WIMEK self-evaluation report 2014 - 2020

Summary and case studies

Wageningen Institute for Environment and Climate Research

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WAGENINGEN UNIVERSITY & RESEARCH

Summary

The Wageningen Institute for Environment and Climate Research (**WIMEK**) was founded in 1993. It currently coordinates the education and research activities of PhD candidates and postdocs of sixteen chair groups of Wageningen University. WIMEK participates in the Netherlands Research School for the Socio-Economic and Natural Sciences of the Environment (SENSE). To this national network of graduate schools WIMEK contributes as one of the schools, to the network for PhD candidates, postdocs and staff, and to the bridge-to-society for the Dutch sustainability sciences.

The main **aims** of the WIMEK Graduate School are:
1 To perform high quality scientific research for impact in the global scientific forefront of environmental and climate research
2 To provide an inspiring tailor-made in-depth and skill oriented training programme for PhD candidates and postdocs
3 To form an internal WU interdisciplinary network and social community of staff, postdocs and PhD candidates on environmental, climate and related sustainability sciences
4 To work transdisciplinary, by exchanging emerging insights, recent research results and novel technological & policy approaches in an interactive way to companies, public institutions, regulating authorities and other parties in society.

The WIMEK Graduate School aims to provide optimal support and **training** for talented young researchers to develop themselves as independent scientists at the highest international standards who have the potential to contribute to solutions for emerging environmental and sustainability problems and can become future scientific leaders in academia, and in public and private sectors in this field. Currently, about 370 PhD candidates are enrolled in the WIMEK Graduate School. In the past seven years, on average 47 (36-61) PhD candidates graduated per year at the WIMEK Graduate School. For a large majority (92%) of those, the PhD degree included a SENSE Diploma of specialized PhD training in sustainability sciences.

WIMEK combines fundamental, strategic and participatory **research** in environmental, climate and sustainability sciences, from both a natural as well as a social sciences point of view. The research focusses on pressing environmental problems and related sustainable solutions from local to global scale within the following three Grand Environmental Challenges:
- Climate action: Towards fair and effective solutions for climate change mitigation and adaptation
- Managing our future biosphere: Developing strategies for the sustainable use of soil, water, atmosphere, biodiversity, ecosystems and landscapes
- Advancing circular systems: Inclusive innovation towards closed water, nutrient, and material flows

Research output and impact: WIMEK's publications over the past six years are well cited. The average Field Weighted Citation Impact is 2.42, which is over two times the world average. Of all publications, 26% belong to the top 10% most cited publications (field weighted). Moreover, WIMEK publications were frequently mentioned in the news or in policy documents, and contribute to the public debate on planetary boundaries, sustainable food production, ecosystem services and clean healthy air, soil and water systems. Among the organizations that use WIMEK research output are international institutions such as the FAO, WMO, EU, UNEP and IUCN, as well as national institutes such as RIVM and PBL. WIMEK also excels in public-private-science & technology partnerships for instance through WETSUS and the large mission driven research programs of NWO, the Top Sector Research of Dutch Ministries and the RTD programs of the EU. These programs generate integrated technological-social solutions based on novel scientific insights and are widely used for upscaling societal transitions to sustainability in the Netherlands, Europe and world-wide. In the period 2014-2020 a number of WIMEK researchers received prestigious grants, namely for NWO Veni (13 researchers), Vidi (3), Vici (1), and ERC consolidator (1) and advanced (1) grants.

In the coming six years WIMEK's **outlook** is to further advance the high quality of the research and the PhD program, and to address the weaknesses identified in this review. WIMEK aims to harvest the opportunities occurring in society, i.e. the rising awareness among policy makers, corporate leaders and youngsters around the globe on the vital importance of tackling the grand environmental challenges of the world. WIMEK will nourish and advance its current collaborations in Netherlands, EU and the North Atlantics and will invest in stronger collaboration with Asian (including China), African and South American countries. Major challenges for global sustainability are awaiting there and need to be resolved in science-society collaboration, to which WIMEK can greatly contribute. WIMEK aims to further its internationally well-respected reputation as front runner school of environment. We will provide to researchers from diverse backgrounds in discipline, culture, and gender a secure home to excel in inter- and transdisciplinary research for the environment. Thus we continue to provide top research findings and scientifically trained leaders to the public and private sectors of society thereby contributing to make our future world sustainable.

Case study: Climate Information Services

Over the last 20 years it has become increasingly clear that climate change will have a severe impact on our environment as well as on water and food availability. Climate change impact assessments initially focused on “warning” the world about the potentially devastating impacts of climate change. The main aim of the impact studies was to stimulate and guide mitigation policies. Now it is clear that climate change is inevitable the development of adequate adaptation strategies is necessary. However, this development is hampered by the fact that much of the climate change data is not available, accessible, usable. Moreover, interpretation of the data is difficult for key stakeholders that need to implement climate change adaptation strategies.

To stimulate the use of climate data in adaptation projects and strategies, scientists within WIMEK started developing climate information services.

Research objectives and approach

The work on climate services within the WIMEK chair groups focus on two key research objectives. The first objective is to improve our general understanding by quantifying the impact of climate variability and climate change on water, food production and the (urban) environment. The second research objective focuses on how to communicate this information to a wider audience, and how to co-create actionable knowledge through the development of climate information services.

