A GPS for Environmental Chemicals

Once released, slowly degrading chemicals from agriculture or industry often set off detrimental effects in the environment. The danger posed by such substances depends not only on their chemical properties but on several factors: where they are released, their dispersal via air and water, and the diverse interactions with different environment media under various climatic conditions. Chemists and climatologists are now cooperating on models to bring all these factors into balance – as Gerhard Lammel from the Hamburg Max Planck Institute for Meteorology reports in the following article.

In the last ten years, the term “sustainability” has shot to stardom: it has forced its way into numerous programs, plans, annual reports and PR brochures released by correspondingly abundant associations, organizations, political parties and businesses – and due to inflationary use, now seems somewhat worn out. Many of the underlying thoughts nurtured by the model “sustainable development” are certainly not new, but take on new relevance in light of the dimensions some economic-ecological problems have attained in the last decade.

Since the end of the 1980s, it has been clear that the purely economic principle of “keep it up!” in many respects equates to “live for today, forget about tomorrow”. But economic, social and ecological conditions in North and South depend on each other, as do current and future living conditions and mankind’s chance to develop. Flawed development in industrial countries – particularly squandering resources and polluting the environment – go hand in hand with under-development in so-called third world countries, which means poverty, hunger, disease and environmental destruction. One-fifth of the world’s population uses up (or better: squanders) around four-fifths of global energy and raw material reserves, causing the most environmental damage. Many key resources that are plundered today unabated – indeed “blindly” – are non-renewable: and with them go the following generations’ chances for development. Moreover, growing environmental pollution hugely overtaxes regional or global regeneration capacities; without a change of course, natural cycles and functions will be threatened by irreversible damage or loss.

With these interrelationships in mind, the international community of states set a precedent in 1992: the UN conference in Rio de Janeiro adopted the “Agenda 21”. Deriving more from general rather than scientific points of view, it listed problem areas, pinpointed related deficits and formulated goals. Sustainability was held up as the model: countries should agree among themselves, should assess the opportunities and risks of current and future developments – and thus each strive for long-term policies based on precautionary measures. Taking precautions with relation to nature must first take into account the diverse “services” that mankind exploits: nature acts as producer, source and drain of diverse materials, and fulfills stabilizing and translocation functions. In order to maintain this capital, mankind should live off only the interest as far as possible.

Little Knowledge, Large Risk

But since many of nature’s activities and functions are scientifically still poorly understood, every new transaction that intervenes with natural interrelationships also conceals a certain risk. This is why Principle 15 of the Rio Declaration stresses the obligation of precaution-taking: “Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation.”

This principle is based on experience: all too often, scientific evidence of a threat to the environment or human health is first produced after the deed has been done. On the other hand, there is the problem of weighing up what is understood as cost-effective, case by case. In addition, liberalized world trade based on General Agreement on Tariffs and Trade (GATT) stipulations makes taking effective precautions difficult. GATT Article 20 permits trading barriers between member countries only if they are applied worldwide in 1980.
if sufficient scientifically based evidence is provided – which contradicts the precautionary principle and is impossible in many contexts of environmental or health risks. This particularly applies to persistent, that is, slowly degrading chemicals that are released into the environment due to human activities. Their danger potential depends essentially firstly on their physicochemical properties and secondly on their behavior in the environment: whether and in which ecosystem or organism they accumulate and act as poisons. A chemical’s threat to the environment can be estimated based on model calculations that predict either the geographical distribution of individual substances and/or their distribution between various environment media. Many compounds’ potential threat can be characterized only by such models, since the persistence of a substance that is at least partially dispersed in mobile environment media – that is, spread via air or water – cannot be measured directly. And just as difficult to quantify is their long-range transport potential: new emissions are superimposed on earlier ones and monitoring networks are too expensive to offer an alternative. Correspondingly, regulatory procedures in the European Union and international chemical policies plan to enlist model calculations to characterize substance risks. Of course, models that can describe particular substances’ transport and distribution in the environment are established climate research tools. Therefore, three years ago, with the Hamburg Ministry of Science and Research’s (BVW) support, a new research field was unveiled: the Hamburg Max Planck Institute for Meteorology together with the Meteorological Institute of the University of Hamburg with their joint dedication to “environmental exposure and threat analysis of slowly degradable substances.”

The goal was to unite chemists and climatologists. The former were to contribute their knowledge about the kind and dynamics of chemical transformations a particular substance undergoes in connection with its dispersal and accumulation under various conditions. And the climatologists were to integrate their experience with global atmosphere and ocean circulation models – models that reproduce transport patterns and are already successfully used to investigate short-lived atmospheric trace substances and their effects on ecosystems. Environmental Chemicals Tend to be Reborn

Within the framework of this collaboration, our research group developed a so-called multi-compartment model that describes semi-volatile substances’ transport and transformation in environmental compartments, taking re-emission processes into account. Once deposited, semi-volatile compounds are not removed from the cycle, but re-enter the atmosphere or hydrosphere via re-emission – a substance-specific behavior, which, however, also depends on temperature as well as on the partitioning and degradation processes determined by the respective environment medium.

This model, the first of its kind in terms of its scale – namely global – was developed using the supercomputer at the German Climate Computing Centre (DKRZ) in Hamburg. Since then, the model has proven its suitability and usefulness. It was used to investigate substance migration tendencies not only within individual compartments but also within the whole system, starting from emissions at different locations and in various climate zones. It revealed that simulations of chemicals’ environmental fate using conventional approaches, which for simplification neglect daily and annual cycles of environmental conditions, do not provide reliable data about the persistence of these substances. Rather, according to the new results, a chemical’s long-range transport potential and persistence also crucially depends on its emission location and time of entry into the environment, as well as the transport medium. This became clear, for example, when comparing the insecticides DDT and α-hexachlorocyclohexane (α-HCH): here DDT proved in general to be the longer lived substance, but not everywhere, and in varying contrast to α-HCH. Strictly speaking, α-HCH is not an insecticide at all; but together with isomers, some of them insecticide compounds, it has been applied in large amounts. Investigations of this kind are significant for applying the precautionary principle in chemicals legislation. Although the model developed in Hamburg facilitates such analyses, it is too complex to be implemented as a routine tool outside research. It can, however, provide standards – and in this sense serve as a benchmark for simpler models.