B Plastics in Nature and Society

The potential risks of plastic debris for human health and the environment have received a growing amount of interest among the general public, media, policy community, and scientific community. Whereas for many chemical stressors established risk assessments have provided clarity about the likelihood of harm and impact, our understanding of plastic debris is still in the early stages. There is no doubt that the presence of plastic debris in the biosphere is unwanted from an aesthetic, ethical, economic, and ecological point of view. However, the actual risks to human health and the environment remain highly uncertain and thus constitute an urgent area of research. It is often said that there is no silver bullet to the problem of pollution with plastic debris. This implies studying a diverse suite of measures, such as changing consumer behaviour, addressing the economics of waste, and prioritising material and product design. These are all determined by human decisions and behaviours, implying an urgent need for behavioural science research. To address these challenges, WIMEK offers a suite of world-leading research lines, ranging from analytical, fate and effect studies in freshwater-, marine and terrestrial systems across scales performed within WIMEK's Climate, Water and Society (CWS) cluster, to research on production and recycling of bioplastics and global environmental and marine governance.

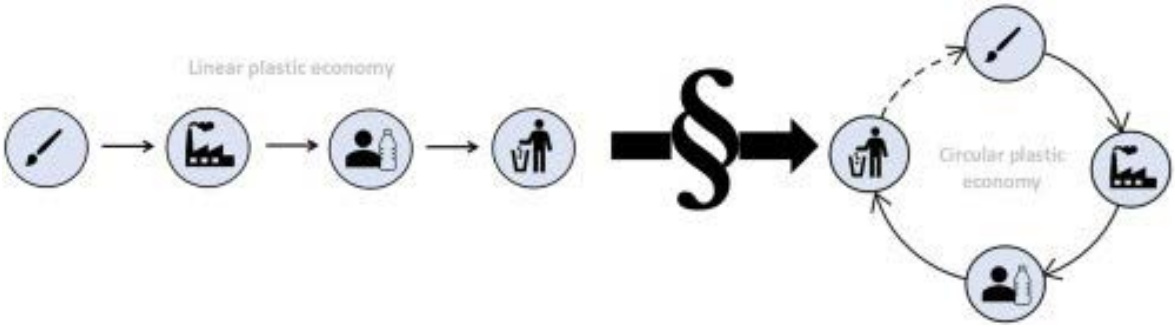

Figure 1: from a linear to a circular plastic economy

Background

Pollution with plastic debris is recognized as one of today's major environmental problems. Solving the problem of pollution with plastic debris requires a range of measures, whereas diverse solutions need to be informed by diverse science. Measures include addressing the economics of waste, changing consumer behaviour, and prioritising material and product design. These are all determined by human decisions and behaviours, implying an urgent need for behavioural science research. Solving the problem through behavioural change and management is a process that can take years, perhaps even decades. Consequently, it is plausible that plastic debris will continue to leach into our environment for many years. This implies that it is essential to understand why and how our economy leads to emissions of plastic debris, how plastic and plastic-associated chemicals behave in the environment, and what the risks are to people and the environment on short and long time scales. Data on risks and impacts in the biosphere are also essential for prioritizing solution methods, while such data on actual risks in turn influences the human perception of the problem. Understanding how plastic moves and the plastic problem exists in our socio-ecological system is key to finding solutions efficiently.[1,] Within this holistic frame, **WIMEK** offers a suite of world-leading research lines, ranging from analytical, fate and effect studies in freshwater-, marine and terrestrial systems across scales, mainly performed within WIMEK's Climate, Water and Society (**CWS**) cluster, to research on production and recycling of bioplastics (**ETE**) and global environmental and marine governance (**ENP**).

Research objectives

WIMEK's research regarding the environmental issue of plastic debris constitutes three major research lines, sparked by the following objectives.

1 Developing analytical, detection and monitoring methods for plastic debris of all sizes, and understanding their fate, exposure, effects and risks for man and the environment.
This work is mainly carried out by the WIMEK chair groups AEW, HWM, WSG (all part of the ESG CWS Cluster) and the chair groups SLM & SOQ (part of the ESG Soil Science Cluster), with strong collaborations between each of the groups. Further strong WUR collaborations exist beyond WIMEK, i.e. with WMR, WEnR, WFSR, WFBR

2 To contribute to achieve a circular economy by developing a waste/biodegradable recycling/ biorefinery platform to close waste/plastics loops, which uses biodegradable plastic waste as feedstock to make new plastic and other products.
This research line is hosted by the WIMEK chair group ETE and by WFBR.

3 To understand how production, consumption and waste of plastic are interlinked and how this differs among products and countries in order to organise a circular chain or to replace plastic with other materials, thereby reducing pollution with plastic.
This relatively new research line is hosted by the WIMEK chair group ENP.

