IRISgroup

WATER TECH RESEARCH IN DENMARK

Mapping and analysis of trends, specialisation, strongholds, and collaboration in Danish water technology research environments

January 2024

Front page photo by EyeEM, Freepik

The report has been prepared by IRIS Group for Water Valley Denmark with support from The Grundfos Foundation.

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Preface

This report has been prepared for Water Valley Denmark with support from The Grundfos Foundation to provide comprehensive knowledge on Danish water technology research.

The report presents a complete mapping of Danish water tech research environments, offering new insights into the development of funding options, research performance, and collaboration patterns.

The report serves two main purposes:

1) Mapping and describing water tech research environments to guide relevant stakeholders into new collaborations.
2) Providing an analysis to drive a dialogue about the conditions for carrying out water tech research and research-based innovation in Denmark.

The background for initiating this report is threefold. Firstly, water tech research in Denmark is spread across several research institutions, and there was no clear understanding of the number, volume, or scientific focus of these environments prior to this analysis. Secondly, water technology is an industrial stronghold in Denmark, representing a global market projected to grow significantly by 15% annually until 2030. Finally, water tech solutions play a vital role in achieving Denmark's climate goals and ensuring access to clean drinking water for future generations. The Danish water sector has set an ambitious target of climate neutrality by 2030, necessitating ongoing research and development in water technology to meet this goal.

A profound understanding of the performance, opportunities, and challenges for water tech research in Denmark is essential to design optimal conditions that support Danish research environments and contribute to the water sector's participation in world-class research and the successful transition of research into new solutions.

Data collection, analysis, and preparation of the report have been carried out by IRIS Group. The scope of the analysis was determined by a steering committee that also contributed with insights and comments during the process. The steering committee was led by Water Valley Denmark and included Poul Toft Frederiksen (Head of Programme, Research, The Grundfos Foundation), Lars Enevoldsen (Senior Vice President, Technology Software, Kamstrup), Martin Rygaard (Strategic Planner, HOFOR), Ulla Sparre (CEO, Water Valley Denmark), and Jesper Borg Christensen (Programme Manager, Water Valley Denmark).

Enjoy your reading.

Executive summary

Background and analytical scope
This report provides comprehensive insights into water technology research in Denmark. Based on a thorough mapping of Danish water tech research environments and activities, the report analyses organisation, research performance, and trends. It also examines developments in public funding over the last decade and collaboration patterns.

In this analysis, water technology research encompasses scientific and engineering fields applied or related to the piped water system. Therefore, research areas such as oceanography, surface water, percolation of water into the soil, or nature-based solutions are not covered in the analysis.

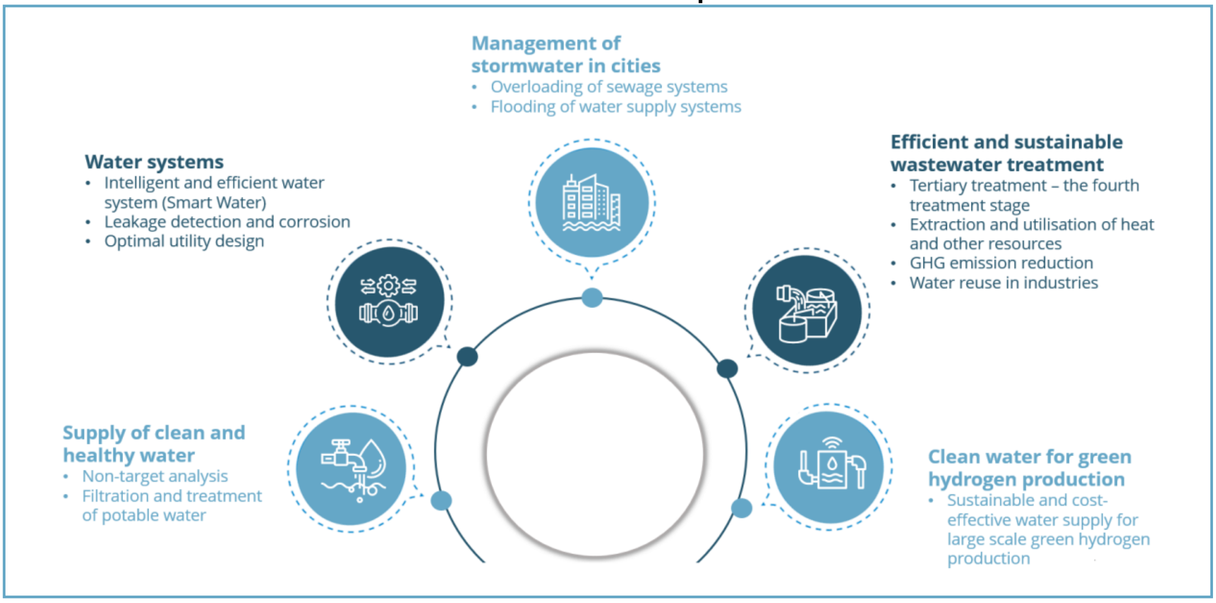
The main conclusions from the report are summarised below.

Water technology plays a crucial role in addressing societal challenges
Solutions within water technology contribute to tackling issues such as contaminated water resources, safe and efficient distribution of potable water, managing the impacts of climate change, and supporting the broader green transition of society.

Water technology solutions from major Danish corporations like Grundfos, Kamstrup, and AVK are implemented worldwide. Additionally, Danish SMEs and startups provide the water sector with specially designed sub-components and innovative solutions.

In the near future, new knowledge and solutions are needed to combat an increasing number of groundwater contaminants (i.e. pesticides and PFAS), manage stormwater on a larger and more frequent scale, and supply large quantities of water for green hydrogen production, which is essential in the green transition of the energy sector. The analysis identifies five focal areas for future water tech research and development, summarised in the figure below.

Five focal areas for future water tech research and development



Source: IRIS Group

The global market for water technology is projected to grow by a significant 15% annually until 2030, and the Danish water industry is well-positioned to capitalise on this growth.

Furthermore, water technology is essential for achieving Denmark's climate goals and ensuring access to clean drinking water for future generations. The Danish water sector has set an ambitious target of climate neutrality by 2030, necessitating ongoing research and development in water technology to meet this goal.

Danish water tech research holds a global leadership position

The analysis demonstrates that water tech research in Denmark holds an international forefront position. Denmark leads with the highest annual number of publications per million inhabitants, and Danish articles receive significant citations from the international research community, indicating a high level of quality.

Researchers in Denmark are actively engaged in all aspects of the water cycle. However, most research institutions concentrate on fields related to water supply and wastewater technologies. Critical areas of investigation include water monitoring and advanced analysis, purification and treatment technologies, resource recovery, and research on systems for water distribution and utility optimisation.

The mapping of Danish research environments also identifies leading researchers focusing on groundwater resources, stormwater management in urban environments, and the adaptation of water infrastructure to climate change.

Nevertheless, the analysis suggests that Danish water tech research strongholds are facing pressure and are at risk of losing ground. Countries such as Singapore, Switzerland, Sweden, and the Netherlands are making strides and are poised to leave Denmark behind unless efforts are made to unite, prioritise, and support Danish water tech research.

Fragmentation of Danish research environments causes vulnerability

In Denmark, 17 research environments are distributed across six institutions conducting water tech research. Research environments and their institutional affiliations are shown in the figure below. The figure also indicates the number of Full-Time Equivalent (FTE) researchers at each institution.

Water tech research environments in Denmark

AALBORG UNIVERSITY
- Systems microbiology in wastewater
- Membrane technology
- Water management systems
- Sewer and wastewater process
- Stormwater forecast modelling

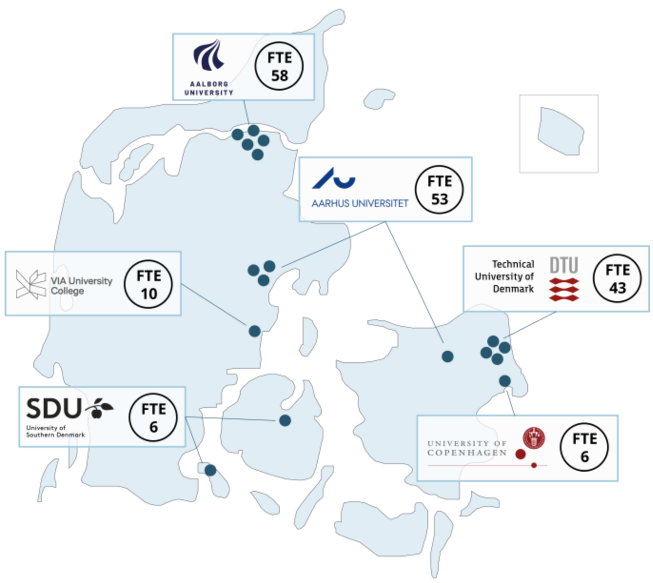
AARHUS UNIVERSITY
- Biological and chemical wastewater treatment
- Hydro-geophysics for ground water mapping
- Advanced water purification
- Sensor development and applications

TECHNICAL UNIVERSITY OF DENMARK
- Water technology and processes
- Climate and monitoring
- Circularity and environmental impact
- Mathematical modelling of water treatment systems

UNIVERSITY OF COPENHAGEN
- Analytical chemistry

UNIVERSITY OF SOUTHERN DENMARK
- System engineering, modelling, and membrane technology
- Technologies for measuring and monitoring of water quality

VIA UNIVERSITY COLLEGE
- Water treatment and distribution



Source: IRIS Group

An important result from the mapping is that Danish water tech research environments are generally small and fragmented. Most environments rely heavily on a few professors and their success in attracting external funding. This leaves the environments vulnerable if key researchers decide to depart from a specific group or institution.

Stagnation in public funding for water tech research

The analysis reveals that water tech research has experienced a consistent level of public funding over the last decade. Meanwhile, the total public research budget in Denmark has increased from 22.5 billion DKK in 2013 to 23.6 billion DKK in 2022.

In comparison to two other technology fields with substantial research and development activities in Denmark, water tech seems underprioritised. The field of robotics has experienced a 330% increase in public funding over the past decade, while funding levels for water and wind technology have remained relatively stable. Despite this stability, wind technology received more than twice the level of public funding than water technology in the last decade.

Competition for funding is a barrier to cross-institutional research collaboration

The analysis indicates that international research collaboration is thriving, but collaboration between Danish universities is less widespread. Research environments at different institutions vie for the same funds, fostering a competitive environment. The fragmentation of research environments and, to some extent, overlapping fields of research intensify the competition among research institutions in Denmark.

Open and extensive collaboration between research environments and utility companies

Despite limited cross-institutional collaboration, all 17 research environments have well-established connections with water utilities and/or wastewater treatment plants. Utility companies serve as test facilities when successful research outcomes need validation in a pilot plant or full-scale operational setting.

Consensus among all interviewed stakeholders affirms that the open and extensive collaboration between research environments and utility companies is a distinctive strength in Denmark. However, involvement in research and development activities varies across utility companies, with most collaboration concentrated around a few major utilities.

Limited collaboration with industry

The large industrial water tech companies in Denmark are not extensively involved in collaborative projects with Danish research environments. The fact that research themes and focus tend to align with available funding options poses a challenge to establishing long-term partnerships, according to several industry representatives. For the industry, access to skilled labour is considered the most significant impact from Danish water tech research environments.

In contrast, consulting engineers specialising in water technology frequently engage in test and demonstration projects with researchers and utility companies. In fact, consulting engineers are often instrumental in bridging research environments and utility companies when they design new solutions for waterworks and wastewater treatment plants.

Action is needed to strengthen conditions for water tech research

A review of funding mechanisms, regulation, and other framework conditions concludes that action is needed in five areas to keep Danish water tech research a national stronghold for the future:

1. **Long-term and coherent national strategy:** The fragmentation of Danish water tech research environments and fluctuating priorities in available funding schemes call for a long-term and

coherent national strategy. A national research strategy for water technology could eliminate fragmentation and secure long-term commitment to prioritised national challenges.

2. **Increased emphasis on strategic research:** A funding gap for strategic research has emerged and needs to be bridged. Funds for strategic water tech research are necessary to support the translation of basic research into innovative technologies and systems.
3. **Incentives for research institutions to participate in development and demonstration:** Conditions for research institutions to participate in development and demonstration projects should be improved. The Environmental Technology Development and Demonstration Programme (MUDP) is the largest public contributor to the development of water technology in Denmark. However, the analysis indicates that MUDP grants are generally unattractive to research institutions due to significantly higher criteria for own financial contributions than required in similar programmes in other technology fields.
4. **Regulation supporting innovation in utility companies:** The current regulation of utility companies in Denmark is not fit for innovation. Continuous efficiency requirements pose a barrier to investments in research and development activities, and ambitious climate targets are not possible to reach without regulatory incentives.
5. **Development of a strong talent base:** A strong talent base is needed to power the future water sector. A collaborative approach towards education activities could help build better and more focused water tech courses, drawing on expertise from several research environments. A joint water tech PhD programme with earmarked PhD funding could educate interdisciplinary PhD students with a comprehensive understanding of the entire water cycle.

The analysis concludes that the current conditions for water tech research and innovation are likely to weaken the global leadership position that Danish research environments have built over more than four decades. Consequently, utility companies are compelled to develop and purchase solutions abroad. Furthermore, the national goal to double the export of Danish water technology, as stated in the cross-ministerial Export Strategy for Water[1], might face challenges without strong research institutions and a supportive chain of innovation, including close academic-industry collaboration.

[1] The goal included in the strategy is to double the export of Danish water technology from 20 billion DKK in 2019 to 40 billion DKK in 2030. The strategy was published in 2021 by the Ministry of Foreign Affairs, the Ministry of Industry, Business and Financial Affairs, and the Ministry of Environment.

PhD students at DTU Sustain

Photo by Thomas Hjort Jensen

1. Introduction

1.1 Background

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A profound understanding of the performance, opportunities, and challenges for water tech research in Denmark is essential to design optimal conditions that support Danish research environments and contribute to the water sector's participation in world-class research and the successful transition of research into new solutions.

1.2 Definition of water technology research

Water technology refers to the application of scientific and engineering principles to the development and utilisation of technologies related to water resources. It encompasses a wide range of techniques, processes, and innovations designed to address various aspects of water management, treatment, distribution, and conservation. Water technology plays a crucial role in ensuring the availability of clean and safe water for human consumption, agriculture, industrial processes, and environmental sustainability.

In this report, the mapping and analysis of Danish water tech research environments are based on the following definition.

[2] Grand View Research (2023): "Water Treatment Systems Market Size, Share & Trends Analysis Report"

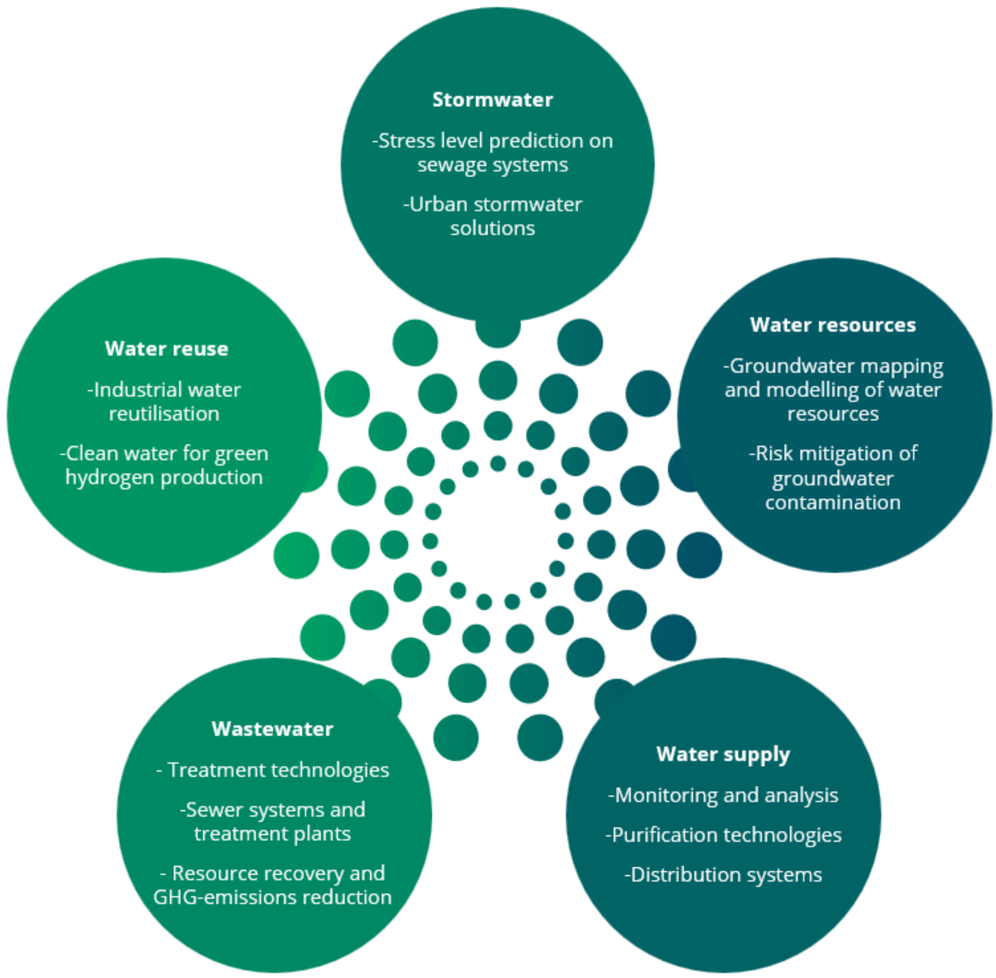
Definition of water technology research

Water technology research covers all aspects of the water cycle, including the identification of water resources, extraction methods, analysis, purification, distribution, water reduction techniques, reuse technologies, wastewater treatment, and resource recovery. Finally, the analysis includes technologies for stormwater management in cities.