The development of the climate services within the WIMEK chair groups started with the development of modelling systems in which climate models were softly coupled with large scale hydrological and agricultural models (Supit et al. 2010a,b, Haddeland et al. 2010, Hagemann et al 2013). These multi

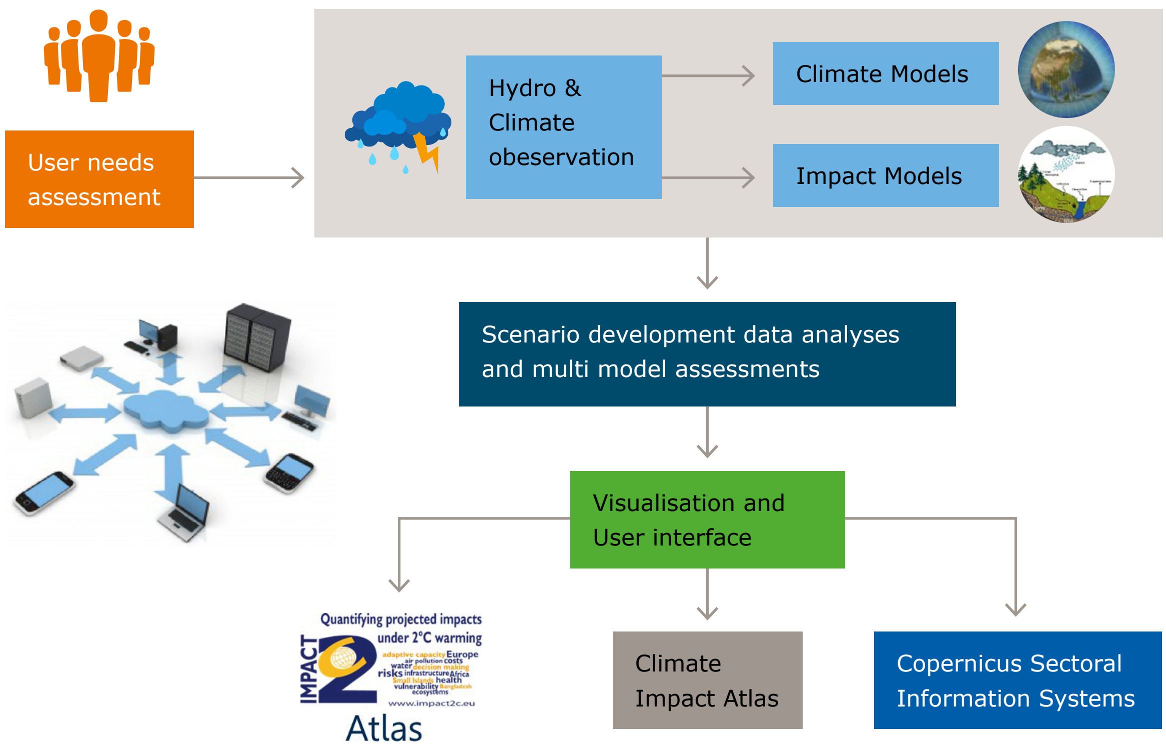

Figure 1. First generation climate information services. In this approach the focus is on improved knowledge and understanding of climate change impacts. Impact analyses, and the selection of scenarios and indicators are guided by assessment of the initial user demands. After this assessment, the team of scientists performs the impact analysis. Results are usually communicated through (assessment) reports, policy briefs, workshops and other outreach activities. Results are made available to the wider public through the development of (interactive) atlases.

climate and impact model approaches in WaterMip and ISIMIP resulted in a much better understanding of future climate change impacts. In a later stage we developed the first European climate services in the context of the EU projects Eclise, Impact2C and Euporias. Within these FP6 and FP7 projects we developed what we now call the first generation of climate services (figure 1). This first generation focused on the development of new data and modelling frameworks, and the integration of climate models, observations and impact models. These climate impact assessments and related climate services are developed within different groups involved in WIMEK. HWM and WRM focused on the development of hydrological models and drought assessments. MAQ on data collection, data integration, and meteorological model development, LAR on urban climate and ESA on environmental impacts. The WSG group has focused on developing a multi-model impact assessment framework, and on food, water quality and water quantity models. The AEW group studied how climate change may trigger different tipping points in the earth system, and to what extent climate change could result in irreversible changes in different (eco)systems.