Research philosophy

WIMEK's research groups mainly use *multidisciplinary* research approaches integrating concepts from environmental chemistry, microbiology, ecotoxicology, toxicology, freshwater and marine ecology, hydrology, and soil science. The groups typically use a systems analytical approach aimed at understanding the chemical, physical and biological processes occurring in and across environmental systems, in order to understand the implications of plastic debris for the environment and human health. This implies a strong integration of experimental work, field work and accumulation and effect modelling covering biological levels of organisation from in vitro cellular to the full ecosystem scale, whereas systems modelling ranges from simulating processes occurring in idealized laboratory systems, up to actual environmental compartments, across environmental media and the global scale. Separate research lines exist to develop novel methods to monitor macroplastics in rivers, and novel analytical approaches to detect nano- and microplastic particles in water, soil, air, biological matrices and food, including drinking water. We develop and apply the newest technologies such as Fourier Transform Infra-Red (FTIR), Raman or Quantum cascade laser (QCL) spectroscopy, and asymmetric field flow fractionation coupled to Pyr-GC/MS. Process and bioaccumulation studies use rare Earth metal-doped nanoplastic particles to enable accurate detection at environmentally realistic, low concentrations.

Stakeholder involvement

Illustrating the outstanding societal relevance of the work, WIMEK's projects and research on plastic debris have a high level of involvement of stakeholders and end-users. These typically include international environmental and/or human health protection agencies or organisations (e.g. WHO, UN, OSPAR, EPA, EC[1], SSCWRP, WWF), companies or trade organisations (e.g. producing chemicals and plastics, recycling or biotechnology companies). On a national level there is direct use and application of research results via close involvement of national water authorities (Rijkswaterstaat), regional water boards, the National Institute for Public Health and the Environment (RIVM), Dutch Food Safety Authority, and drinking water companies. WIMEK researchers on plastic debris (microplastic, macroplastic, nanoplastic) also have a very high profile with the public, which manifests via many media occurrences, keynotes for specialised scientific - as well as general public audiences, e.g. in Science Café's.

Link to education

An education package has been developed for primary school students enabling them to become aware of the concept of the 'plastic soup' and some basic research tools. Almost all chair groups integrate their newest research on plastic debris in their regular BSc and MSc courses, some of which have the issue of plastic pollution as a module or theme for e.g. a week or case study. Research on plastic debris still is a young subdiscipline in the environmental sciences, yet around five PhD theses have been completed over the past years. A first specialised international course for PhD students 'Plastic in Nature and Society' has been organised by WIMEK researchers, advertised and scheduled, yet had to be postponed due to the COVID-19 pandemic.

Research Highlights

WIMEK researchers have produced ground-breaking and WoS highly cited research especially on the detection, fate and effects of microplastic in aquatic and terrestrial systems. They were the first to develop biomonitoring methods using fulmars, to provide experimental and assessment models to assess the role of plastic-associated chemicals in risk of microplastic3, effect and risk assessment methods for the particles themselves, quantitative quality assurance and - control (QA/QC) assessment methods for analysis and effect tests[4], single species bioassay methods for micro- and nanoplastic including use of metal-doped particles, long term community effect test approaches, microplastic food web accumulation and lake food web effect models, river transport models and global multi-pollutant models.[6] WIMEK researchers invented theoretical approaches to capture the diversity as present in the plastic size, shape and polymer continuum via probability density distribution functions enabling breakthroughs in data processing, probabilistic fate, effect and risk modeling and assessment. With this, WUR, via WIMEK, ranks second in terms of plastic debris research output (after Plymouth University, UK) and WIMEK's top scientists rank highest among plastic researchers on the 2018, 2019 and 2020 Clarivate lists of high cited researchers.

The diversity of microplastic particles - photo: Merel Kooi, WUR/AEW

The aforementioned measurement methods, QA/QC recommendations, models, experimental and characterization methods are widely used by peers. For example, the WUR models to assess the relative role of microplastic as a vector for chemical uptake are widely applied by other researchers. Oceanographers are using the WUR 1D model for vertical distribution of microplastic in the oceans to implement it in their 3D models building on it to account for lateral transport and ocean circulation. WIMEK's research on plastic debris is well-funded via National Research Council Grants (Dutch, i.e. NWO, as well as international, e.g. Norwegian Research Council), industry funding (CEFIC-LRI), EU/

European funding (e.g. JPI-Oceans PLASTOX, ANDROMEDA, H2020-MINAGRIS). Two WIMEK CWS researchers received prestigious NWO Veni grants for their research on plastic.

Impact

WIMEK's research and impact has led to nominations by the EC's SAM unit as well as by the KNAW to lead the SAPEA international expert group that produced the Evidence Review report on 'Microplastic in Nature and Society'[1] for Brussel's Group of Chief Science Advisors advising the College of European Commissioners, as well as to lead the first WHO report on Microplastic in Drinking water[10], as well as to become Editor-in-Chief of the new Springer Journal *Microplastics and Nanoplastics* (2020), all having high scientific as well as societal impact. The reports contributed to the development of European scale policy, e.g. ECHA's restriction of single use plastic. A risk assessment method developed by WIMEK researchers has been adopted and further implemented in collaboration with the US State of California to be used for the first definition of safe standards for microplastic in drinking water and seawater. WIMEK impact further consists of authoring the first UNEP Guidelines for plastic monitoring in freshwater ecosystems; the UN-ESCAP eLearning module on plastic monitoring, focused on local stakeholders (i.e. gov) in Southeast Asia and developing a Roadmap for a Dutch national plastic monitoring strategy.

Selected WIMEK References on plastic debris

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