Following the definition above, water tech research focuses on water technologies applied or related to the piped water system. Therefore, research areas like oceanography, surface water, percolation of water into the soil, or nature-based solutions are not covered in this report.

Figure 1.1 illustrates the water cycle and presents Danish research strongholds in headlines. Activity in Danish water tech research environments is described in Chapter 2. The water cycle illustrates the movement of water in an integrated system where water is transformed from one from to another.

Figure 1.1. The water cycle



Source: IRIS Group based on the water cycle developed by Water Valley Denmark (www.watercycledenmark.com).

1.3 Approach

The analysis in this report is based on a mixed-method approach and includes multiple data sources.

Interviews
Interviews were conducted with all water tech research environments in Denmark and representatives from water tech companies, utility companies, research and technology organisations, as well as ecosystem agents. In total, 42 interviews were completed in October and November 2023. In addition, a mini survey was distributed to all research environments to collect details on researchers and funding. Appendix 2 offers a list of all interviewees.

Funding analysis
To analyse the development in public funding for water tech research, information on grants awarded by public funds and programmes were collected from all relevant research funding organisations.

A keyword analysis was designed to identify grants awarded to water tech research (as defined above) and to identify research in wind technology and robotics for a comparative analysis (see results in Chapter 3).

A combined list with project titles from all public grants awarded in the period 2013-2022 was automatically searched for keywords and manually validated to ensure that the primary focus of the projects was related to the specific research area. The list of keywords is provided in Appendix 3.

Bibliometric analysis
To analyse performance of Danish research environments, a bibliometric analysis was designed. Bibliometric analysis is a quantitative method used to evaluate and analyse scholarly literature and its quality and impact. It involves the statistical examination of publications, typically academic articles, and papers, to gain insights into various aspects of research output, impact, and trends within a specific field or discipline.

The bibliometric analysis in this report is based on a topic analysis. In the international bibliometric database, Scopus, all research articles are grouped into series of topics, each containing a collection of publications with a common research interest. Water technology, as defined in the previous section, was customised as a research area by combining series of topics in Scopus.

In total, 198 relevant topics were identified and related to the water cycle. For instance, wastewater comprises 66 topics, including "Wastewater Treatment, Anaerobic Digesters, Fouling" and "Nutrient Removal, Wastewater Treatment, Activated Sludge." See Appendix 3 for more examples of topics included in the analysis.

International good practice
A case study on water tech research and innovation in the Netherlands is included in the report to compare framework conditions with Denmark and identify best practice examples to inspire initiatives to support Danish water tech research.

The case study is based on desk research and interviews with key stakeholders in the Dutch water tech ecosystem.

1.4 Report structure

The following chapters present the main results from the mapping and analysis of water tech research in Denmark. Each chapter starts with a short introduction and overview of key conclusions.

Chapter 2 provides an overview of water tech research environments and relevant research and innovation infrastructure in Denmark. The overview is based on thorough mapping and includes all relevant research environments in Denmark. Size, specialization, and strongholds are described.

Chapter 3 examines public funding for Danish water tech research. The development in grants and types of projects financed by public funding bodies are analysed and benchmarked against funding available for other important technology areas (wind technology and robotics).

Chapter 4 offers a discussion of the academic output and scientific quality of Danish water tech research. The chapter examines the development in academic output (research articles, papers, etc.) from Danish water tech research environments, and discusses the scientific impact of Danish water tech research. Scholarly performance is benchmarked against other technology areas (wind technology and robotics) and other countries.

Chapter 5 first explores collaborative patterns across research environments and with other stakeholders in the water sector. Second, the societal impact of water tech research (including the development of the utility sector) in Denmark is discussed.

Chapter 6 offers a deep dive into water tech research in the Netherlands.

Chapter 7 completes the report by examining framework conditions, such as funding mechanisms and regulation, for water tech research and innovation in Denmark. Areas for improvement in current framework conditions are identified.

Mobile lab facility at VIA University College

Photo by VIA University College

2. Mapping water tech research in Denmark

2.1 Introduction and key conclusions from the chapter

This chapter provides an overview of water tech research environments and relevant research and innovation infrastructure in Denmark.

The mapping was carried out in two steps. First, all Danish research environments within the scope of this analysis (see definition in Chapter 1) were identified. This exercise was based on a snowballing approach with input from The Grundfos Foundation and Water Valley Denmark as a starting point.[3]

Secondly, relevant research group leaders and heads of departments were interviewed to uncover the content, competencies, and history of each environment. Additionally, a short questionnaire was distributed and answered by representatives from each environment to reveal the size, development, and structure of Danish water tech research. Input on relevant research and innovation infrastructure was provided partly by research group leaders and partly by representatives from Research and Technology Organisations (RTOs) and water utility operators.

Key conclusions from the chapter are:

- 175 Full-Time Equivalent (FTE) researchers are engaged in water tech research in Denmark. Research is carried out at six institutions and involves 17 research environments.
- Danish water tech research environments are generally small and fragmented, which leaves the environments vulnerable if key researchers decide to depart from a specific group or institution.
- Denmark has researchers active in all parts of the water cycle. However, most research institutions focus on research fields related to water supply and wastewater technologies.
- A lack of unity and rather quick shifts in funding focus are emphasized as challenges to continuity and a sound division of labour between research environments. As a result, there seems to be an overlap of several research themes across different research environments.
- Lab facilities and instruments to support research activities are generally good and found in all research institutions housing water tech research environments. As technologies mature and need to be tested outside of the lab, utility companies provide pilot facilities and large-scale test facilities. The open and extensive collaboration that exists between research environments and utility companies is a unique force in Denmark.
- Two RTOs, the Danish Technological Institute and DHI, play a key role in linking water tech and business.

The following sections elaborate the main results from the mapping and offer a complete overview of Danish research related to different parts of the water cycle. An appendix at the back of the report provides

[3] By "snowballing" we refer to a process in which interviewees (researchers and companies) referred to colleagues and partners at (other) Danish knowledge institutions. We also contacted deans from some universities who helped by pointing out relevant institutes and research environments.

more comprehensive insights, including descriptions of each research environment and essential lab facilities.

2.2 Size, structure, and organisation of water tech research in Denmark

175 FTE researchers are engaged in water tech research
Water tech research is conducted at six institutions, involving a total of 175 Full-Time Equivalent (FTE) researchers. Most water tech researchers in Denmark are affiliated with three universities, namely Aalborg University (AAU), Aarhus University (AU), and the Technical University of Denmark (DTU).

Table 2.1 provides an overview of FTE researchers by institution in 2018 and 2023. The last column of the table shows the change in FTE over the five-year period. Only researchers within the scope of this analysis are included (see analytical scope in Chapter 1). This excludes researchers focusing on, for example, surface water and nature-based solutions to combat climate change.

Table 2.1. Full-Time Equivalent (FTE) researchers by institution, 2018 and 2023

	2018	2023	Change
Aalborg University	46	58	+12
Aarhus University	42	53	+11
Technical University of Denmark	63	43	-20
University of Copenhagen	1	6	+5
University of Southern Denmark	5	6	+1
VIA University College	6	10	+4
Total	**162**	**175**	**+13**

Source: Survey of Danish water tech research environments.
Note: Numbers are based on estimates provided by representatives from each research environment.

The table indicates a slight increase in the total number of Full-Time Equivalent (FTE) researchers from 2018 to 2023. The Technical University of Denmark (DTU) stands out as the only institution that has experienced a decline in FTE researchers. This decline is a consequence of a general round of layoffs at the university in 2023 (not specific to water tech) and mobility to other universities and private companies. However, it is anticipated that the water tech environments at DTU will experience growth again from 2024 due to planned hires.

17 research environments across six institutions
There are a total of 17 research environments spread across the six institutions conducting water tech research, as shown in Figure 2.1. Comprehensive descriptions of each research environment are provided in the appendix.

Figure 2.1. Water tech research environments in Denmark

AALBORG UNIVERSITY
- Systems microbiology in wastewater
- Membrane technology
- Water management systems
- Sewer and wastewater process
- Stormwater forecast modelling

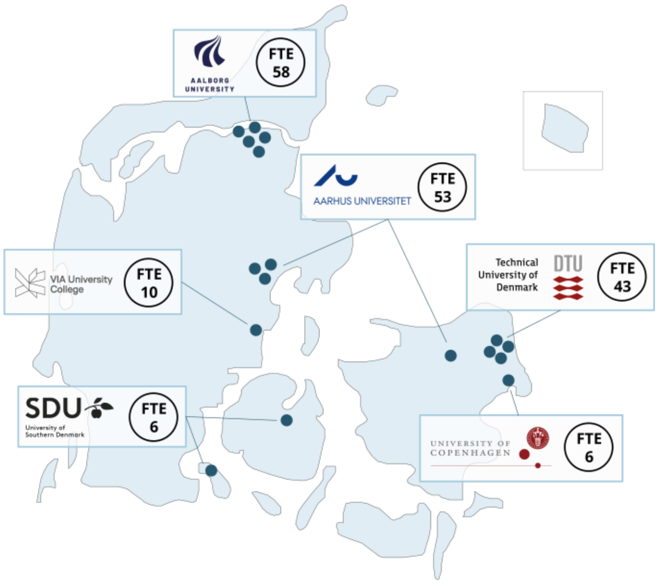
AARHUS UNIVERSITY
- Biological and chemical wastewater treatment
- Hydro-geophysics for ground water mapping
- Advanced water purification
- Sensor development and applications

TECHNICAL UNIVERSITY OF DENMARK
- Water technology and processes
- Climate and monitoring
- Circularity and environmental impact
- Mathematical modelling of water treatment systems

UNIVERSITY OF COPENHAGEN
- Analytical chemistry

UNIVERSITY OF SOUTHERN DENMARK
- System engineering, modelling, and membrane technology
- Technologies for measuring and monitoring of water quality

VIA UNIVERSITY COLLEGE
- Water treatment and distribution



Source: IRIS Group

The organisation of water tech research at the six institutions differs notably:

- Water tech research at Aalborg University (AAU) is carried out in five individual research groups across three departments. There is no joint organisation of water tech research at AAU.
- Since 2017, Aarhus University has organised water tech research around the interdisciplinary Centre for Water Technology (WATEC). The four environments covered in this analysis represent four different departments – three in Aarhus and one located in Roskilde. Prior to the establishment of WATEC, water-related research at AU mostly focused on ecological issues in open water environments.
- The Technical University of Denmark (DTU) has a long track record in water tech research. In 2023, three of the four research environments are part of DTU Sustain. Some sections in the overview have a broader scope than water tech research and focus on several issues related to climate adaptation and the environment in general.
- At the University of Copenhagen, one research group at the Department of Plant and Environmental Sciences is engaged in research activities within the scope of this analysis. Most water-related research areas at the university fall outside the scope of this analysis (e.g., surface water, percolation issues, nature-based solutions, etc.).
- The University of Southern Denmark does not host sections or research groups with water technology as the main domain. However, several researchers at the Faculty of Engineering and the Faculty of Science are engaged in research projects within the water cycle as defined in Chapter 1[4]. Water tech researchers at SDU are found in Odense and Sønderborg.

[4] SDU hosts, for example, a strong research group within membrane technologies focusing on both the water cycle, industry, agriculture, and open water environments.

- VIA University College in Horsens operates four research programs. One is specialized in water technology as defined in Chapter 1[5].

Vulnerability arises from the size and fragmentation of research environments
An important result of the mapping is that Danish water tech research environments are generally small and fragmented. Most environments rely heavily on a few professors and their success in attracting external funding. On average, there are fewer than four senior researchers per environment. The fact that 65 senior researchers (professors or assistant professors) are spread among 17 research environments leaves the environments vulnerable if key researchers decide to depart from a specific group or institution.

Additionally, water tech research environments in Denmark are organised in various ways and are geographically dispersed. Nevertheless, several research environments in Denmark are internationally acknowledged and perform among the best in the world within their fields of research (see Chapter 4). There is a general understanding among the interviewees – both at and outside research institutions – that research strongholds in Denmark were strategically built up from the late 1980s and during the 1990s. However, in the last two decades, water tech has not gained as much attention nationally. Consequently, water tech researchers have been organised in broader departments and have become more fragmented over the years.

The next page provides figures on water tech researchers in Denmark, and the following section delves into research themes and strongholds in Danish water tech research.

[5] Another research group focuses on climate adaptation, including nature-based solutions in the treatment of rainwater and wastewater in cities.

Water tech researchers in numbers

Figure 2.2. Distribution of Full-Time Equivalent (FTE) researchers by title, 2023

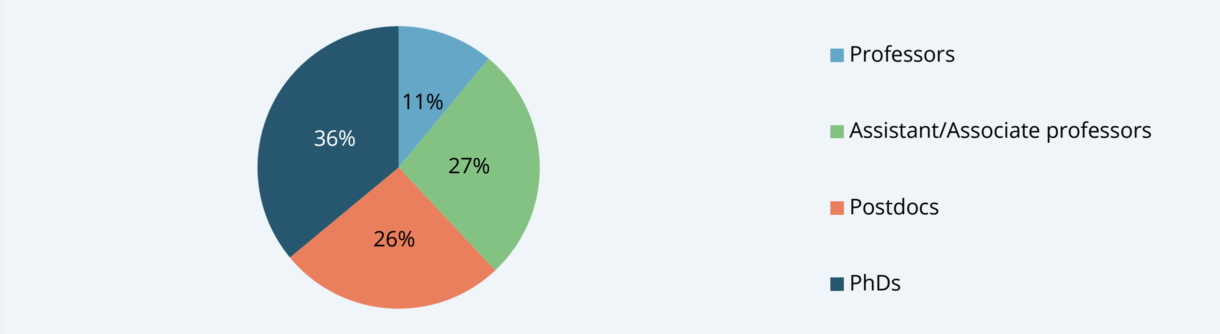


Figure 2.3. Number of Full-Time Equivalent (FTE) researchers by title, 2018 and 2023