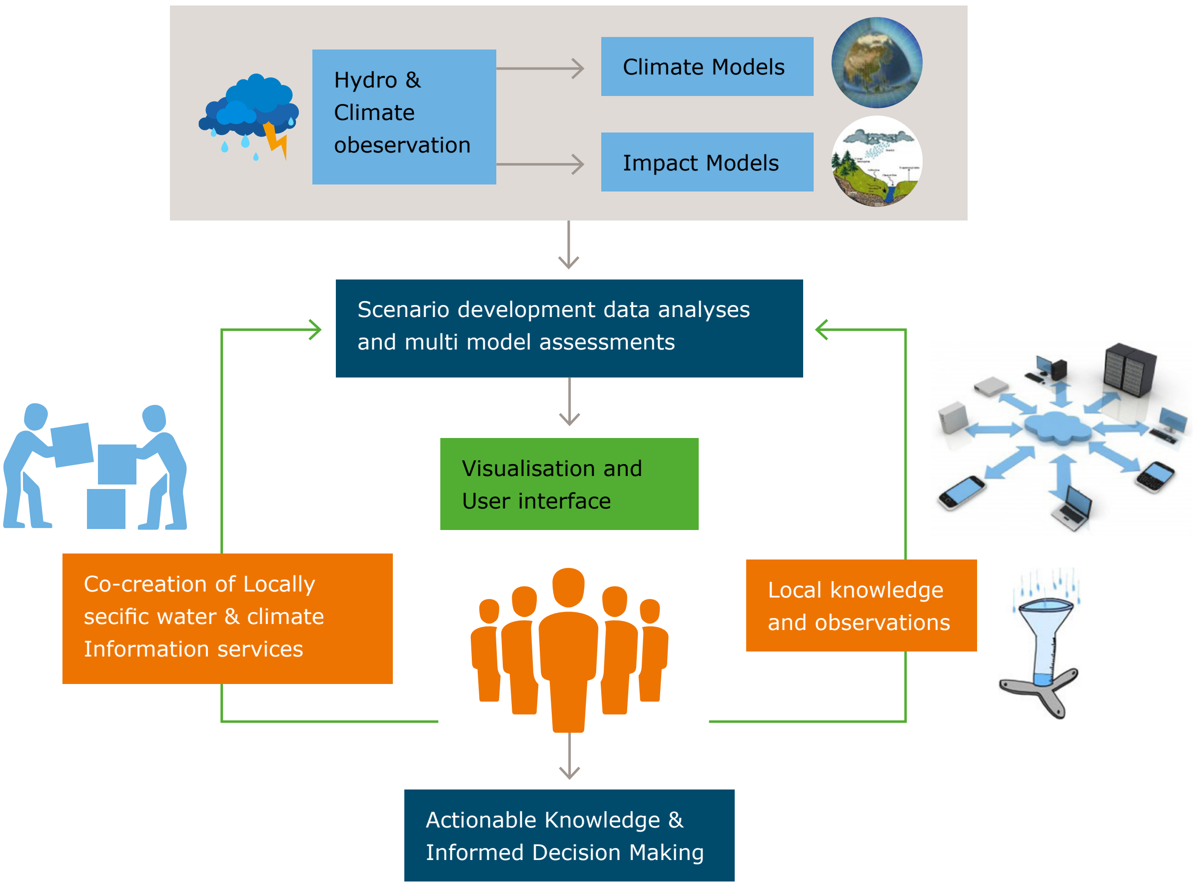

Figure 2. Second generation climate information services. In this approach the user has a central position. Together with users, information services are developed through co-production and co-learning approaches with the aim to develop actionable knowledge and information decision making.

These climate impacts assessments have generated a wealth of information and resulted in many high impact publications and a special PNAS issue. However, a first evaluation of the developed climate services indicated a number of limitations for the users. The information was too uncertain, not at the right spatial scale, projected too far into the future, and thus did not warrant immediate action. These limitations triggered us to develop a second generation of climate services. This new approach focusses on co-development and co-learning and puts the users central in the development of the climate services. This approach ensures more intensive interactions with the users and makes them partly responsible for the development of the products. This interactive approach has been used at local to global scale. Within the EVOCA and WaterApps project we have co-developed apps and other digital communication services with local farmers in Ghana and Bangladesh. These services focussed on the integration of local, indigenous knowledge with global scientific knowledge on climate and weather to develop services which aimed at improved agricultural production. Seasonal and long-term weather forecasts help the farmers to prepare for extreme events. At regional and global scales, climate information systems have been developed for the water, agriculture and tourism sectors. Together with users it was studied how the Copernicus Climate Change Service can be improved to develop tailored products in the different sectors. We developed a global data and modelling platform in combination with novel visualization tools to make the climate data usable to key users in the public and private sectors. These new approaches require more intensive collaboration between biophysical and social scientist and the co-creation projects include not only the ESA and WSG groups, but also the ENP and PAP groups.

Involvement of stakeholders, users and partners

From the beginning, development of the climate information services has been in collaboration with a range of partners and end users. Our regional and global scale information services focus on informing policy makers from national government, the EU and international organizations (IPCC, UNDP, FAO, WMO and WHO) and river basin management authorities. Over the last 5 years our focus has shifted from top-down approaches guided by stakeholder consultation, to a co-production and co-learning approach in which the services are developed with and for the targeted users. These targeted users still include policy makers but in addition we also started to work with local water boards, farmers, consultancy companies, NGOs, foundations and the private sector. This work is funded by a large range of organizations, including NWO, Copernicus Climate Change Services, INREF, EU, Rabobank, and JPI, NUFFIC, Ministry of Foreign Affairs. Finally, it is important to acknowledge the importance of working with a wide range of partners. In terms of research partners, we work with universities across the world, with meteorological organizations such as KNMI, SMHI, ECMWF, Ghana Met Office, and the CCAFS program of CGIAR. Within Wageningen UR, Wageningen Environmental Research (WEnR) is a very important partner and many climate service projects are run together with WEnR.

Impact

The work of WIMEK has had clear scientific and societal impacts. In terms of science the work has resulted in a large number of papers in prestigious journals and many of these papers are highly cited. The work is also highly valued by research funders showing the large number of research grants supporting this work. In terms of societal impacts, our work has informed national, international (EU/UN) and regional policymakers. We have contributed to the IPCC and a range of other policy relevant documents on climate change services, impacts and adaptation. In addition, the climate services have helped local government, businesses (for example Thomas Cook, De Heus, Heineken, PGM pension fund), and local farmers to better manage their climate risks and adapt to future climate change. For example, our climate services developed in Bangladesh gave farmers access and trust in longer term forecasts of cyclones. During interviews the farmers indicated that they used the 7-day cyclone warning to inform relatives about the predicted emergency. In response, the population started to repair households and livestock sheds, cutting of tree branches above their roofs, and did not allow livestock to graze in open field. They also collected additional fodder for their cows, and bought emergency household supplies to prepare for the cyclone. Many farmers indicated that the (financial) damage of the cyclone was much lower because of the longer preparation time they had as a result of the developed weather and climate service.

Link to education and capacity building

Our research on climate information services is well linked to our education. In terms of Bachelor and Master Education he main links are with the Masters Climate Studies and Master Earth and Environment and the BSc minor climate change mitigation & adaptation. The concepts and techniques of tailoring climate data, developing climate services and stakeholder and user interaction are discussed in a number of courses. Often the cases from our research projects are used in our BSc and MSc education. In addition in many of our projects most of the research is done by MSc and PhD students. In our projects in Africa and Asia, we work with local universities and educate PhD students from the region. However, we do not only educate our students. The development of climate services is very often embedded within co-learning and co-creation processes. Results of our projects have shown that by being closely involved in developing and testing of the services the envisioned users of our services go through a learning process which is essential to trusting and appropriately using the services for decision making. Finally, together with Wageningen Environmental Research and Wageningen academy, a user learning services (ULS) platform was developed for Copernicus Climate Change Services (C3S). In addition, 28 different training events in almost all EU countries were organised to train professionals in using the C3S climate data store and the associated toolbox for developing tailor made climate services.

Key Publications

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Case study: 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.

