondly, there is an enormous number of species in a large number of highly different ecosystems that are affected by exposure to anthropogenic chemicals. The combination of the high number of chemicals with the high number of species in the many different ecosystems of the world makes the derivation of a planetary boundary for chemical pollution a formidable task.

Thirdly, the ways in which each individual chemical may act in an organism are again nearly uncountable. For example, there are more than 50 endocrine systems in wildlife and humans, among which many are the same or similar. The mechanisms of actions are very different and the endpoint likewise, different. We need to distinguish between toxicological endpoints and endocrinal endpoints, the former leading to effects in the exposed individual, whereas endocrine effects may harm next generations. In addition, there are many more than hormonal effects, e.g. cancer, immunological effects, organ toxicities and teratogenicity.

How might this task be approached, how can we determine what parts of the task are tractable, and what can be expected as an outcome of this endeavor? To address these questions, we depart from the concept of chemical risk assessment as it is applied for single chemicals in specific regions. Chemical risk assessment includes the main components of emissions, environmental fate, human and environmental exposure, and adverse effects in humans and wildlife. From emissions and environmental fate of a chemical, the substance's Predicted Environmental Concentration (PEC) is calculated. Toxicity data are used to derive a Predicted No-Effect

Concentration (PNEC) by applying safety factors to the effect thresholds determined in toxicity tests on selected species; the safety factors depend on the number and quality of the toxicity test results.

When we proceed from a single chemical in a single certain region to a large number of chemicals in the global system, it seems to be conceptually possible to estimate the emissions of chemicals and the resulting environmental exposure. This requires spatially and temporally resolved emission inventories for the large number of chemicals that need to be based on extensive information about application patterns of chemicals and chemical-containing materials, about the composition of materials and release rates of chemicals from these materials, retention factors of chemicals in treatment systems for waste air, waste water, and solid wastes etc. In a next step, these emission data have to be combined with chemical property data for all chemicals and used as input to environmental fate models of different scales, depending on the properties and the use patterns of the chemicals. Environmental fate models in combination with chemical property data and spatially and temporally resolved emission inventories have been shown to yield accurate results on scales from local to global[6–9].

Estimating emissions and environmental and human exposure at the global level according to this approach would require huge efforts but would be conceptually possible. For the adverse effects of chemicals, in contrast, the step from a single chemical and a well-defined region to all chemicals and the global system is considerably more difficult. Currently, it is not even conceptually clear how safe levels for the combination of all chemicals that are released from human activities and may affect thousands of species in numerous ecosystems from polar to arid to rain forests may be derived.

At this point, it is helpful to consider those types of chemicals where boundaries have already been established, in some cases even at the global level. A first type of boundary applies to persistent chemicals with the potential for global distribution, specifically chlorofluorocarbons (CFCs) and POPs. For these chemicals that have potential for global impact and cannot easily be removed from the environment once they have been released, emissions targets of zero have been set under the Montreal Protocol and the Stockholm Convention[10,11]. The two groups of chemicals regulated under the Montreal Protocol and the Stockholm Convention are relatively small and a target of zero emissions is possible in such a case. However, a boundary defined by zero emissions cannot be established for all types of chemicals because it would be too restrictive.

A second type of boundary has been established for food additives and food contaminants. This type of boundary includes the Acceptable Daily Intakes (ADIs) and Tolerable Daily Intakes (TDIs) defined by the Joint FAO/WHO Expert Committee on Food Additives (JECFA)[12]. These boundaries are established at the global level; they represent intake rates of chemicals (in mg per kg body weight and day) below which a lifelong intake is considered safe. They have been defined for almost 3000 chemicals present in food (food additives, contaminants and naturally occurring toxicants, and veterinary drugs) and are based on current toxicological information about the chemicals. Compared to the zero emission target of POPs and CFCs, this type of boundary is conceptually different because it is defined in terms of non-zero intakes and is derived on the basis of scientific information about potential adverse effects. In other words, intakes below the ADI or TDI can be considered to occur within a "safe operating space". However, this safe operating space is specific to the chemicals considered and to the associated human health effects.

In conclusion, chemical pollution is certainly a strong anthropogenic impact of global relevance. However, because of the local or regional nature of many exposures and effects caused by chemicals, there is probably not a single tipping point for the global system that would have to be reflected by a planetary boundary. Therefore, in order to assess and manage chemical pollution, it seems to be more promising to focus on certain classes of chemicals separately and to derive boundaries of different types for these classes of chemicals, as illustrated above for CFCs, POPs and food contaminants. Such a differentiated approach takes into account the high diversity of (i) chemicals, (ii) types of adverse effects caused by chemicals, and (iii) of species and ecosystems affected by chemicals and will probably be most effective. This does not imply that chemicals assessment and management should take place without international and even global collaboration. It is necessary to integrate chemicals assessment and management on the global level and to reduce impacts on environment and human health by joint efforts in all parts of the world.

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