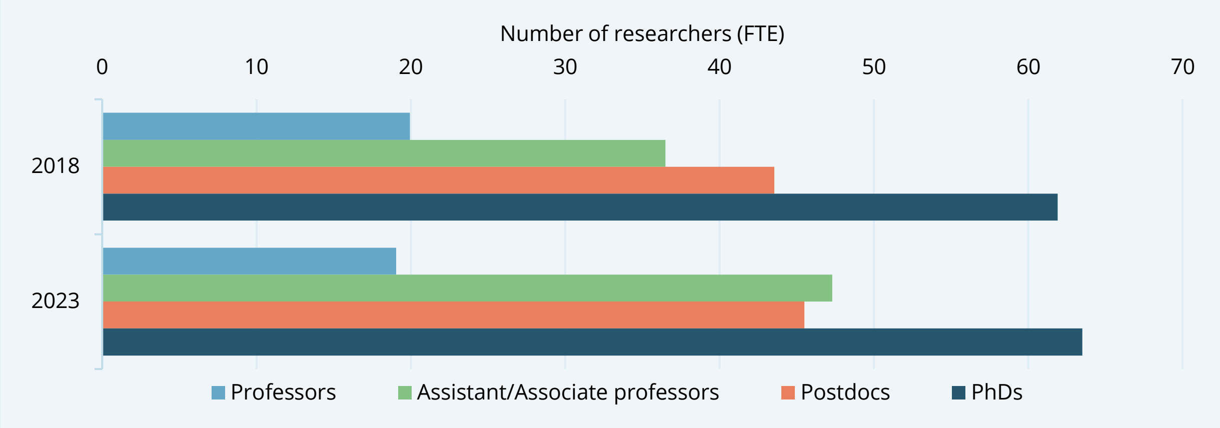


Figure 2.4. Distribution of researchers by nationality, 2023

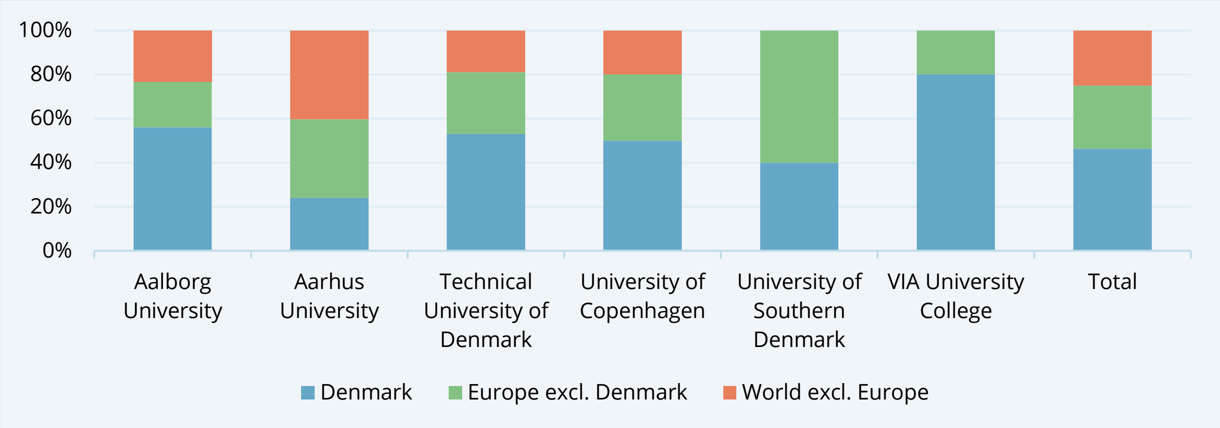
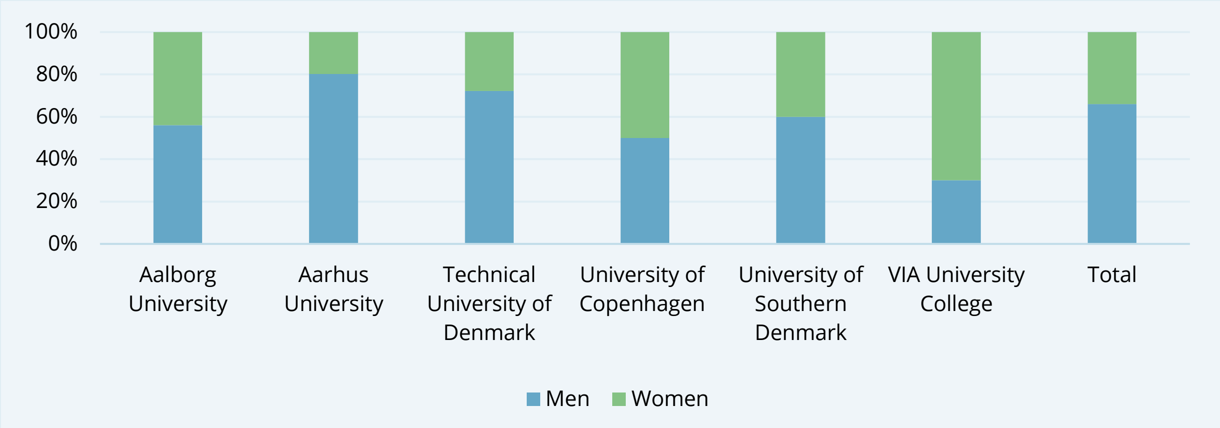


Figure 2.5. Distribution of researchers by gender, 2023

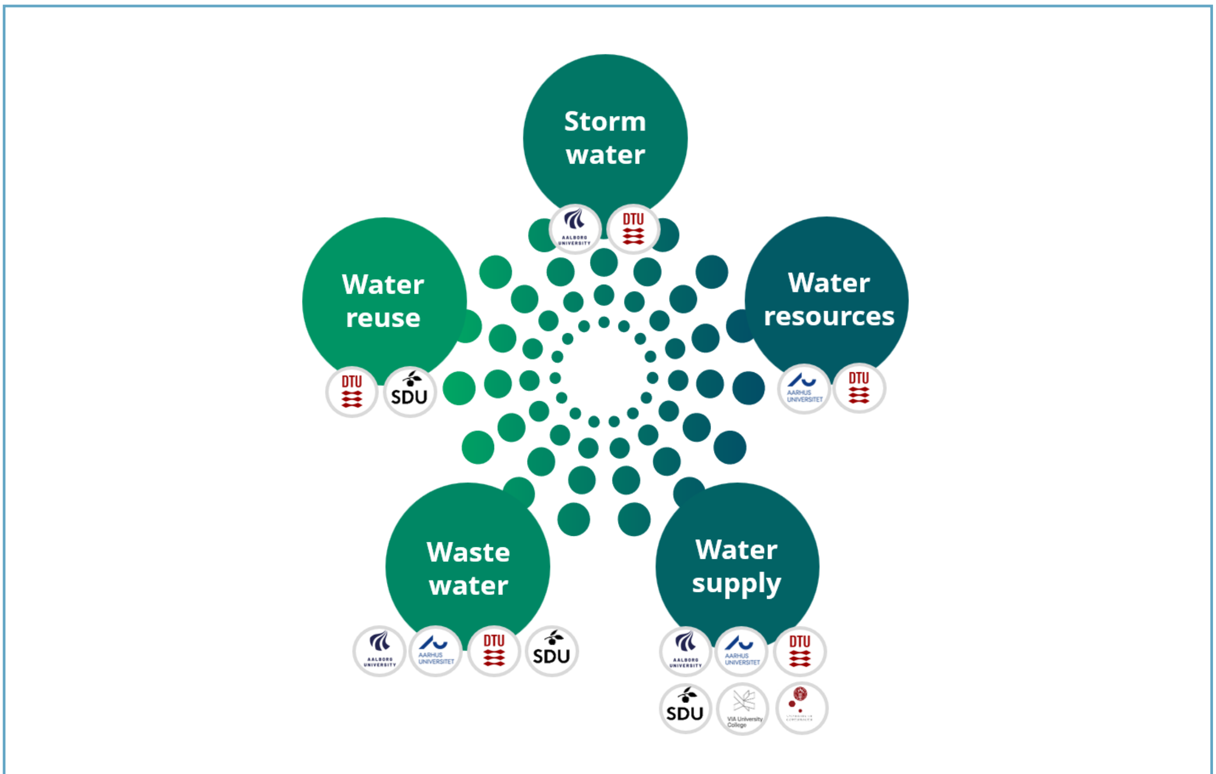


Source: Survey of Danish water tech research environments.

2.3 Water tech research areas and strongholds

Most research activity within water supply and wastewater technologies
Danish water tech research takes place in all parts of the water cycle. However, most research institutions are active in fields related to water supply and wastewater technologies, as indicated in Figure 2.6.

Figure 2.6. Water tech research focus at Danish institutions



Source: IRIS Group mapping

The following subsections offer an overview of the main research themes and strongholds in Danish research environments. Descriptions are organised according to the water cycle. However, some fields of research generate technologies and know-how relevant for more than one part of the water cycle (e.g., various water treatment technologies). Main research themes have guided the alignment of research environments with the water cycle. Yet, some environments are mentioned several times in the following descriptions.

2.3.1 Water resources

Two main research themes relate to water resources:

- **Groundwater mapping and modelling of water resources**
  At AU, a group of geophysicists and data scientists develops methods for mapping and modelling groundwater resources. A key research focus has evolved around geophysical investigations of the subsurface, where large areas are mapped for groundwater resources. Research activities combine geophysical instrument development with advanced data processing and inversion algorithms and

hydrological modelling. The group has been active since the 1990s and is internationally renowned. A major part of the group's research projects is carried out abroad.

- **Risk mitigation of groundwater contamination**
  A section at DTU identifies and quantifies the risk of groundwater contamination from chemicals, micro-pollutants, etc., and advises on new legislation and guidelines for water testing. The researchers at DTU hold an internationally unique combination of theoretical and experimental process understanding, advanced technology assessment tools, and insights into societal and regulatory challenges.

2.3.2 Water supply

All six institutions are active in research areas related to water supply. Essential fields of research include:

- **Water monitoring and analysis**
  Research environments at AU, KU, and SDU specialise in technologies with the ability to detect and analyse unwanted substances in water, such as micro-pollutants and harmful chemicals. The development of sensor technology is a primary research focus at AU and, to a lesser extent, at SDU. Strong competencies in advanced analysis, such as chemical fingerprinting, are found at AU and KU. Sensor and analysing technologies are applied in both drinking water and wastewater systems.

- **Water purification**
  AU, DTU, and VIA hold strong research competencies in water purification technologies:
    - A large environment at the Department of Biological and Chemical Engineering at AU focuses on chemical and biological treatment of water, including microbial technologies to remove micropollutants such as pharmaceuticals and biocides, and novel chemical approaches for the degradation of environmentally hazardous substances in water, such as PFAS.
    - At DTU Sustain, a research section carries out basic and experimental research (across lab, pilot, and full scale) within micro-pollutant removal processes and microbial technology, including biological transformation of pollutants and biofilms and bio-aggregates for water treatment.
    - Finally, VIA University College is involved in a number of research projects covering the effects of microbiological processes (such as biofilm) on water quality.

- **Water distribution systems**
  Three institutions host world-leading research environments specialised in various aspects of water management and the design of water distribution systems:
    - A research group at AAU is world-leading in the development and testing of advanced digital water systems (smart water), including pressure management and detection of leaks in water pipe infrastructures.
    - At DTU, researchers are engaged in monitoring and control system analysis, including an analysis of how materials in the distribution system (such as plastic and substances used for the removal of micropollutants) affect water quality. Another leading research area is the development of remote sensing and drone technologies used for monitoring leakages.

- At VIA University College, practice-oriented research activities focus on how different kinds of water resources and the composition of the distribution system interact with optimal utility design.

2.3.3 Wastewater

Four universities host research environments focusing on wastewater technology and processes:

- **Water treatment technologies**
  Water treatment technologies encompass a vast research field that is scientifically challenging to isolate to a single area of application. Basic research in membrane technology, for example, might be applied in the treatment of drinking water, wastewater, and in industrial water reuse processes. Thus, environments focusing on water purification, as mentioned above, are also relevant here. Scientific strongholds in water treatment technologies are found at AAU, DTU, AU, and SDU.
  - A large group of researchers at AAU conducts fundamental research on microorganisms in engineered ecosystems, such as wastewater treatment plants. The group focuses on identifying and understanding various bacteria and their function in wastewater to optimise water treatment based on biological separation processes.
  - Another research group at AAU specialises in membrane technology, focusing on mechanical and chemical separation processes for water treatment.
  - DTU Sustain also has a research group with a long history in fundamental and applied research within membrane technology. The group carries out leading research within new materials for membranes, as well as the use of enzymes to increase the effectiveness of membranes. Moreover, the group focuses on how electrochemistry can enable the transition of microorganisms to new proteins, such as amino acids.
  - At AU, the Department of Biological and Chemical Engineering focuses on chemical and biological treatment of water, including microbial technologies and chemical approaches.
  - Another AU environment located at the Department of Environmental Science (Roskilde campus) is dedicated to water treatment, primarily focusing on wastewater but also extending to drinking water. All technologies with the potential to eliminate micropollutants are studied, with a particular emphasis on biofilm technologies.
  - Finally, a relatively high share of SDU's water tech research is focused on water treatment technologies, including the development of advanced materials and processes for water purification, waste reduction, reuse of wastewater, and conversion of waste. The most prominent area of research is membrane technologies.

- **Sewage systems and treatment plants**
  Three institutions have research activities on system design and modelling of sewage and treatment plants:
  - AAU is world-leading within wastewater process engineering. The Urban Pollution group is specialised in the design and operation of sewer systems and technologies for predicting maintenance, asset life, and solutions to odour and corrosion. Lately, they have also implemented sewer process models as digital twins for integrated system management.
  - DTU has a strong track record in research into the design and modelling of sewage systems. Today, key aspects of research at DTU Sustain include utilising and developing new data sources, as well as using AI and digital technologies to develop new solutions that can

  - be used for monitoring and forecasting the impacts of extreme weather phenomena on sewage systems in cities.
  - The DTU Department of Chemical and Biochemical Engineering hosts a group specialised in mathematical modelling and computer simulation in relation to water treatment and resource recovery systems. The group develops and assembles mathematical tools to assess and predict the impact of various changes at municipal and industrial treatment plants.
  - SDU houses a few researchers with broad knowledge on the design and modelling of wastewater systems. Key themes include models for material flows in urban environments and the design of resilient and sustainable urban wastewater systems.

- **Water resource recovery and GHG-emissions reduction**
  Two fields of research related to sewage systems and treatment plants are 1) technologies to subtract and recover resources from wastewater, and 2) approaches to reduce GHG emissions from treatment plants:
  - AAU is world-leading in the field of microbial ecology of wastewater treatment and resource recovery systems. Research focuses on ways to recover valuable substances that bacteria produce in the sludge at wastewater treatment plants. Today, sludge is typically used in biogas plants, incinerated, or spread on fields as fertiliser. But sludge contains valuable substances that can be used in bioplastics and building materials – and in the future, perhaps also in food and medicine.
  - At AU, research in resource extraction from wastewater focuses on new technologies that enable the recovery and valorisation of extracellular polymeric substances from microbial biomasses.
  - A research group at DTU has a strong focus on modelling GHG emissions, which, together with the data collected from sensor-based measurement systems, can be used to quantify the effectiveness of mitigation measures used at the level of wastewater treatment plants.

2.3.4 Water reuse

Most research relevant for developing industrial water reuse technologies relates to water treatment technologies. In that sense, all environments mentioned above are relevant. Two areas can be highlighted specifically relating to industrial applications.

- **Industrial water reutilisation**
  The analysis did not identify any active projects. However, a large Danish public/private partnership called DRIP was active in the period 2015 - 2021, involving water tech environments from DTU, KU, and SDU. The 12.8 million Euro budget partnership focused on water efficiency in the food industry, one of the largest water-consuming industries. The DRIP partnership aimed to reduce water consumption in leading Danish food producers by developing new sustainable water and production technology solutions and concepts. At the end of the project, a total annual water saving of 905,400 m3 or 20% of the total consumption at the end users was realized through the complete project portfolio, and a further 535,000 m3 or 12% water saving potential was demonstrated in several pre-studies and pilot projects[6].

[6] DTU (2022): "DRIP Completion Report"

- **Clean water for green hydrogen production**
  An emerging field of research is clean water for green hydrogen production. Green hydrogen is produced via electrolysis by using electricity to split water into hydrogen and oxygen. To run electrolysis, renewable energy and water are needed in large quantities, and water for electrolysis must be of extremely high quality. Energy research departments at AAU and DTU have initiated activities with water tech research environments at their home institution to explore the cross-field between electrolyser and water purification technologies. However, this field of research is at an early stage, and only a few researchers are currently involved.

2.3.5 Stormwater

Two universities host research environments focusing on stormwater in urban environments and adaptation of water infrastructure to climate change. Research on stormwater is generally very practice-oriented.

- **Stress level prediction on sewage systems**
  - AAU is home to a world-leading research group that develops mathematical models using real-time weather data and machine learning to better manage urban sewage systems. The research conducted seeks to measure, control, and regulate water systems intelligently to better control water flow and ultimately prevent floods.
  - At DTU Sustain, researchers combine new data sources, AI, and digital twins to develop new solutions that can be used for monitoring and forecasting the impacts of extreme weather phenomena on sewage systems in cities.

- **Urban stormwater solutions**
  - The Urban Pollution group at AAU is engaged with the treatment of stormwater from cities and highways. Research activities focus on technologies for advanced chemical and biological treatment of stormwater from entire cities and highway systems.
  - At DTU Sustain, researchers look into the urban redesign of water infrastructure to deal with extreme weather and sustainability goals, including distribution and collection systems, monitoring, and real-time control system analysis.