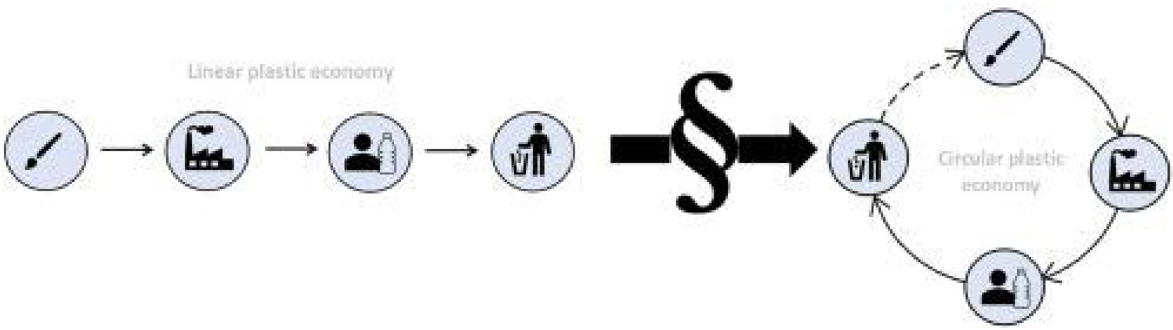

Figure 1: from a linear to a circular plastic economy

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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Case study: Sustainable nutrient management

Summary

Inputs of nitrogen (N) and phosphorus (P) are crucial for food production but inherent inefficiencies in crop and livestock production imply that much of those are lost to the environment. This results in multiple pollution threats, such as dead zones in coastal oceans, harmful algal blooms, terrestrial and aquatic biodiversity loss, nitrate contamination of drinking water and climate change. WIMEK's research on sustainable use of nutrients aims at providing solutions towards nutrient circularity in agriculture by: (i) developing (global) nutrient flow and impact models across different scales (landscapes, water basins, countries, continents and world), (ii) developing sustainable nutrient removal, recovery and reuse technologies and (iii) governance of nutrient management. By applying multidisciplinary research methods, new integrated concepts are developed towards closing the gap between current and environmentally acceptable nutrient inputs while ensuring or even enhancing food production. We work in close cooperation with stakeholders, ensuring that our science is used both by policy makers and farmers to solve the world's challenge to feed 10 billion people by 2050 sustainably.

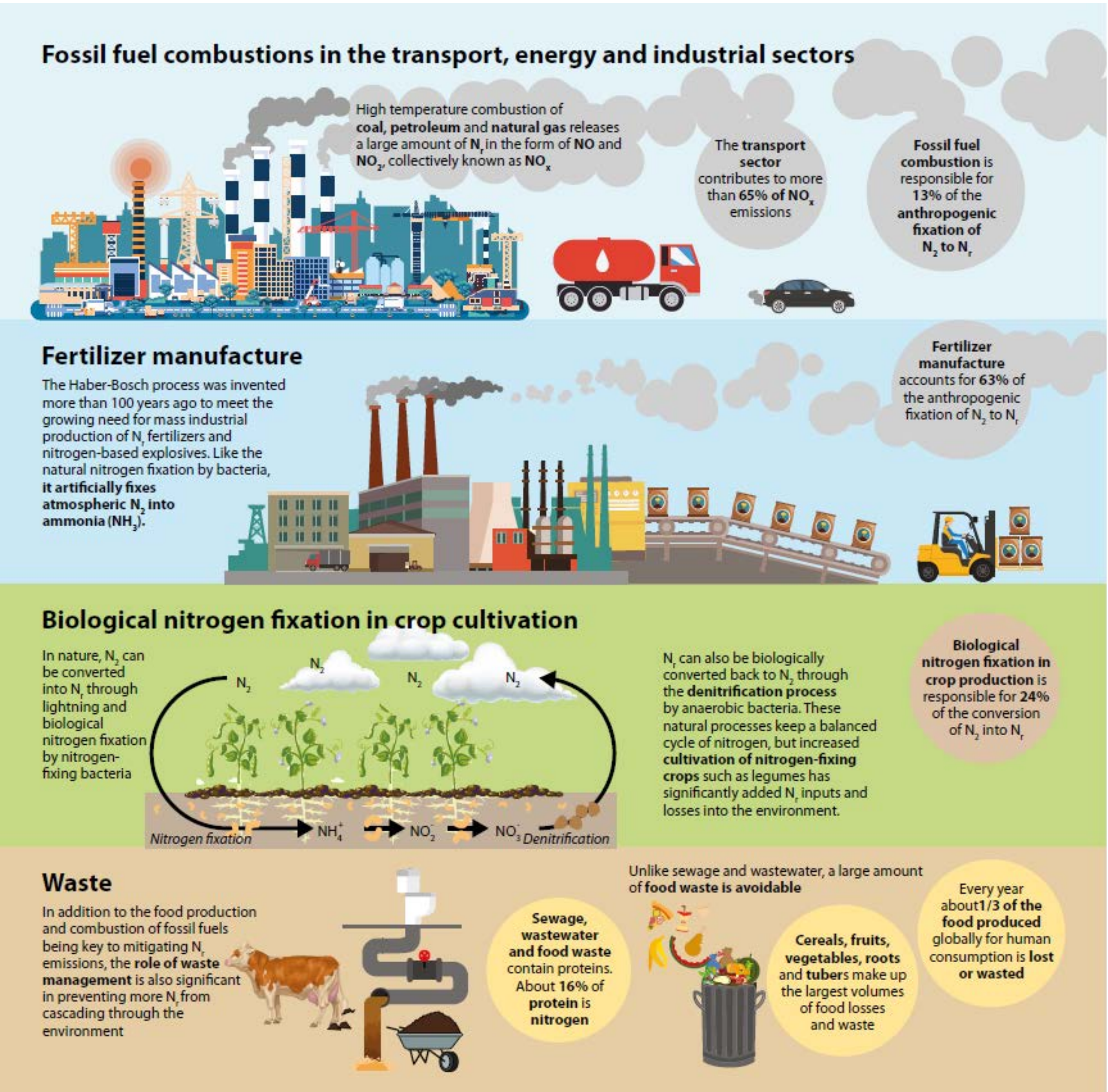

Figure 1: Nitrogen fixation and nitrogen flows (taken from Sutton et al., 2019)

Background

Sustainable use of nutrients, with a focus on nitrogen (N) and phosphorus (P) is at the core of several Sustainable Development Goals. Food security depends on inputs of N and P. Inputs by biological N fixation and by mineral and organic fertilizer application is, however, highly unevenly distributed on a global scale, ranging from N and P inputs that are inadequate to maintain soil fertility in many developing countries to excessive surpluses in many developed and rapidly growing economies. Nutrient-limited regions include much of Africa, Latin America and South East Asia, where too low levels of available N and P limit food production, also leading to depletion of soil nutrient stocks, posing risks of land degradation. However, in other regions, such as Western Europe, US and China, there is ample use of N and P fertilizers to increase crop yields, but the inherent inefficiencies in crop and livestock production implies that much of the N and P inputs to food production are lost to the environment. Together with N emissions from traffic and industry (Figure 1), this results in multiple pollution threats, such as dead zones in coastal oceans, harmful algal blooms, terrestrial and aquatic biodiversity loss and health impacts by nitrogen in particulate matter nitrate contamination of drinking water (Figure 2, 3). In addition, nitrogen use also affects climate change, amongst others by the warming impact of enhanced nitrous oxide (N_2O) emissions and the cooling impact of increased productivity and carbon (C) sequestration in terrestrial and marine ecosystems.