A lack of unity and strategic direction
A lack of unity and strategic direction seems evident in the analysis and descriptions provided above, indicating that certain research themes are the focal point in multiple research environments. Competencies in water treatment and purification technologies are prevalent across various institutions, with AAU, AU, DTU, and SDU all housing researchers dedicated to developing technologies for the removal of micro-pollutants in drinking water, employing both biological and chemical approaches. Additionally, the development of new membranes using advanced materials appears to be another shared area of interest among several research environments.

Interviews with stakeholders outside of research environments suggest challenges in obtaining a comprehensive overview of research activities and locating the latest knowledge on practical issues. To illustrate the issue, a representative from the water utilities sector recounts instances where she had to initiate a study with one research environment only to discover that another utility operator had initiated a similar project with a different research institution.

In interviews with researchers, rather quick shifts in funding focus are emphasised as a challenge to continuity and a sound division of labour between research environments. Strong competition for earmarked funding has, in some instances, resulted in similar research themes being the focal point in multiple research environments.

Finally, several researchers interviewed for this analysis stress a direction towards more technology-driven research funding as a challenge to maintaining systemic know-how in Denmark. Systemic know-how refers to knowledge of entire water systems, such as sewage systems interacting with wastewater treatment plants. The risk of focusing too much on specific technologies is, according to the researchers, that knowledge on the systemic level gets lost over time.

2.4 Research and innovation infrastructure

Research and innovation infrastructure support water tech research activities and provide testbeds for technology demonstration.

The six research institutions housing water tech research environments all have lab facilities and instruments to support their research activities. As technologies mature and need testing outside of the lab, utility companies provide pilot facilities and large-scale test facilities. Finally, two of the seven government-approved Research and Technology Organisations (RTOs) in Denmark offer water-oriented test and demonstration facilities.

The following two sections offer an overview of research and innovation infrastructure located 1) at research institutions, and 2) outside research institutions.

2.4.1 Lab facilities at research institutions

Research infrastructure used by water tech research environments includes specific water tech labs and facilities shared with other disciplines. Four main types of labs are briefly described below. Descriptions of specific lab facilities and types of equipment at each institution are provided in Appendix 1.

Labs for advanced chemical and microbiological analysis
All six research institutions have lab facilities with equipment to carry out chemical and microbiological analyses of water samples. The research labs contain equipment and clean rooms that enable a broad range of chemical and microbiological analyses, including the identification of substances such as micro-pollutants, pesticides, and pharmaceuticals at all concentrations.

DTU also has specialised labs for chemical analyses and the measurement of greenhouse gases, including a mobile analytical lab used in the field to measure atmospheric levels of methane and nitrous oxide emissions and quantify emission rates, respectively.

Facilities for membrane research
AAU, DTU, and SDU house the most advanced lab facilities for membrane research. Researchers at all three universities have access to a wide range of filtration equipment and analytical tools to test, analyse, and characterise membranes. Labs are also provided with tools/equipment for the fabrication of membranes in various materials and sizes.

Smart water lab
AAU is home to the Smart Water Infrastructures Lab, a modular test facility that can be configured to emulate water distribution networks, wastewater collection, or district heating systems. This laboratory aims to address problems in water cycle management with a focus on how control technology can contribute to new solutions.

High-performance computing
Researchers at DTU and AAU have access to high-performance computing systems that enable them to perform computationally demanding tasks beyond the capability of traditional computing systems. High-performance computing is used to process and analyse large, complex datasets, perform simulations, and run resource-intensive applications.

2.4.2 Test facilities located outside research institutions

As technologies mature, access to out-of-the-lab test facilities becomes crucial. Two segments are important in this respect: the water utility sector and the RTOs.

Extensive collaboration between research environments and utility companies
A significant aspect in Denmark is the open and extensive collaboration that exists between research environments and utility companies (see more on collaboration in Chapter 5).

The water sector in Denmark has a decentralised structure and consists of some 2,600 waterworks and 701 wastewater treatment plants[7]. Most utilities are small, but Denmark also has some large multi-utility operators (handling drinking water, wastewater, district heating, town gas, etc.).

In principle, all utility companies constitute a relevant test facility, and many utilities test new sensors and similar equipment that are easy to set up and do not require many resources from the utility companies.

Pilot plants for more complex tests can also be found at many utility companies, including facilities for advanced analysis, treatment, resource extraction, and digital modeling. All large multi-utility operators are engaged in research and development projects.

RTOs in charge of business uptake of water technology
RTOs play a key role in the Danish innovation system as the link between technology and business. They seek to make new technological methods applicable to businesses and promote the uptake of new technology by businesses. Water tech is no exception.

The Danish Technological Institute has well-equipped laboratories capable of assessing bacteria and chemical substances in water systems. The institute helps private companies carry out accredited testing in relation to the development and documentation of new products.

DHI has many years of expertise in digital modelling of water solutions, including data-driven decision support tools, IoT-based services, and digital twins.

The two RTOs are both highly engaged in projects with utility companies and private technology providers. Collaboration with research environments mainly occurs through such projects.

[7] DANVA (2022): "Water in figures"

Students attending a summer school on Advanced Water Cycle Management hosted by WATEC, Aarhus University

Photo by WATEC

3. Public funding for water technology

3.1 Introduction and key conclusions from the chapter

This chapter examines the development of public funding for Danish water technology research. First, the chapter provides an overview of the composition of funding sources for Danish water tech research. Next, the development in grants from public funding bodies is examined. The analysis delves into the types of projects financed by public funding agencies and assesses the overall funding opportunities for water tech research in the Danish funding landscape. Finally, the development in public funding for water tech is benchmarked against the funding for wind technology and robotics. The purpose of this benchmark exercise is to highlight potential differences in the priorities of public research grants.

Key conclusions from the chapter include:

- External research funding plays a crucial role in water tech research environments. Only 10% of the research is covered by the home institution. National public funding agencies account for nearly 40% of the research funding, whereas private foundations contribute 34% of the total funding.

- From 2013 to 2022, public funding agencies have awarded a total of 846 million DKK to water tech research.

- The level of public funding directed at the field of robotics has experienced considerable growth. From 2013 to 2022, the funding amount has increased by more than 300%, whereas the funding for water technology has remained consistent.

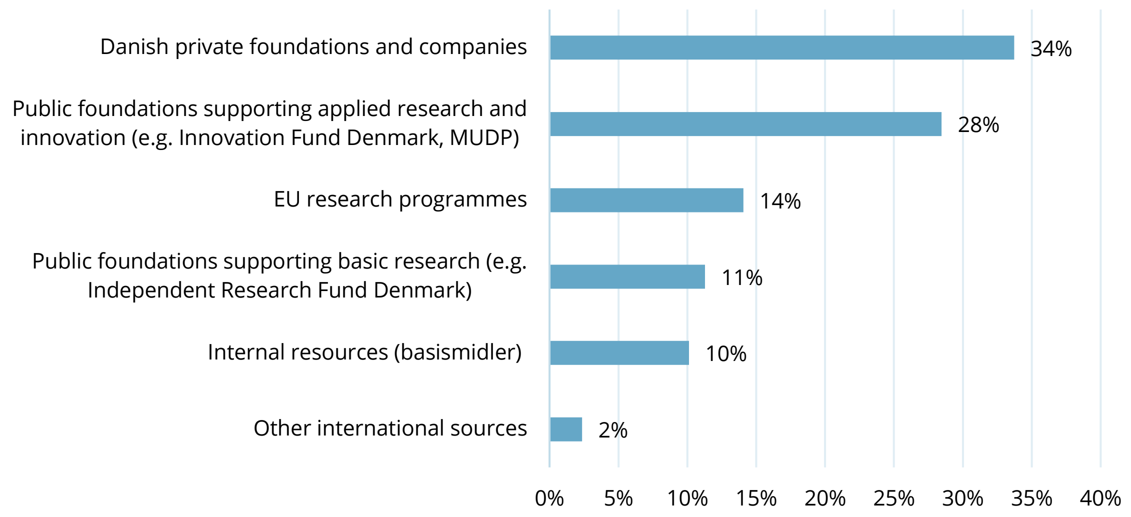
- The Environmental Technology Development and Demonstration Programme (MUDP) is the single largest public funding programme supporting water technology. Grants from MUDP constitute approximately a quarter of all public funds allocated to the field.

- In the past 10 years, there has been a shift in focus towards a higher level of Technology Readiness Levels (TRL) in public funding programmes.

3.2 An overview of funding sources

National public funding constitutes 50% of all funding for water tech research
Collectively, national public funding accounts for half of all water tech research funding. The other half originates from private sources (34%), or EU research programmes and other international sources (16%), as indicated in Figure 3.1.

Figure 3.1. Research funding sources for Danish water tech research



Source: Survey of Danish water tech research environments.
Note: The figure is based on estimates provided by representatives from each research environment.

Public funding for water tech research is provided by two types of public foundations and via internal resources (the so-called "basismidler" at Danish research institutions). Public foundations supporting applied research and innovation account for 28% of the financing, while public foundations supporting basic research make up 11%.

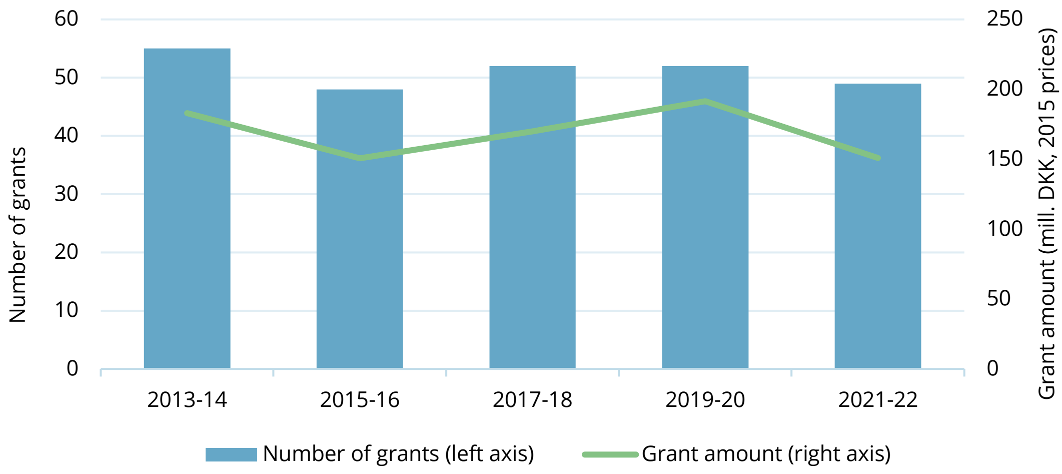
Danish private foundations also play a significant role in funding water tech research. In total, they finance approximately one-third of the research activities and support research activities spanning from basic research to applied research. The interviewed researchers highlight significant grants from the Novo Nordisk Foundation and the Villum Foundation as important for their research activities.

The EU research programme for research and innovation – Horizon Europe – is also an important funding source. Like private foundations, the EU also supports a wide range of activities at all Technology Readiness Levels (TRL), including both basic research and collaborative projects with companies and utility companies across member states.

3.3 Development in public funding for water technology

To comprehend the prioritization of water technology research in terms of public funding, all relevant projects granted between 2013 and 2022 have been identified and mapped. The results are depicted in Figure 3.2.

Figure 3.2. Public grants and grant amount (in millions DKK) for water tech research, 2013-2022



Source: Based on data from The Environmental Technology Development and Demonstration Programme (MUDP), Innovation Fund Denmark (IFD), EU, The Independent Research Fund Denmark, and the Ministry of Higher Education and Research.
Note: Two projects financed by the Danish National Advanced Technology Foundation in 2013 are not included in the total grant amount in the period 2013-2014 due to missing information.

Consistent level of public funding for water tech research in the past decade
In the period 2013-2022, a total of 256 grants have been allocated to the field of water technology, with a total value of 846 million DKK.

The number of grants allocated to water technology has been relatively stable over the past decade, ranging from 24 to 31 grants annually. The grant amount awarded to water technology research fluctuates between 60 million and 112 million DKK annually. This variation is closely correlated with occasional large grants in specific years.

The overall trend, however, is that water tech research has experienced a consistent level of public funding during the last decade. Meanwhile, the total public research budget in Denmark has increased from 22.5 billion DKK in 2013 to 23.6 billion DKK in 2022[8].

The table below briefly describes the public funding agencies included in the analysis.

Public funding agencies included in the analysis

The Danish National Research Foundation supports outstanding basic research across all research fields to strengthen the development of Danish research. The foundation has not allocated funds to the water tech area during the period and therefore is not included in the analysis.

Independent Research Fund Denmark (DFF) funds activities based on researchers' own initiatives across all scientific areas. The Fund primarily supports basic research and awards approximately 400 grants amounting to well over DKK 1 billion on an annual basis.

Innovation Fund Denmark (IFD) supports the development of knowledge and technology, which contributes to strengthening research and innovative solutions. The fund is focused on supporting solutions for societal challenges and enhancing research and innovation efforts in companies.

[8] Statistics Denmark: "Public research budget" (https://www.statistikbanken.dk/foubud)

Horizon Europe is the EU's framework programme for research and innovation. They support bottom-up research, mobility of researchers, and strategic research and innovation where interdisciplinary, international cooperation is paramount.

The Environmental Technology Development and Demonstration Programme (MUDP) aims to promote the development and implementation of environmentally efficient solutions for prioritized environmental challenges through grants for the development, testing, and demonstration of new technologies.

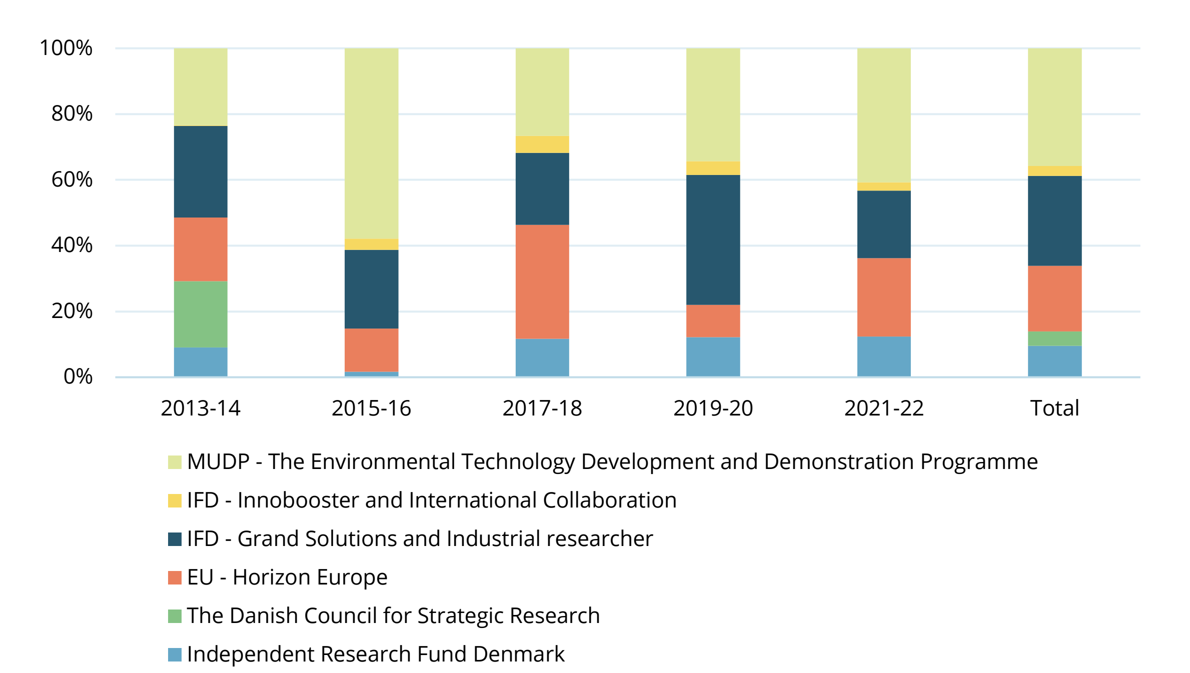
The Danish Council for Strategic Research (DSF) was established with the purpose of supporting research within politically prioritized and thematically delimited research areas. DSF supported strategic research, often conducted across scientific disciplines. The research council was discontinued in 2014.

The Danish Council for Technology and Innovation (HTF) was established with the purpose to strengthen growth and innovation through R&I initiatives related to technology and innovation policies. The research council was discontinued in 2014.

MUDP is the largest public contributor to the development of water technology

In the past decade, the Environmental Technology Development and Demonstration Programme (MUDP) has been the primary public funding source for water technology. In total, MUDP grants constitute 36% of the public funds allocated to the field. Notably, MUDP grants constituted almost 60% of all public funds in the 2015-2016 period, as shown in Figure 3.3.

Figure 3.3. Distribution of public grant amount for water technology by funding source, 2013-2022



Source: Based on data from The Environmental Technology Development and Demonstration Programme (MUDP), Innovation Fund Denmark (IFD), EU, The Independent Research Fund Denmark, and the Ministry of Higher Education and Research.
Note: Innobooster includes projects from the programme Innovation Voucher in 2013.

Grants from the Innovation Fund Denmark under the programs "Grand Solutions" and "Industrial Researcher" account for a quarter of the total awarded grant amount within water tech. Most of this funding originates from large Grand Solutions projects.

The EU research and innovation programme – Horizon Europe – also plays a significant role, on average accounting for 20% of the total grant amount for water tech research.

Finally, Figure 3.3 reveals that the former Danish Council for Strategic Research was a significant contributor to water tech research before the council was surpassed by the Innovation Fund Denmark in 2014. In the 2013-14 period, the Danish Council for Strategic Research accounted for 20% of all public funds for water tech research. Also, in interviews with researchers, the importance of the Danish Council for Strategic Research was stressed alongside the significance of the Strategic Environmental Research Programme that was active from 1992-2004.

The fluctuations over time evident from Figure 3.3 are caused by significant projects initiated by various funding agencies in specific years. Examples of significant projects are provided in the box below.

Examples of large public grants for water technology research and innovation

Innovation Fund Denmark (2020) "Hi-PreM: High Pressure Membranes for next generation innovative green energy and water technologies", 25 million DKK.

The project aims to increase energy efficiency by using PRO technology and components developed specifically for osmotic energy generation. The ambition is to leverage the next generation of high-pressure pumps and state-of-the-art osmotic membrane systems.

Participants: Technical University of Denmark, Danfoss & SaltPower.

MUDP (2022) "Cost Efficient Reduction of MicroPollutants", 15 million DKK.

The overarching goal of the project is to reduce micropollutants, including pharmaceuticals, industrial chemicals, and PFAS, in the purification process conducted at wastewater treatment plants.

Participants: Aalborg University, Køge Afløb A/S.

MUDP (2020) "Data-driven solutions for reducing environmental impacts from overflows",11.6 million DKK.
The project aims to quantify the hydraulic and substance-related effects resulting from wastewater systems' overflow. The focus lies on data collection, validation, and modeling. The measurement outcomes are utilized to modify overflow structures, limiting environmental impacts from overflows.

Participants: Aalborg University, University of Southern Denmark. Vandcenter Syd A/S, Aarhus Vand A/S, Krüger A/S, Informetics ApS, Novafos A/S, Dryp ApS, BSS ApS, COWI A/S.

Independent Research Fund Denmark (2020) "ToxiTrace: A Chromatographic Bioassay for Tracing Toxicant Removal in Water Treatment" 2.8 million DKK.

This project aims to develop a new bioanalytical technology that integrates advanced chemical and toxicological analysis methods to detect and identify pollutants in the Danish water environment. The participants aim to develop new techniques to identify the most toxic chemicals in wastewater.

Participants: Aarhus University.

Europe Horizon (2022) "Sustainable membrane distillation valorises wastewater and delivers freshwater from saline sources" 2.7 million DKK.

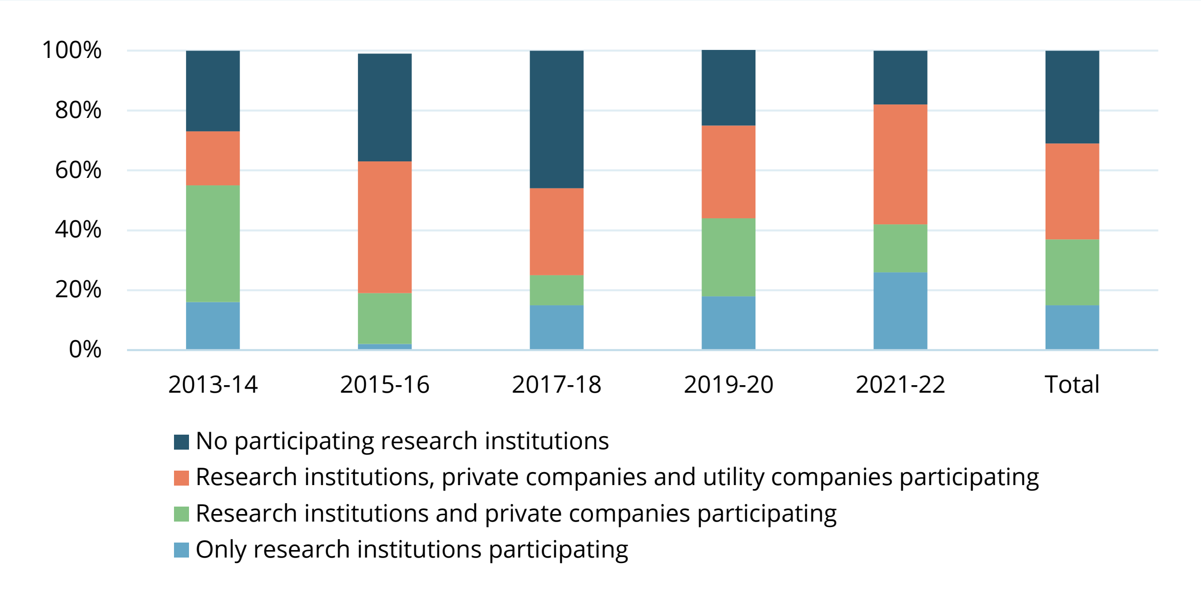
The project aims to develop high-performance membranes and modules for membrane distillation running on 90-100% sustainable energy from waste heat and/or solar energy. The prototypes will target industrial wastewater reuse and the recovery of valuable nutrients from aquaculture wastewater.

Participants: Aalborg University.

A shift towards projects with higher technology readiness levels
Research projects at low Technology Readiness Levels (TRL)[9] typically only involve research environments. As technologies mature, more partners are usually involved.

Figure 3.4 shows the distribution of grant amounts for water technology projects based on the involvement of research institutions. The relatively low share of the total grant amount for projects only involving research institutions indicates a rather high TRL in most projects.

Figure 3.4. Distribution of public grant amount for water technology, by participation of research institutions, 2013-2022



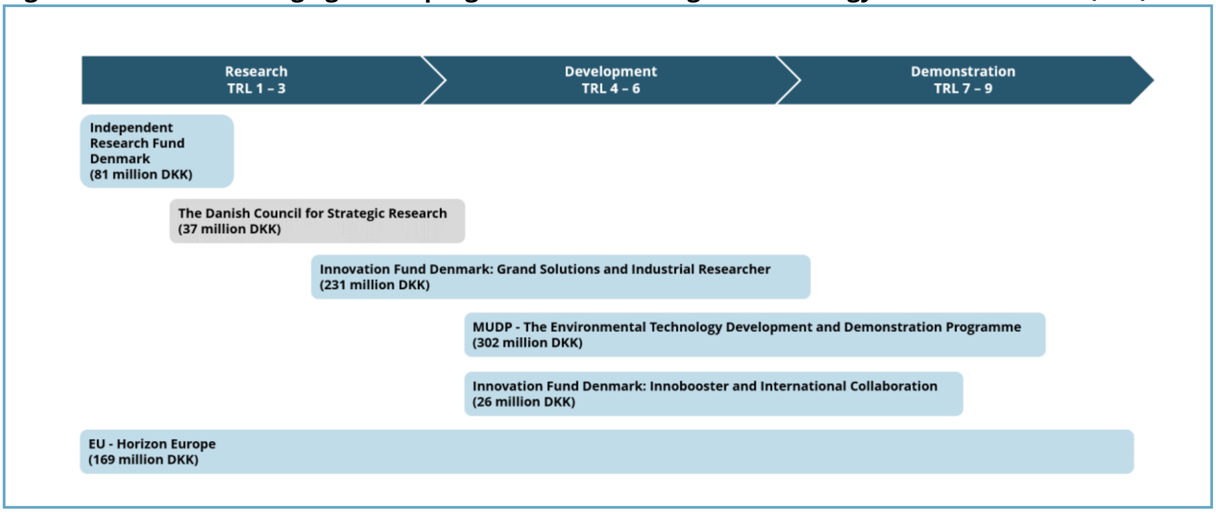
Source: Based on data from The Environmental Technology Development and Demonstration Programme (MUDP), Innovation Fund Denmark (IFD), EU, The Independent Research Fund Denmark, and the Ministry of Higher Education and Research.

A shift in funding focus towards projects with higher TRL is expressed by many water tech stakeholders (researchers, utility operators, engineering consultants, etc.) interviewed for this analysis. According to the interviewees, public funding for water technology research and development has become less evenly distributed along the TRL scale.

In Figure 3.5, public funding agencies/programmes relevant for water tech research and development are shown according to TRL focus. With grants from the Innovation Fund Denmark and MUDP as the single largest contributors, most funding is available for projects focusing on TRL 5-7.

[9] TRL is a method for estimating the maturity of technologies from basic technology research to full-scale test and demonstration.

Figure 3.5. Public funding agencies/programmes according to Technology Readiness Levels (TRL)



Source: IRIS Group
Note: Funding allocated to water technology from 2013-2022 is indicated in brackets. The Danish Council for Strategic Research (grey box) was succeeded by the Innovation Fund Denmark in 2014.

The only national public funding agency that supports low TRL projects is the Independent Research Fund Denmark. However, several large private foundations, such as the Villum Foundation and the Novo Nordisk Foundation, also support basic research in the field of water technology. Moreover, EU grants support basic research, although EU calls on water technology primarily focus on projects in the middle and upper end of the TRL scale.

The analysis indicates that a funding gap was created when the Danish Council for Strategic Research (grey box in Figure 3.5) was succeeded by the Innovation Fund Denmark in 2014. In interviews, water tech stakeholders experience a lack of funds for strategic research (TRL 2-4) in comparison to the available resources for basic research and development and demonstration.

The Innovation Fund Denmark supports activities through Grand Solutions, spanning from strategic research to commercialisation and implementation. However, according to the interviewees, most Grand Solutions are focused on activities at the higher end of the TRL scale.

The challenges that arise from this experienced lack of funding for strategic research are discussed in Chapter 7.

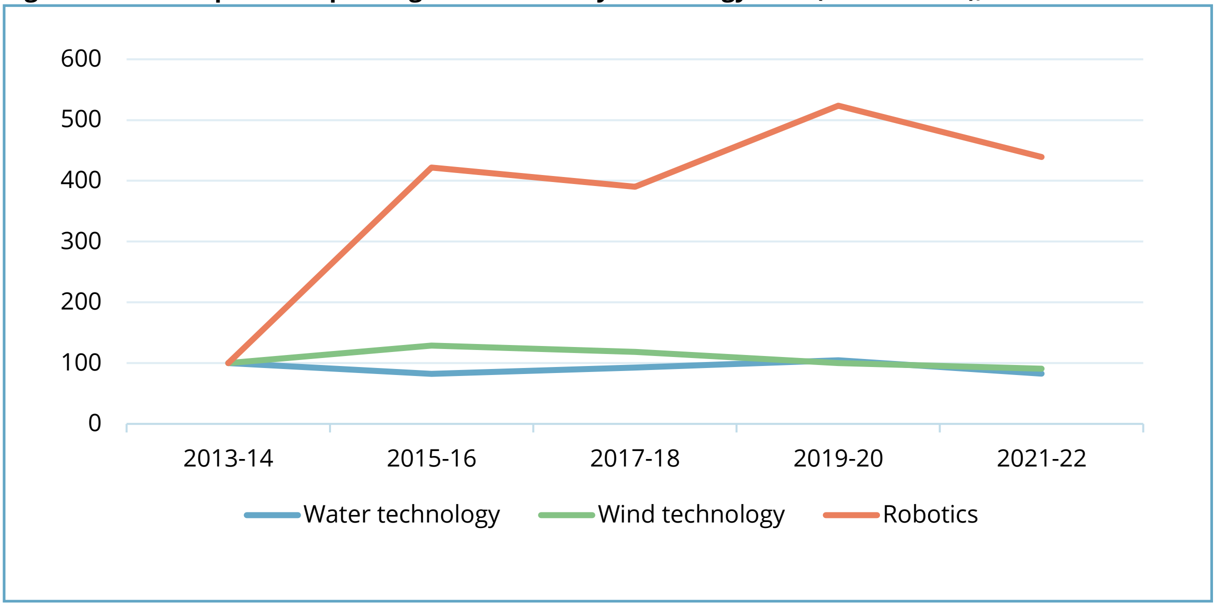
3.4 Public funding for water technology compared to robotics and wind technology

In Section 3.3, the analysis concluded that the level of public funding for water tech research has been stable with only minor variations from year to year during the past decade. To put that conclusion into perspective, it can be useful to compare the development in funding for water technology to other technology areas.

In this section, public funding for water technology is compared to robotics and wind technology. Both are areas with significant scientific and industrial strongholds in Denmark, and – like water technology – both areas have been part of Danish cluster organisations and recently appointed as industrial lighthouses and thus strategically prioritised nationally.

Significant increase in public funding allocated to robotics
Research and development funding granted to the field of robotics has increased by approximately 330% over the past decade, while funding levels for water and wind technology have remained relatively stable. Figure 3.6 illustrates the difference.

Figure 3.6. Development in public grant amount by technology field (2013-14=100), 2013-2022



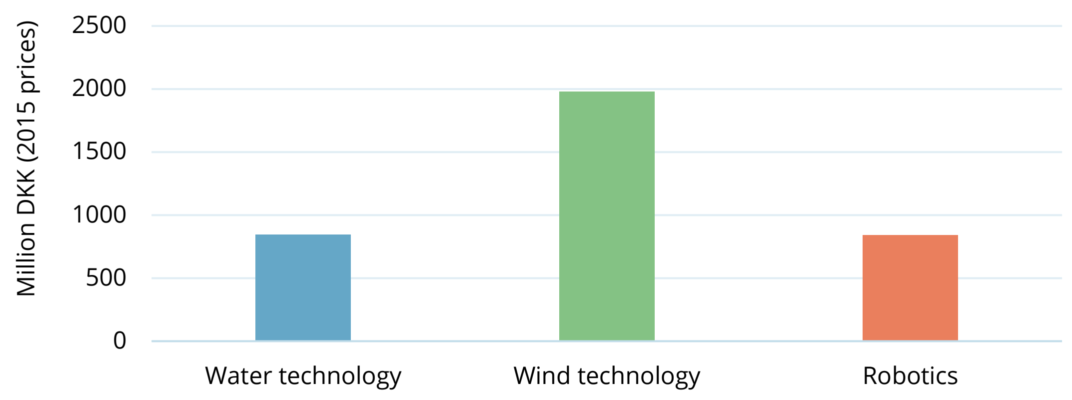
Source: Based on data from The Environmental Technology Development and Demonstration Programme (MUDP), Innovation Fund Denmark (IFD), EU, The Independent Research Fund Denmark, and the Ministry of Higher Education and Research.
Note: The analysis of public funding allocated to specific technology areas is based on a keyword search on public grants.

Compared to wind and water technology, robotics is a relatively young industry in Denmark. The substantial increase in public research funding for robotics aligns with the notable growth experienced by private companies in the robotics sector in recent years. Particularly, the robotics cluster in the region of Funen has seen remarkable advancement, with several major companies emerging from the research environments at the University of Southern Denmark.

This significant progress in the field has led to the establishment of multiple research programs and initiatives tailored specifically to the field of robotics.

Twice the Level of Research Funds Allocated to Wind Technology
Over the last decade, an approximately equal amount of public research funding has been allocated to the fields of robotics and water technology. In contrast, more than twice the level of funding has been directed towards research in wind technology, as shown in Figure 3.7.

Figure 3.7. Accumulated public grant amount by technology field, 2013-2022



Source: Based on data from The Environmental Technology Development and Demonstration Programme (MUDP), Innovation Fund Denmark (IFD), EU, The Independent Research Fund Denmark, and the Ministry of Higher Education and Research.
Note: The analysis of public funding allocated to specific technology areas is based on a keyword search on public grants.

The difference in public funding highlights the notable predominance of wind technology in Denmark compared to robotics and water technology.

In conclusion, the comparative analysis shows that funding for water and wind technology research has been relatively stable, but with funding for wind technology starting from a much higher level. Robotics is catching up and will surpass water tech research if the trend continues.