In view of multiple impacts of N and P use, 'planetary boundaries' have been proposed for the intentional chemical N fixation from the atmosphere and for the mining of P for the use of N and P fertilizers. However, these boundaries do not well account for the spatial variation in nutrient problems over the world, nor do they link well to the need for food security. In many parts of the world, an increase in N and P input is needed, while in other parts N and P application need to be reduced, with the challenge to maintain or even enhance yields and reduce environmental impacts.

Research objectives

WIMEK is involved in a suite of research lines that contribute to sustainable nutrient management with multidisciplinary and transdisciplinary research objectives, linking expertise from different disciplines to create scientific and societal impact. This includes the assessment and modelling of (i) the fate and effects of nutrient flows in agricultural systems, air, freshwater-, marine and terrestrial systems across different scales (landscapes, water basins, countries, continents and world), (ii) the overall impact of nitrogen use on greenhouse emissions, (iii), regional boundaries for nitrogen losses, surpluses and inputs, (iv) required increase in nutrient use efficiencies to reconcile food production and regional boundaries for agricultural nitrogen inputs (most within WIMEK's Climate, Water and Society (**CWS)** cluster). Other research lines include (v) the removal, recovery and reuse of nutrients from waste water (**ETE**) and (vi) the governance of nutrient management for food production and its trade-offs with the provisioning of water and energy in urban areas (**ENP**) and (vii) the evaluation of policy options for stimulating organic waste applications on nutrient losses by integrating spatial agent-based models (LSP) with soil-carbon-and-nutrient-cycling models (ESA).

Below three examples are given on specific research objectives, i.e.

- Integrated nitrogen impact analysis at environmental systems analysis (ESA) group ; read more. This includes the integrated impacts of nitrogen use on soil quality (acidification), air quality (ammonia and nitrous oxide emissions) and water quality (nitrate runoff and leaching) with related impacts on crop yields, biodiversity and forest growth and the related assessment of critical nitrogen losses and inputs in view of those impacts with a focus on EU27, China and the world (papers 1-7).
- integrated modelling of nutrient flows in aquatic and terrestrial systems at the Water Systems and Global Change (WSG) Group; read more. This includes the assessment of impacts of agricultural and waste water nutrient management on the export of dissolved (inorganic and organic) and particulate N and P by rivers to coastal seas with a focus on China and the world (papers 8-10).
- removal, recovery and reuse of nutrients from wastewater at the Environmental Technology (ETE) Group read more. This includes the development of methods for recovering N and P from domestic wastewater, which could satisfy a quarter of the present worldwide P fertiliser use (papers 11-13).

Research approach

WIMEK performs multidisciplinary research by focusing simultaneously on the environmental, technological, and social challenges to feed 10 billion people by 2050 sustainably. In this context comprehensive and integrated modeling of the nutrient flows on land, in air and in water, affecting soil, air and water quality, is a key foundation of our understanding of the impacts of nutrient flows at various scales. This is essential to identify the main causes of nutrient losses and their related impacts, and to evaluate the effectiveness of interventions. The modelling approaches are used to support spatially-explicit policies to improve nutrient management, whereas scenario analyses are used to assess the potential impacts of changes in socio-economic development, combined with the implementation of technological interventions.