Smart Water Infrastructures Laboratory at Aalborg University

Photo by Aalborg University

4. Academic output and scientific quality

4.1 Introduction and key conclusions from the chapter

This chapter offers a discussion of the academic output and scientific quality of Danish water tech research. The discussion is based on a bibliometric analysis, briefly described in the box below.

First, the chapter examines the development in academic output (research articles, papers, etc.) from Danish water tech research environments. Second, the chapter discusses the scientific impact of Danish water tech research. Scholarly performance is benchmarked against other technology areas (wind technology and robotics) and other countries.

Key conclusions from the chapter are:

- In recent years, the annual number of published water tech articles has remained relatively constant, while other research areas such as robotics have grown considerably.
- Compared to other countries, Denmark still produces a large volume of water tech research articles, but the gap has narrowed over the last years.
- More than half of the Danish water tech research articles concern issues relating to Wastewater. Water supply and Stormwater each make up 19% of all articles.
- Danish water tech research enjoys great scientific impact as Danish articles are highly cited by international peers.

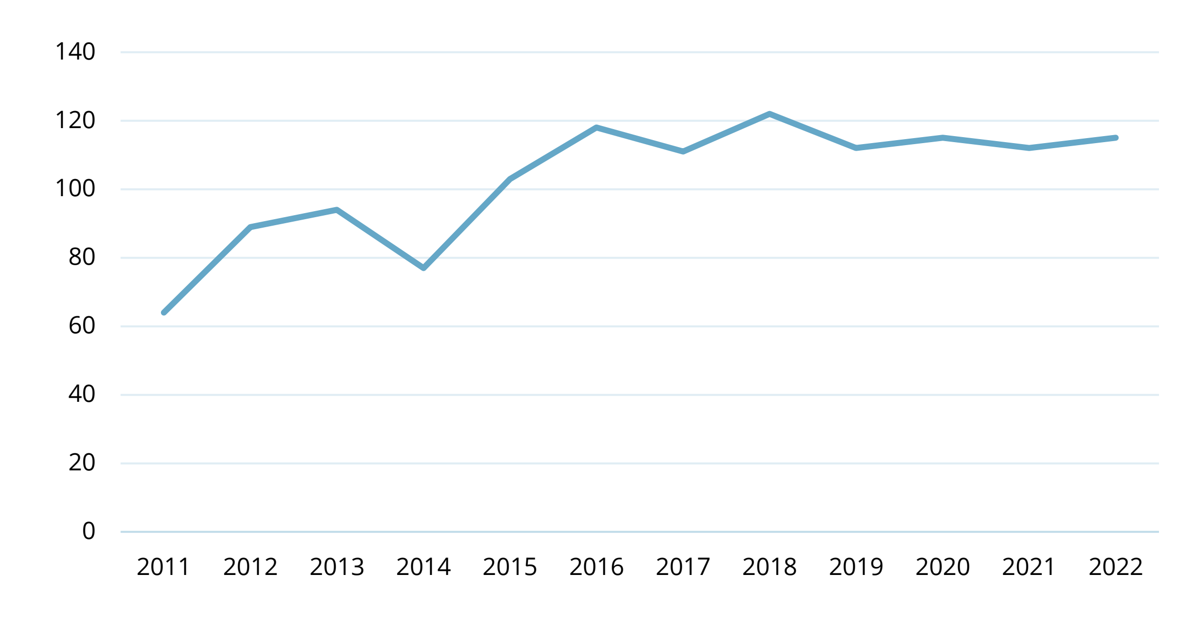
4.2 Academic output

Danish water tech research articles are published in a wide array of journals, including both specific water technology journals and broader engineering journals. Moreover, relevant articles occur in scientific journals within the field of biology and chemistry.

The figure below shows the number of scientific articles, reviews, and conference papers in the field of water technology published by researchers in Denmark from 2011 to 2022.

Increase in Number of Water Tech Research Publications Until 2016
In 2022, researchers in Denmark published 115 articles within the field of water technology. From 2011 to 2016, the number of articles grew from about 60 to 115, equalling an 85% increase. Since 2016, the number of articles has remained at around 115 annually.

Figure 4.1. Development in number of Danish water tech publications, 2011-2022



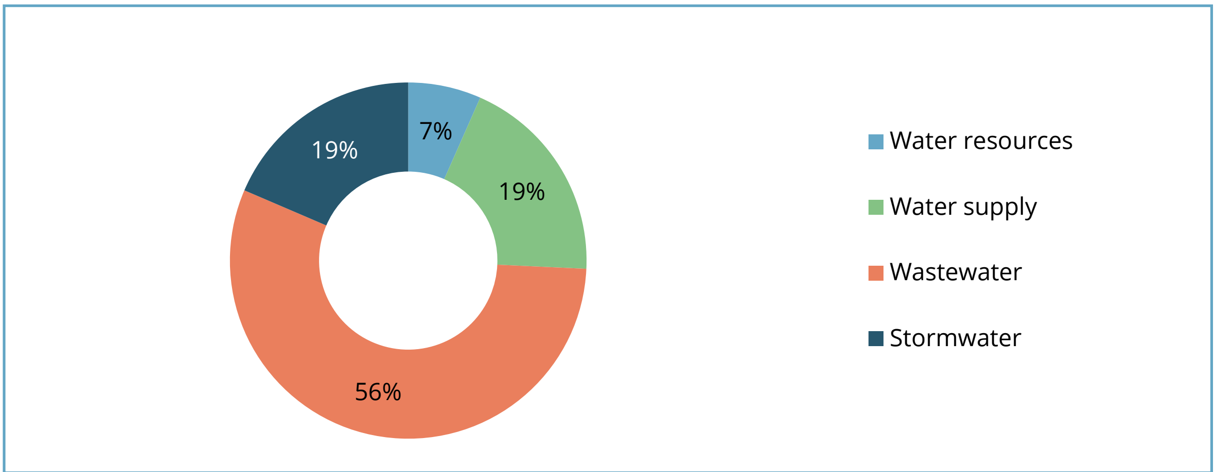
Source: IRIS Group based on data from SciVal.
Note: Scientific publications include articles, reviews, and conference papers.

The stagnation in academic output from 2016 onwards aligns well with the fact that the level of funding for water tech research has been stable since 2013/2014, as shown in the previous chapter. As it usually takes a few years to convert research funding into scientific publications, the stagnation in academic output might be a consequence of the development in public research funding for water technology.

Wastewater research accounts for more than half of all publications

Among all water tech articles published in the last decade, 56% relate to wastewater research (See Figure 4.2). The heavy focus on wastewater reflects the fact that major research environments at Aalborg University, Aarhus University, and the Technical University of Denmark are specialised in this part of the water cycle, as discussed in Chapter 2.

Figure 4.2. Distribution of Danish water tech publications by focus area, 2011-21



Source: IRIS Group based on data from SciVal.
Note: It is not possible to treat the area, Water reuse, as an independent unit. Scientific publications include articles, reviews, and conference papers.

When interpreting the results, it is important to note that several water treatment technologies span across multiple research domains and are not easily categorised into a singular application. For instance, membrane technologies and biological purification processes are commonly utilised for both treating wastewater and purifying potable water.

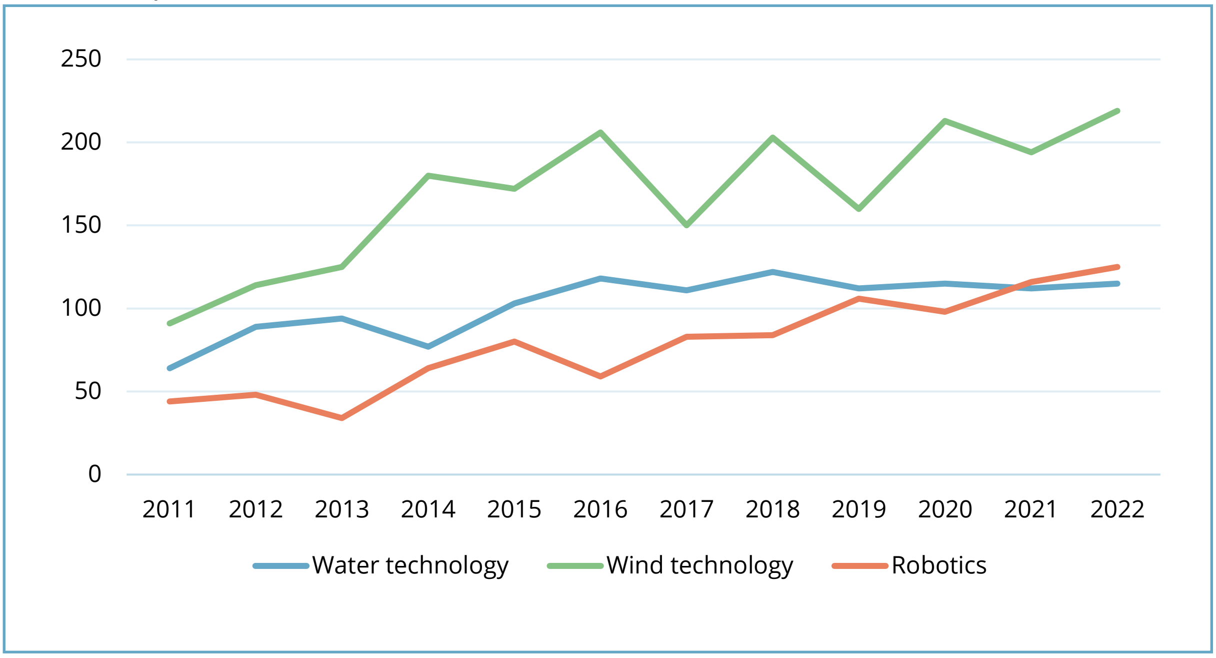
Moreover, identifying scientific articles exclusively related to water reuse has been challenging. This is because the research field is young and emerging. As a result, some of the articles within the wastewater domain also encompass aspects of water reuse.

Number of Water Tech Articles Falls Behind Robotics

Examining the period from 2011 to 2022, the bibliometric analysis shows that the number of water tech articles grew by 80%, while there has been a 141% increase in scientific articles on wind technology, and a 184% increase in articles on robotics.

Figure 4.3 shows that the volume of scientific publications on robotics has surpassed the number of publications on water technology.

Figure 4.3. Development in number of Danish publications on water technology, wind technology and robotics, 2011-2022

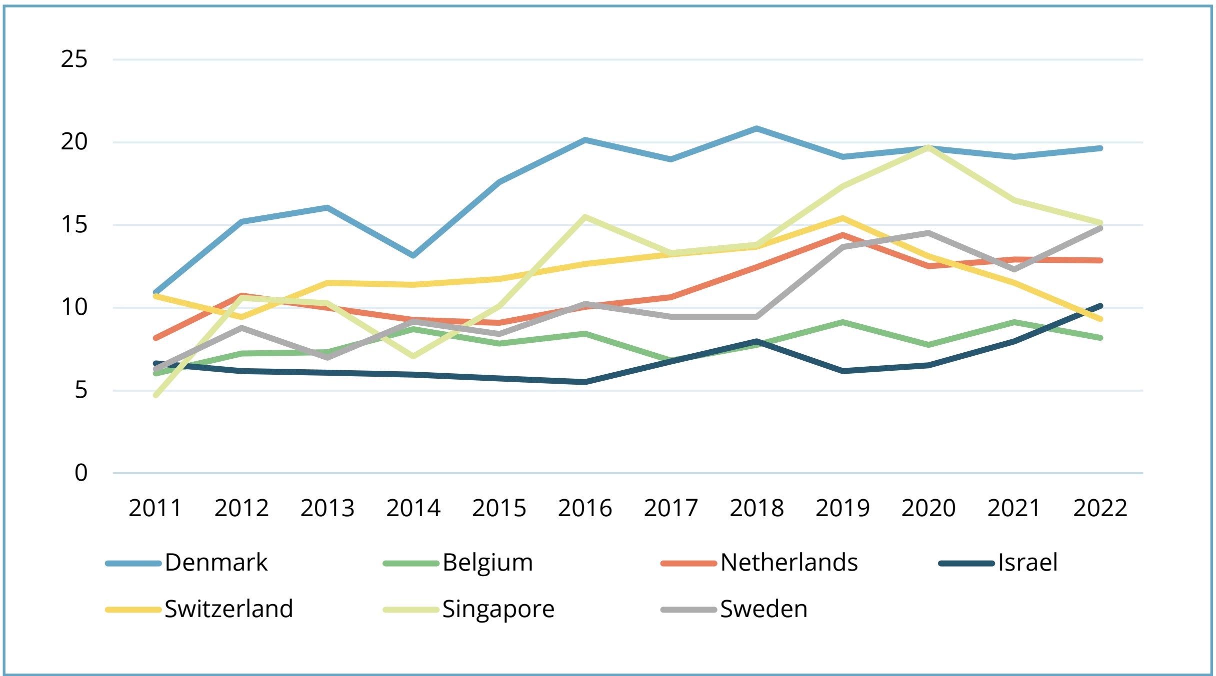


Source: IRIS Group based on data from SciVal.
Note: Scientific publications include articles, reviews, and conference papers.

High volume of articles, but other countries are catching up

Compared internationally, Danish water tech research environments are very productive. Figure 5.4 shows the number of water tech publications per million inhabitants for Denmark and six other countries. Benchmark countries have been chosen to mirror Denmark in size and general research sensitivity.

Figure 4.4. Number of water tech publications per million inhabitants, 2011-2022



Source: IRIS Group based on data from SciVal.
Note: Scientific publications include articles, reviews, and conference papers.

Throughout the entire period, Denmark is in the lead with the highest annual number of publications per million inhabitants. In 2022, nearly 20 articles per million inhabitants were published in Denmark, followed by Sweden and Singapore, publishing approximately 15 articles per million inhabitants. The figure indicates that Denmark has a strong specialisation within the research themes defined as water technology in this report (see the definition in Chapter 1).

From the figure, it is also evident that the gap between Denmark and most other countries has been narrowed in recent years. While the number of Danish articles has remained relatively constant from 2016 onwards, other countries have increased their scholarly output. This is particularly notable for Singapore, Sweden, and the Netherlands.

The trend evident from the bibliometric analysis is supported in interviews with Danish water tech research environments. The general picture is that water technology research has not been a priority in Denmark for many years, while neighbouring countries have boosted research activities in this field.

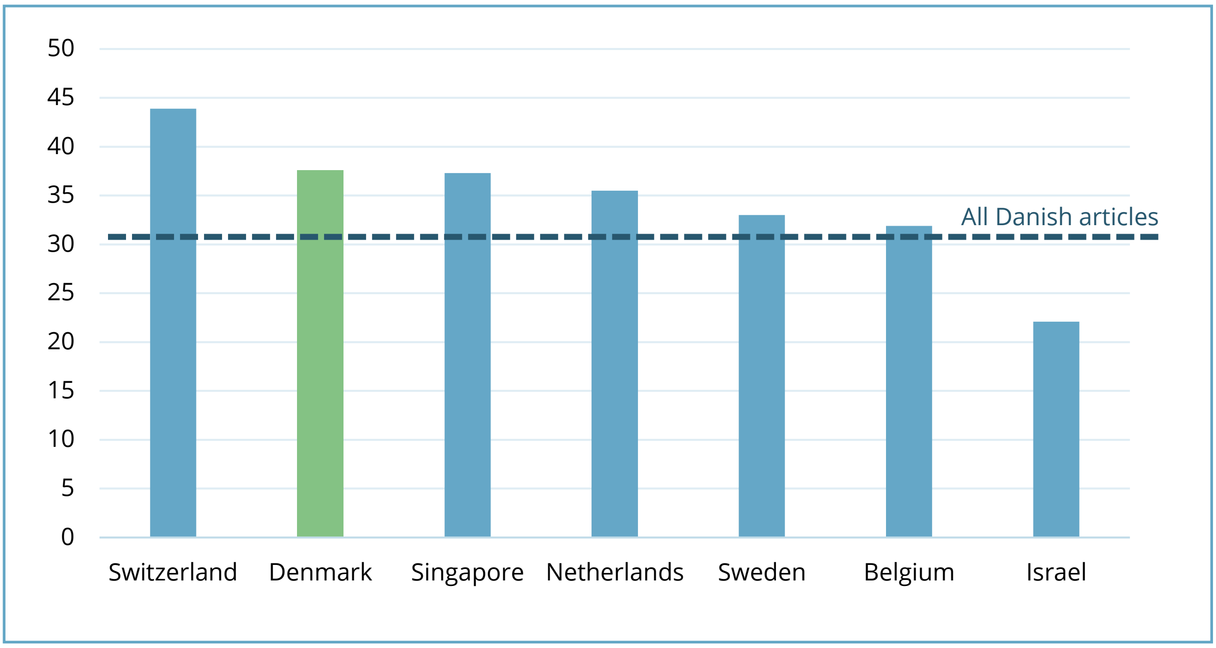
4.3 Scientific impact and quality

This section investigates the scientific impact and quality of Danish water tech research. Scientific impact refers to the effect of research articles on the development and progress in science.