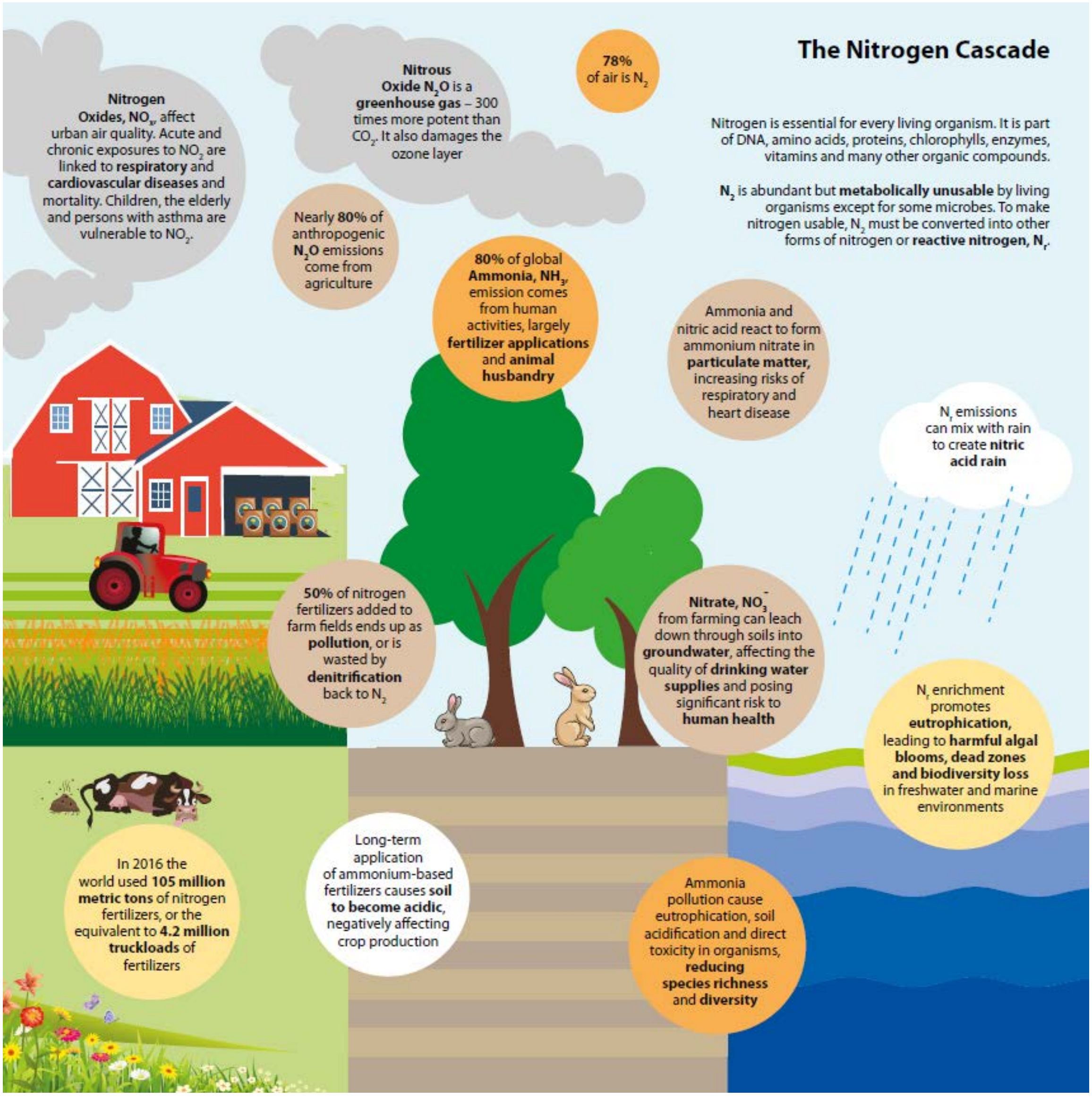

Figure 2: the Nitrogen cascade (taken from Sutton et al., 2019

Both the Integrated nitrogen impact analysis and the integrated modelling of nutrient flows is carried out with a focus on China in view of the high potential to reduce N and P inputs in this country in various programmes and projects, including the:

- WUR-CAU AGD Programme
- PhD project Agricultural Green Development for integrated nitrogen management of air and water in Quzhou and North China Plain; read more
- PhD projects on Modelling past, present and future nutrient flows from land to sea in China: using the MARINA familiy of models; read more

Stakeholder involvement

The work of WIMEK has had clear scientific and societal impacts. In terms of science the work has resulted in a large number of papers in prestigious journals and many of these papers are highly cited. The work is also highly valued by research funders showing the large number of research grants supporting this work. The research is performed in close collaboration with relevant stakeholders, including government regulators, environmental agencies (GPA, EEA) fertilizer industries (International Fertilizer Association, Fertilizers Europe), farmer organizations (LTO). This guarantees that research results are used in policymaking, fertilizer management and farm management, all contributing to a more sustainable management of nutrients. The WIMEK researchers also participates in the coordination of several Networks, including:

- INMS: Towards the Establishment of an International Nitrogen Management System
- WWQA: World Water Quality Alliance
- CDM: Commissie van Deskundigen Meststoffenwet

Figure 3: Multiple pollution threats of Nitrogen

Link to education

WIMEK is active in providing education on sustainable nutrient management. We teach students the impacts of nutrient management on agricultural production and on the environment in terms of air, soil and water quality and thereby on health, climate and nature. We teach them the use of various (chains of) models and modelling approaches to evaluate the effects of policy scenarios and management options on the environmental quality and related impacts. We engage them in modelling tools that can be used support managers (e.g. farmers or foresters) or policy/decision-makers in taking appropriate management or policy measures.

Research Highlights

Sustainable nutrient management is related to all three Grand Challenges of WIMEK, i.e.: climate action, managing our future biosphere and advancing circular systems. WIMEK researchers have produced several WoS highly cited research papers in high impact journal, that also attained press attention, on these topics. Examples of highlights are

- *Climate action:* A combination of several studies showed that at global scale the estimated CO_2 uptake due to N inputs to terrestrial, freshwater and marine ecosystems largely (on average near 75%) compensates the stimulating effect on direct and indirect N2O emissions. However, this effect is partly reduced by NOx-induced O3 exposure, which reduces CO_2 uptake, thus implying a compensation near 60%[1]. On European scale the N induced CO_2 compensation is likely higher[2]. However, on the long term, effects on ecosystem CO_2 sequestration are likely to diminish due to growth limitations by other nutrients such as phosphorus[3] and there are amplifying effects of Earth system interactions[4]. These insights affect sustainable management of both agriculture and forests

- *Managing our biosphere:* Various studies show that a reduction in N losses and related N inputs near 50% is needed at global and at EU scale. Highly cited papers in high impact journals present those results in terms of a planetary boundary for P inputs[5], N surplus[6] and N inputs[7], as compared to current inputs and surpluses. The needed reduction of 50% is now mentioned in several policy documents including the Colombo declaration on sustainable nitrogen management for the world and the Green deal for Europe.
- *Advancing circular systems:* A study that assessed integrated approaches to meet food demand in 2050 within planetary boundaries of, amongst others, nitrogen and phosphorus showed that: (i) the environmental impact of food production will increase by 50 to 90 percent until 2050 in a business as usual scenario and (ii) only a combination of diet change, waste reduction, circular agriculture and new sustainable technologies with high ambition can reverse this trend to impacts below the current level (Springmann et al., 2018).

Impact

The nutrient research has large societal impacts both in the Netherlands and worldwide. This holds for example for the research on the potential to feed the world sustainably in 2050, which got ample press attention[1,2] with related presentations[3,4] for e.g. public and food companies interview[5]

The large attention for the "Integrated nitrogen impact analysis" research is related to the Dutch 'nitrogen crisis', where a high court ruled that the government needs to take immediate action to reduce NH3 and NOx emissions to reverse widespread transgression of critical loads on natural ecosystems. WIMEK researchers estimated that N emissions have to be reduced by 50% and 80%, respectively, to protect 75% and 95% of all Dutch Natura 2000 sites. This research result was included in an advice to the Dutch government by a policy advisory board.