A way to measure scientific impact is by counting citations of research articles. An article that is frequently cited can be considered to have a high degree of scientific impact – and by extension to be of high quality.

Danish articles are generally highly cited by the international research community
On average, Danish water tech publications were cited 35 times in the period 2011-2022. For comparison, the average number of citations for all Danish research articles during the period is 31, as indicated with a dashed bar in Figure 4.5.

Figure 4.5. Average number of citations per water tech publication, 2011-2022



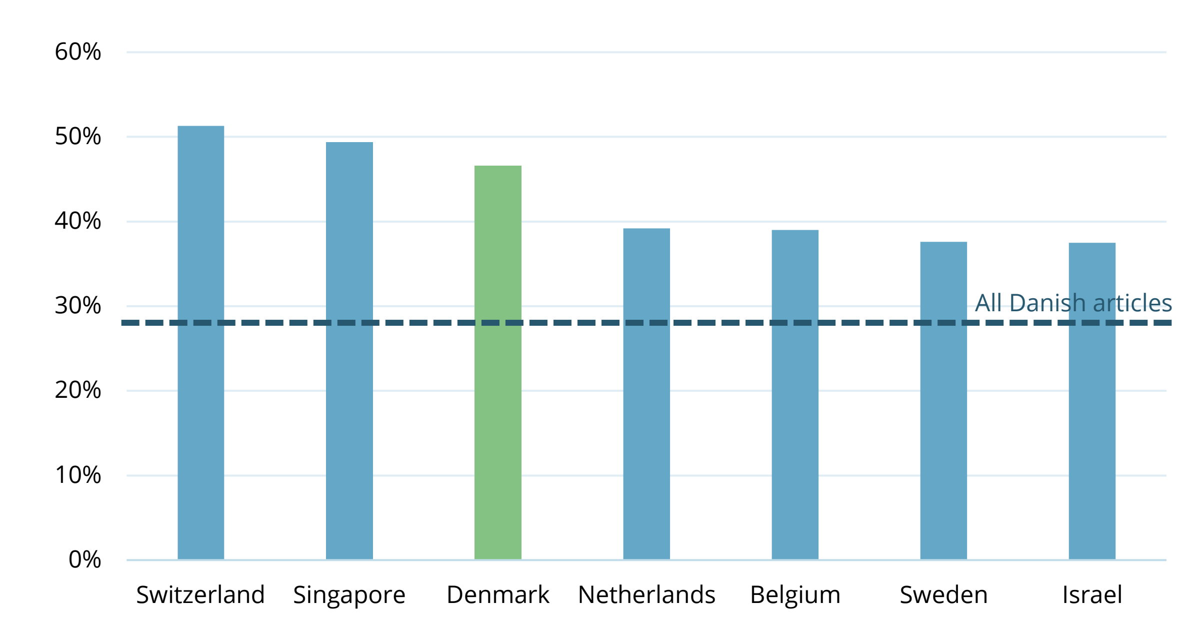
Source: IRIS Group based on data from SciVal.
Note: Scientific publications include articles, reviews, and conference papers.

The figure also shows that only articles published by researchers in Switzerland are cited more frequently than those from Denmark. Switzerland has several world-leading technical universities and is often in the lead when it comes to scientific impact.

Almost half of all Danish water tech research articles are published in high-impact journals
Scientific quality can also be evaluated by calculating the share of publications that are published in high-impact journals (i.e. the 10% most cited journals within a certain research field).

Figure 4.6 shows the share of Danish water tech publications published in high-impact journals compared to the six benchmark countries. Denmark is in the lead with Switzerland and Singapore. Almost half of all Danish water tech research articles are published in the 10% most cited – and thus most prestigious – scientific journals.

Figure 4.6. Share of water tech publications published in high-impact journals, 2011-2022



Source: IRIS Group based on data from SciVal.
Note: Scientific publications include articles, reviews, and conference papers. The indicator is based on the SNIP-score.

High scientific impact across all research areas in the water cycle
In Table 4.1, the share of publications in high-impact journals is shown for specific research areas in the water cycle.

Overall, a relatively large share of Danish articles is published in high-impact journals across the four research areas. The highest shares relate to wastewater and water supply, where 54% and 42% of the articles, respectively, are published in the 10% most cited journals.

Looking at the benchmark countries, Switzerland stands out with the highest share of articles published in high-impact journals across all four research areas.

Table 4.1. Share of water tech publications published in high-impact journals by research area, 2011-2022

Country	Water resources	Water supply	Wastewater	Storm water
Denmark	30 %	**42 %**	**54 %**	35 %
Belgium	**33 %**	**38 %**	41 %	33 %
Netherlands	**40 %**	32 %	50 %	29 %
Israel	28 %	37 %	38 %	**36 %**
Switzerland	**45 %**	**43 %**	**59 %**	**44 %**
Singapore	-	31 %	**57 %**	**43 %**
Sweden	25 %	32 %	40 %	**36 %**

Source: IRIS Group based on data from SciVal.
Note: Scientific publications *include articles,* reviews, *and conference papers. The indicator is based on the SNIP-score.*

New lab facilities at DTU Sustain opened in 2023

Photo by Morten de Fine Olivarius

5. Collaboration and societal impact

5.1 Introduction and key conclusions from the chapter

In this chapter, collaborative patterns and the societal impact of Danish water tech research environments are explored.

To exploit research results and turn scientific know-how into innovative solutions, collaboration is essential. Collaboration is needed both across water tech research environments to exploit complementary competencies and with industry, utility companies, and other stakeholders in the water sector to apply results in real-world settings. When research is applied, it impacts society.

First, the chapter examines collaboration across research environments and collaborative activities with other stakeholders in the water sector. Second, the impact on society of water tech research in Denmark is discussed.

Key conclusions from the chapter are:

- International research collaboration is thriving, but collaboration between Danish universities is less widespread due to a lack of incentives (including a high degree of competition for research funding).
- All research environments have established relations with utility companies. However, most collaboration is concentrated around a few large utilities.
- Collaboration is pronounced with consulting engineers, but less frequent with large water industries.
- Water tech research has played a pivotal role in Denmark's development of one of the world's most efficient water cycles.
- Access to candidates trained in water tech research environments is crucial to the industry.

5.2 Collaborative research

International collaboration is thriving, but collaboration between Danish universities is less widespread

Water tech research in Denmark maintains a notably high scientific standard, as substantiated in the preceding chapter. Consequently, Danish research environments are sought-after partners in international research endeavours. According to Danish water tech researchers, robust connections have been established with research groups abroad sharing similar fields of interest. Notably, collaborations with research environments at Lund University in Sweden, TU Delft in the Netherlands, and Ghent University in Belgium have been highlighted as examples of significant scientific partnerships.

Internal collaboration within research environments at the same university also appears to be thriving. Despite the diverse internal organisation of water tech research outlined in Chapter 2, most environments exhibit strong connections with relevant peers within their home institutions.

In contrast, collaboration among Danish research institutions is generally infrequent and ad hoc. Apart from VIA University College, there is limited evidence of cross-institutional collaborative research in Denmark.

Some researchers recollect a time when research groups across Danish universities collaborated more extensively, but the prevailing consensus among interviewees is that such collaboration is not prevalent today.

The value of cross-institutional collaboration was also recalled by several researchers. Joint projects typically apply a broader perspective on challenges in the water sector, and participating PhD students obtain a better understanding of the entire water cycle, systems, and how technologies link to one another.

An explanation for this collaboration pattern can be discerned in the structure of research funding. Research environments at different institutions vie for the same funds, fostering a competitive environment. The lack of unity and, to some extent, overlapping fields of research, as detailed in Chapter 2, intensify the competition among research institutions in Denmark. Collaborations at the national level are further hindered by the challenges posed by EU funds, as EU research programmes often mandate international collaboration. According to researchers interviewed for this analysis, the participation of two institutions from the same member state tends to lower the success rate in securing EU funds.

Close relations with utility companies
All 17 research environments have established connections with waterworks and/or wastewater treatment plants. Utility companies serve as test facilities when successful research outcomes need validation in a pilot plant or full-scale operational setting (refer to Chapter 2).

Consensus among all interviewed stakeholders affirms that the open and extensive collaboration between research environments and utility companies is a distinctive strength in Denmark. However, involvement in research and development activities varies across utility companies. Most research collaboration is concentrated around a few major Danish utilities such as VandCenter Syd, Aarhus Vand, BIOFOS, HOFOR, and TREFOR. Nonetheless, there are instances of small utility companies allocating resources to development activities.

Regulation of Danish utility companies is highlighted as a barrier to research and development activities by interviewees within the water sector. The demand for cost-efficient operation leaves limited financial resources and time for investment in development activities. Particularly, small utility companies find it challenging to participate in collaborative projects (see Chapter 7 for a more in-depth discussion on framework conditions).

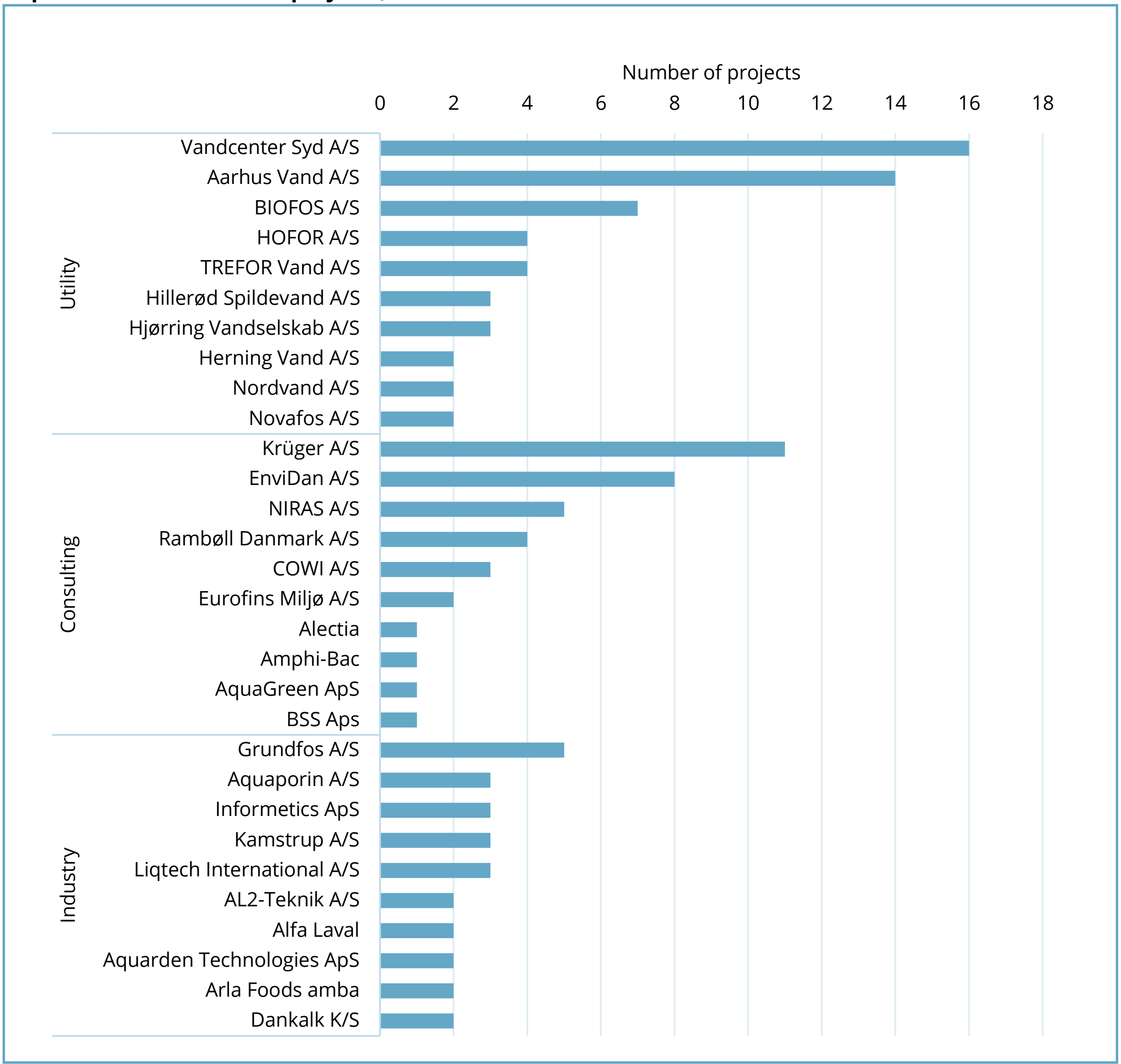
Limited collaboration with industry
Denmark hosts a cohort of consulting engineers specialising in water technology. These large companies frequently engage in test and demonstration projects with researchers and utility companies. Consulting engineers are often instrumental in bridging research environments and utility companies when they design new solutions for waterworks and wastewater treatment plants.

Furthermore, Denmark is home to some of the largest water companies globally, namely Grundfos, AVK, and Kamstrup. However, these major industrial players are not extensively involved in collaborative projects with Danish research environments.

Figure 5.1 illustrates the top ten collaboration partners for Danish research institutions, based on participation in publicly funded research projects. It should be noted that the figure does not encompass all collaborative activities but serves as an indicator that a few large utility companies and consulting engineers account for the majority of publicly funded collaborative research in Denmark.

The figure shows the ten companies (utility, consulting, and industry respectively) with the largest number of joint research projects with Danish research environments.

Figure 5.1. Top ten utility, consulting, and industry collaboration partners by number of participation in public funded research projects, 2013-2022



Source: Based on data from The Environmental Technology Development and Demonstration Programme (MUDP), Innovation Fund Denmark (IFD), EU, The Independent Research Fund Denmark, and the Ministry of Higher Education and Research.
Note: The names of companies were registered in the year when a particular collaborative project was granted. However, some of the companies depicted in the figure no longer exist due to mergers or acquisitions.

An essential mechanism fostering academic-industry collaboration in Denmark is the Industrial Researcher Programme. This initiative supports PhD students and postdocs funded by the Innovation Fund Denmark, aiming to generate commercial benefits for companies and enhance the ties between universities and the industry.

From 2015 to 2022, a total of 1,150 Industrial Researchers were awarded in Denmark. Among these, 18 projects were associated with water technology, with only 4 of these projects involving an industrial partner.

The remaining projects entailed collaborations between research institutions and utility or consulting companies.

5.3 Societal impact of water tech research

Evaluating the societal impact of technological advancements is a complex task, as it involves assessing not only tangible outcomes but also the broader influence on society. This section aims to shed light on the qualitative aspects of the societal impact of water tech research in Denmark, drawing insights from interviews with researchers and various stakeholders in the water sector.

Denmark has one of the world's most efficient water cycles
The interviews with both researchers and utilities reveal that water tech research has played a pivotal role in the development of one of the world's most efficient water cycles. This success can be attributed to several key factors:

- Water tech research conducted at Danish universities has led to the formulation of innovative principles, techniques, regulation, and guidelines. These advancements serve as the foundation for the efficient management of water resources, addressing challenges such as water quality, distribution, and sustainability.

- The collaborative ecosystem between universities, utility companies, and consulting companies in Denmark has been instrumental in translating research findings into practical applications. This synergy fosters a dynamic exchange of knowledge, allowing for the integration of cutting-edge research into real-world water management practices.

- The (historical) availability of funding across all Technology Readiness Levels (TRL) has been crucial for the successful implementation of water tech research in Denmark.

A tangible example of impact was provided by a water utility representative interviewed for this analysis: Towards the end of the Strategic Environmental Research Programme (active from 1992-2004), extensive research was funded on the occurrence of the substance BAM (the third most prevalent environmental contaminant in Danish groundwater). The targeted research indicated that the substance would naturally decrease in the future. Research efforts also identified the most effective purification methods. Over the years, the substance did indeed decrease, leading utilities to implement only the most necessary measures. Without this knowledge, utilities would have invested significantly more in purification technologies that would have proven unnecessary. The point stressed by the utility representative is that without the right knowledge, there is a risk of making misguided investments.