The research is explained to te broader public on various websites such as: WUR dossier Nitrogen, https://www.biomaatschappij.nl/online-dossier/dossier-stikstof/ and The nitrogen problem explained. Furthermore, the research results on nitrogen and the potential to solve the problem is not only communicated to policymakers, but also to the business community, banks and the general public, by interviews in newspapers, radio and TV in the Netherlands (and foreign channels in e,g. Belgium, Germany and the UK. For the combination of innovative research and research communication, an award nomination has been made: Nitrogen expert Wim de Vries nominated for Huibregtsen award 2020

1 https://www.ad.nl/wageningen/mondiale-studie-10-miljard-mensen-duurzaam-voeden-is-mogelijk~a744bf16/

2 https://www.volkskrant.nl/kijkverder/2018/voedselzaak/artikelen/zo-voeden-we-die-10-miljard-monden-in-2050-met-behoud-van-de-aarde/

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Case study: Circular water systems

Abstract

Economic growth and human livelihood consume large amounts of water, while also producing wastewater of poor quality. Over extraction of water and discharge of contaminated water affect environments and human livelihood. Even though many water treatment facilities have been implemented worldwide in the past decades, scarcity of clean fresh water is still an aggravating problem. Climate change and contamination by an ever growing number of different types of pollutants are the main causes of this. Continued availability of sufficient and clean water depends on our ability to move away from the current linear practices towards circular practices. Central to this goal is creating clean water cycles in which sufficient water of sufficient quality is available for humans and the environment. WIMEK's research on clean water cycles aims at providing solutions towards circularity by, among others, developing water quality models, sustainable water technologies and urban wastewater reuse strategies. Our research relies on multidisciplinary research methods to develop new integrated concepts on closing water cycles. In addition to scientific impact, we work in close cooperation with stakeholders to ensure that our science leads to solutions for the world's water challenges.

Background

Water flows through environmental, agricultural and urban systems, cycling through different usages. While floods and droughts make the news, water quality often ultimately determines actual availability of water resources. Water scarcity stems from a lack of water of sufficient quality for supporting domestic and industrial use, crop production, and aquatic ecosystems. Water quality is affected by anthropogenic activities, resulting in contamination with chemicals, metals, pathogens, plastics, nutrients and salinity. Many water treatment facilities have been implemented worldwide in the past decades, improving water quality at many places. However, in many areas, unsatisfactory wastewater treatment continues to release common pollutants, such as organic waste and nutrients, thus polluting rivers, lakes and coastal areas. Furthermore, worldwide we are challenged by emerging contaminants, including chemicals in consumer products, agroindustry and industry, as well as pathogens and plastic nanoparticles. Our global linear resource approach results in contaminated water unfit for reuse. Water scarcity is further exacerbated by climate change and over extraction, causing salt accumulation and intrusion.

Water contamination affects biodiversity, burdens ecosystem functioning and human health, restricts agricultural and industrial activities, thus carrying high economic costs. Since economic and ecological functioning is increasingly under threat worldwide, circular water system solutions are urgently needed. WIMEK develops innovative approaches to help understand how to create and sustain clean water cycles ensuring that clean water is renewably available for all uses. Therefore, WIMEK links the fields of water management and governance, environmental technology, microbiology, and water quality and aquatic ecology to help to re-establish clean water cycles and ecological, human health and economical functions around the globe.

Research objectives

Below three examples are given on multidisciplinary and transdisciplinary research objectives, linking expertise from different disciplines to create scientific and societal impact.

1. Developing **comprehensive modelling** tools for water quality assessment. Assessment of water quality forms the foundation of our understanding of current and future water quality, at the scale of river basins, lakes and coastal areas. These water quality models build on expertise within WIMEK on water quantity assessments and incorporates evaluation of global change, including climate change, impacts and influence of interventions on the water quality. *This work is led by the WIMEK chair groups WSG and AEW, in collaboration with WRM, among others. Further WUR collaborations exist beyond WIMEK. The work strongly contributes to the newest World Water Quality Assessment*[1]*.*
2. Developing sustainable **water technology**. Water technologies produce clean water for safe discharge into the environment or for reuse in domestic, industrial or agriculture uses. We develop sustainable technologies based on combining fundamental physical, chemical, and biological processes to remove contaminants from water to create water fit for purpose. *Technological innovation is led by the WIMEK chair group ETE, collaborating with other chair groups (MIB, SOC, SLM, WRM, ENP, ENR) and stakeholders (waterboards, technology providers, municipalities).*

3 Developing strategies for **wastewater re-use** in agriculture. Different uses of water demand different water quality standards. We develop context-specific assessments and strategies to match demand and supply, involving upgrading by treatment or mixing water from different sources. *This sustainable development oriented research line is hosted by the WIMEK chair group WRM, collaborating with other chair groups (ETE, ENP).*

Research philosophy

WIMEK performs multidisciplinary research on the environmental, technological, and societal challenges to achieving clean water cycles. **Comprehensive modelling** of water quality forms the foundation for our understanding of current and future water quality. Our focus is mostly on river, lake and coastal water quality, evaluating the recent past and future until ~2100. Comprehensive assessments are required to identify pollution sources and impacts of poor water quality, and to evaluate the effectiveness of interventions, such as implementing technologies. Measuring water quality is essential, but this cannot be done for all water bodies on Planet Earth. Therefore, modelling is an indispensable method to make adequate analyses and predictions, particularly for water scarce areas. Modelling supports an increased understanding of spatially-explicit water quality in data-scarce areas. Moreover, model studies that use scenarios enable evaluation of potential future changes in the water quality and impacts due to changes in socio-economic development, climate change and the implementation of technological or other interventions.

Water technology is one approach to closing water cycles by producing clean water. By treating contaminants, water technologies produce clean water for safe discharge into the environment or fit for reuse in agriculture or drinking water. Developing and implementing water treatment technologies is challenging, as these treatment technologies need to be sustainable, economically feasible, and robust, able to treat varying water quality under different environmental conditions. WIMEK performs research to develop fit-for-purpose water technologies that are used by stakeholders across the globe. Based in a scientific understanding of the mechanisms by which contaminants are removed, our technologies sustainably treat contaminants, ensuring clean water supplies for humans and the environment.

Wastewater reuse potentially provides a reliable strategy to meet increasing demands by water users with different water quality requirements. To match demand and supply, upgrading can be achieved by treatment or mixing of water with varying qualities. An example is the use and management of wastewater for (peri-)urban agriculture in the urbanizing areas of the world. We aim to support safe wastewater re-use in (peri-) urban irrigated agriculture to sustainably provide food to growing urban populations. This is done by studying the practices and politics of wastewater reuse in African and Asian (peri-)urban agriculture. We contribute to a better understanding of effective governance arrangements for small-scale reuse practices and thereby stimulate safe and productive agriculture in urbanizing landscapes across Africa and Asia.

Stakeholder involvement

Together with stakeholders in Uganda we developed a **comprehensive modelling** tool that simulates the number of pathogens that reach the surface water (emissions).[2] The tool provides spatially explicit emissions globally for grids of approximately 50x50 kilometres latitude x longitude and for case studies, such as parishes in Kampala, Uganda. The pathogens can cause disease, such as diarrhoea. Stakeholders, including sanitation safety planners in Kampala, use this tool to prioritise areas for sanitation implementation by evaluating areas with high pathogen emissions. Additionally, they use our tool to evaluate the efficiency of sanitation technology interventions, such as eradicating open defecation, making pit latrines watertight, or improving treatment, in reducing pathogen emissions.

Our **water technology** research is performed in close collaboration with relevant stakeholders, including drinking water companies, water boards, water technology providers, government regulators, industries, farmers and citizens. These stakeholders provide important input on the boundary conditions for new technologies, such as sustainability, treatment efficiencies, or effluent requirements. Our interdisciplinary approach ensures that our technologies are fit-for-use for current demands and future applications. Conducting research on **wastewater reuse** in urbanizing regions is both relevant and challenging since large groups are relying on food production from these systems, while crucial information and knowledge on safe and productive practices is lacking. To explore how best to make water reuse effective in supporting safe and productive irrigated agriculture we team up with local actors (i.e. farmers, public and authority organisations in Bangladesh, Indonesia, Vietnam, African, South American countries) and international organizations such as the International Water Management Institute (IWMI), FAO and the World bank.

Link to education

WIMEK is very active in providing education on water quality, water technology, water microbiology, agricultural water management and water governance. We teach students how to assess water quality by measuring and modelling, develop technologies and design intervention strategies. Several BSc and MSc level courses are available for students in the study programmes Environmental Science, Urban Environmental Management, Earth and Environment, Climate Studies, International Land and Water Management and Biotechnology. At WIMEK we engage in capacity development by supervising students from developing countries and by developing training programs. For example, water quality is a focus within the Copernicus project in which we teach users to develop their own climate and water services. Similarly, we have many sandwich PhD candidates, in which PhDs work part time in Wageningen and their home country to investigate and improve water quality and availability locally.

Research Highlights

Currently, water quality variables, such as nutrients, pathogens, pharmaceuticals, pesticides and plastics are studied individually, although interactions between the variables can be important and interventions for one variable can influence another. We develop **comprehensive** multi-pollutant **models** that uniquely incorporate these interactions to better assess the current and future water quality and potential interventions[3,4]. Nutrient pollution still turns lakes worldwide into toxic soups of algal blooms. **Comprehensive models** help to understand the interactions between society and the environment to Develop new solutions to prevent algal blooms in order to restore lakes back to healthy environments[5,6].

We engineer cost effective and **sustainable water technologies** for use in emerging economies and dense urban spaces. Sustainable water technologies are already available for treating classic macro-contaminants (organic matter, phosphate, and nitrogen) present in wastewater. However, implementation of existing technologies is sometimes restricted by limitations in existing infrastructure or local economy. Therefore, we develop technologies that are technically feasible while also recovering economically viable products, such as biogas, nutrients for agriculture, or clean water for irrigation. A notable example is our work on the Vital Urban Filter, where we develop a compact wetland system that treats wastewater for reuse in irrigation while producing ornamental plants with economic value.[7]

Another key challenge is the development of **sustainable technologies** to treat microcontaminants such as micropollutants and pathogens. Clean water cycles are currently threatened by trace concentrations of organic micropollutants, including pharmaceuticals, chemicals in personal care products, pesticides, and hormones as well as pathogens, like antibiotic resistance. These micro-quality parameters form a major hurdle to water reuse in clean and safe water cycles. We perform research to understand the fate and transformation of these contaminants[8], and develop technologies for their removal[9]. We aim to develop technologies that fit market needs for sustainability, affordability, and effective microcontaminant removal. Thus, we design innovative bioreactors and nature-based solutions in combination with advanced physical[10] and chemical[11] techniques.
We explore opportunities for conjunctive use and **wastewater re-use** (surface water, groundwater, treated wastewater) for irrigated agriculture that contribute to increasing health, food security and environmental sustainability. By studying practices along the water chain from upstream users to downstream (re)users, we evaluate how local sociotechnical configurations of water reuse emerge and evolve under influence of both technical and institutional interventions[12,13].

We are active in organising scientific meetings, such as an International Workshop on Global Water Quality Modelling in September 2018 and the Water Science for Impact Conference in October 2018 in which closing water cycles played a major role. These meetings generated scientific outputs, including two special issues in a leading scientific journal[14,15].

Impact

WIMEK is nationally and internationally recognized for its contribution to global efforts to improve water quality and accessibility to clean water. For example, our multi-pollutant modelling and other modelling efforts supports the preliminary World Water Quality Assessment of the United Nations Environment Programme[1]. Our sustainable water technologies are implemented around the world, winning prizes for their innovation and application.[16] For example, WIMEK researchers from ETE currently collaborate with Indian partners on a pilot plant for urban wastewater treatment in New Delhi. Funded jointly by Indian and Dutch governments, the pilot was recently visited by the King and Queen.[17] Our constructed wetland technology is currently piloted at Dow Chemical in Terneuzen[18], where we treat industrial wastewater for reuse at the DOW Chemical plant.

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