For industry, access to skilled labour is considered the most significant impact
In general, industry stakeholders identify access to a skilled labour pool as the primary driver of knowledge transfer between Danish knowledge institutions and the industry. According to representatives from the industry, students from research-based educational institutions play a crucial role in effectively integrating the latest advancements into operational practices. However, interviews underscore a significant challenge: a decline in student enrolment in recent years, as highlighted by stakeholders across the water sector.

Beyond educational activities, major companies do not prioritise collaboration with Danish research environments as a pivotal factor in developing new technologies. While there are exceptions to this general trend, the reasons for not collaborating also vary. An explanation mentioned by several companies is that research themes and focus tend to align with available funding options, posing a challenge to establishing long-term partnerships.

Conversely, some companies assert that collaboration with foreign universities has proven more influential for growth and exports than national research and innovation projects. The explanation provided is that foreign environments are perceived as a better platform for accessing new markets.

The wastewater treatment plant at Hillerød Forsyning is the only fully covered treatment plant in Denmark. The covering reduces odour issues for the neighbours and allows the plant to blend in with the surroundings.

Photo by Hillerød Forsyning

6. Case study – Water tech research in the Netherlands

This chapter offers a deep dive into water tech research in the Netherlands.

The Netherlands has been highlighted in several interviews with Danish water tech stakeholders as an interesting case to study. Like Denmark, the Netherlands has a long history and a strong track record in water tech research. However, unlike Denmark, societal awareness of issues related to water is deeply embedded in the Dutch mind.

The purpose of this case study is to highlight good practice examples from the Netherlands and explain important structural differences between Danish and Dutch water tech ecosystems.

The case study is based on desk research and interviews with water tech stakeholders in the Netherlands.

Water is top of mind and politically prioritised in the Netherlands
Almost one-third of the country lies below sea level, and more than half of the country is vulnerable to flooding. Enormous efforts have been made to keep this low-lying delta area a safe place to live and to ensure that there is sufficient clean water. Naturally, a strong focus on water technology has developed in the Netherlands.

Every five years, the Dutch government renews a National Water Programme (NWP) that lays out strategic directions for dealing with water-related challenges in the Netherlands. The NWP has a broad scope, covering everything from work on flood protection, surface water quality, wastewater management, and sustainable drinking water supply. The NWP does not outline specific initiatives or explicit directions for water-related research, but the programme guides the overall direction for public agencies and funding bodies in matters related to water for a five-year period.

Furthermore, the Dutch government has selected nine so-called Top Sectors that have received continuous political awareness and support to further strengthen their international position. One of these Top Sectors is water.

National funding for water tech research and innovation is primarily supplied by the Dutch Research Council and the National Growth Fund (NGF). The latter was set up in 2020 with the objective of undertaking one-off public investments. In early 2023, NGF allocated 135 million EUR to a Water Technology Growth Plan. Additional funding will come from businesses (106 million EUR), and local authorities and knowledge institutions (101 million EUR). In total, the Water Technology Growth Plan will invest 342 million EUR over the next ten years in the development, growth, and exports of the water technology sector. In comparison, a total of 145 million DKK equivalent to 19.5 million EUR will be allocated in the years 2022-2025 to the establishment of a business lighthouse for water technology in Denmark [10].

Water tech research environments with critical mass
A notable difference between Denmark and the Netherlands is the size and organisation of water research environments. While Danish water tech research is generally conducted in small and fragmented

[10] Includes grants and own financial contributions for phase I and phase II of the Danish business lighthouse for water technology.

environments (see Chapter 2), water tech research at Dutch universities appears to be more coherently organised, with large research units located at Delft University of Technology (TU Delft) and Wageningen University.

At TU Delft, the majority of water tech research is consolidated at the Department of Water Management within the Faculty of Civil Engineering and Geosciences. The department comprises 10 professors, 30 associate/assistant professors, 14 postdocs, and more than 60 PhD students. The focus is on the entire water cycle, and the philosophy is to incorporate all relevant disciplines to create synergies and critical mass. In addition to the Department of Water Management, a group of approximately 30 researchers (mostly PhD students) at the TU Delft Faculty of Applied Sciences is dedicated to research in microbial ecology and its application in designing new processes for wastewater treatment and waste-to-product processes.

The WaterLab at TU Delft is a unique facility that allows studying water systems from laboratory scale to field labs, to grasp the full complexity of real-world water systems based on a thorough understanding of the underlying processes. The combination of science and engineering, and the broad range of water applications involved make WaterLab at TU Delft unique.

Wageningen University adopts a broader environmental technology scope but maintains a rather large research unit concentrating on the development of electrochemical, bioelectrochemical, and membrane-based water treatment technologies.

Apart from TU Delft and Wageningen, smaller water tech research environments can be found at the University of Twente (specialising in membrane technology for water treatment) and the University of Groningen (focusing on water resources and stormwater management). Both environments employ 1-2 senior researchers and approximately 5 PhD students.

Academia-industry collaboration
Similar to Danish research environments, Dutch researchers engage in extensive collaboration with utility companies and relevant consultancy firms. According to the Dutch stakeholders interviewed for this analysis, collaboration between universities and private technology providers is also flourishing in the Netherlands. This contrasts with the general situation in Denmark, as described in Chapter 5.

A unique initiative in this regard is the Engineering Doctorate programmes (EngD) offered by the four universities of technology in the Netherlands. Similar to a PhD, an EngD is a postgraduate degree. However, while a PhD is a four-year programme focused on scientific research, an EngD is a two-year design-oriented doctorate tailored to the immediate needs for product, process, and system innovation of industry and society. The pragmatic approach, relatively short duration, and the absence of a requirement for academic publications have made EngD projects popular among water companies and technology providers. The programme serves as an important bridge between academia and industry.

A strong utility sector with its own R&D funds
Ten large drinking water companies in the Netherlands supply drinking water to 17.5 million people, and wastewater is managed at 350 treatment plants. In Denmark, approximately 2,600 waterworks and 701 wastewater treatment plants serve 5.9 million people. The size of Dutch utility companies is a notable difference between the Dutch and Danish water sectors.

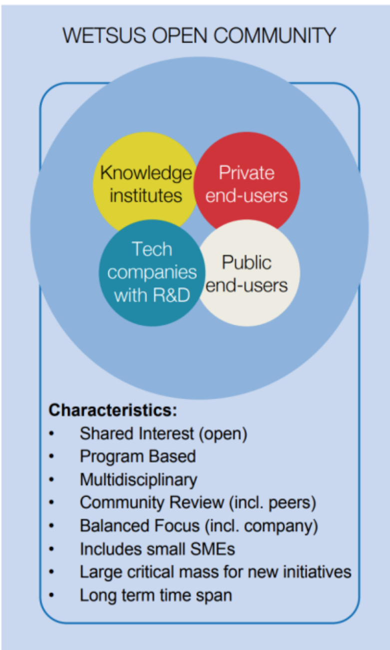
The organisation and financing of the water sector are two other important differences. Water management in the Netherlands has its own governmental authority, with 21 regional water authorities overseeing flood protection, water quality management, and wastewater treatment. Dutch water authorities are managed by elected board members and are authorised to collect taxes.

Water authorities can initiate R&D projects independently, but they also contribute to STOWA (an acronym for the Foundation for Applied Water Research). STOWA is a Centre of Expertise for the regional water authorities, with a mission to develop, collect, distribute, and implement applied knowledge essential for effective and efficient water management. With an annual budget of around 7 million EUR, STOWA funds research and innovation projects on topics of common interest to the water authorities.

Research and innovation at the ten drinking water companies in the Netherlands are organised around KWR, a specialised drinking water research center. KWR conducts exploratory work related to drinking water and implements solutions in the individual water companies' own practices, adding value to the collective sector. Research projects often involve collaboration with universities, and much of the scientific staff at KWR is also affiliated with TU Delft. KWR was co-initiator of the Water Technology Growth Plan mentioned above and will have a coordinating role in its realisation. In 2022, KWR had revenues totalling 25.9 million EUR. 25% of the revenues came from competitive grants, the rest was obtained equally from research contracts and a special joint research programme with the water utilities[11].

Wetsus – a Centre of Excellence for sustainable water technology
Finally, the establishment of Wetsus in 2003 is an important addition to the Dutch water tech ecosystem. Wetsus is a research and innovation center organised to stimulate collaboration between the various public and private organisations that together constitute the water sector: i.e. between public companies, private companies, and universities; between scientific chairs; and between regional, national, and European policymakers (see figure).

Figure 6.1. Wetsus Open Community Cooperation model



Source: Wetsus

Within several national and international scientific programmes at Wetsus, research institutions and industry jointly implement market-driven and application-oriented scientific research in the field of sustainable water technology. This is typically done in four-year-long research projects carried out by PhD students.

The philosophy of Wetsus is to bring water tech PhD students together to collaborate interdisciplinary on a campus away from established research environments and close to water tech companies and private and public end-users. Currently, 65 PhDs are affiliated with Wetsus. All PhDs are supervised by both Wetsus and a university in the Netherlands or abroad.

[11] KWR Year Review 2022 (https://www.kwrwater.nl/en/year-review-2022/financial-overview/)

Wetsus has its own state-of-the-art research infrastructure and dedicated staff to operate these facilities. One floor of the Wetsus building is completely dedicated to research, with almost 500 m2 laboratory space, divided into analytical, biological, chemical, and synthesis laboratories.

In innovation, Wetsus is active from TRL 2 up to TRL 9 covering strategic research and all the way to demonstration in proven operational environments. In education, Wetsus is engaged from primary and secondary schools, and from vocational education and training to PhD.

In 2022, the Dutch government appointed Wetsus as the national institute for strategically important research. Leeuwarden, in the Northern part of the Netherlands where the Wetsus building is located, was appointed as the focal point for water technology development.

WaterCampus Leeuwarden stands out as an innovation ecosystem. It is home to the Dutch water technology cluster organisation with 250 water tech SMEs, five demonstration sites, and a supportive environment for start-ups, including matchmaking between investors and water tech companies in need of capital.

According to the Dutch stakeholders interviewed for this analysis, three key elements of Wetsus have helped place water technology at the national research and political agenda: 1) that Wetsus represents all four Dutch universities with water tech research environments, 2) that Wetsus has built a large and strong network with water tech companies and utilities, and 3) that Wetsus has a very organised structure around strategic research topics.

Wetsus derives its funding from multiple sources. Regional, national, and European government funds are combined with contributions from participating companies and universities. This way, a total budget of around 15 million EUR per year is available.[12]

What can Denmark learn from the Dutch?
There are several societal and structural differences between Denmark and the Netherlands that are important to keep in mind when comparing water tech ecosystems in the two countries.

First, water is deeply embedded in the Dutch mind and politically prioritised in the strategic National Water Programme and in national research and business policies.

Second, the water sector in the Netherlands is organised around a few large utility companies with substantial resources to support research and development activities. In contrast, the Danish water sector is characterised by many small utilities with very limited resources for such activities. Dutch water utility companies possess significant in-house expertise dedicated to research collaboration. Key employees are frequently affiliated with a research environment at a university, Wetsus, or KWR.

Societal and structural differences apart, the Netherlands has managed to internationally showcase water technology as a Dutch stronghold. The establishment of Wetsus 20 years ago is an important part of the explanation. Wetsus has united all Dutch water tech research environments around strategic research topics and connected industrial end-users to academia.

A water campus closely connected but physically apart from established research environments might be a solution to the fragmentation of Danish water tech research.

[12] Wetsus Annual report 2023

Wetsus Water Campus in the Netherlands

Photo by Wetsus

7. Framework conditions for water tech research and innovation

7.1 Introduction and key conclusions from the chapter

This final chapter examines framework conditions, such as funding mechanisms and regulation, for water tech research and innovation in Denmark. Proper framework conditions are important to maintain the strong position of Danish water tech research, as well as to stimulate innovation and the transition of research into better solutions.

First, the chapter pinpoints the role of water technology in solving societal challenges, according to water tech stakeholders in Denmark. Second, the chapter identifies areas for improvement in the current framework conditions.

Key conclusions from the chapter are:

- Water tech solutions can help deal with societal challenges such as polluted water resources, managing the consequences of climate change, and supporting the overall green transition of society. Five focal areas for future water tech research and development are highlighted.
- Actions to improve framework conditions include:
    - A long-term and coherent national strategy.
    - Increased emphasis on strategic research.
    - Improved conditions for research institutions to participate in development and demonstration projects.
    - Enhanced opportunities for utility companies to invest in research and innovation.
    - Development of a strong talent base.

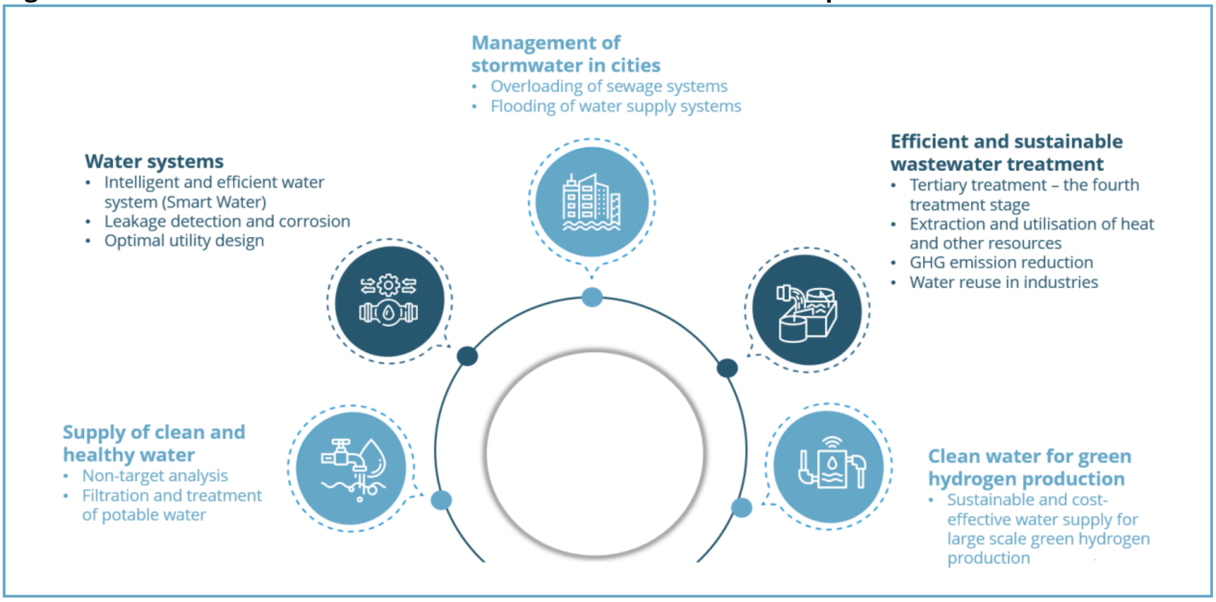
7.2 The role of water technology in solving societal challenges

Five focal areas for future water tech research and development

In interviews, water tech stakeholders were asked to point out central areas for future water technology development. The answers left no doubt that water tech solutions are an essential part of dealing with societal challenges such as polluted water resources, managing the consequences of climate change, and supporting the overall green transition of society. Furthermore, the answers indicate further potential for improvements of efficiency in the water cycle as a whole.

The analysis points to five broad focal areas for future water tech research and development. As many interviewees are occupied with challenges facing the Danish water sector, the five areas are shaped around this context. However, many of the challenges stressed in interviews are not unique to Denmark. Water tech solutions addressing these challenges thus present export potential. The five areas are summarised in Figure 7.1 and briefly described below.

Figure 7.1. Five focal areas for future water tech research and development



Source: IRIS Group

Supply of clean and healthy water
The Danish water supply has traditionally relied heavily on clean groundwater, with most Danish waterworks performing only basic water treatment before delivering high-quality drinking water to consumers. However, the discovery of an increasing number of groundwater contaminants, such as micro-pollutants, poses a significant threat to this approach, necessitating the development of new technologies dealing with these contaminants.

Water systems
Danish water tech stakeholders, led by the organisation Water Valley Denmark, envision Denmark as the home of the world's most sustainable and efficient water cycle by 2030[13]. Achieving an economically sustainable and real-time controlled water cycle, aiming for net-zero greenhouse gas emissions, requires the development and implementation of smart water systems and optimal utility design.

Management of stormwater in cities
Climate change presents a serious challenge to the water sector. As global temperatures rise, weather patterns become increasingly erratic, leading to more frequent and intense rain, floods, and storms. Stormwater challenges sewage systems in cities and risks inflow of contaminated waters into treatment plants. Solutions that predict overflow and manage large bodies of water in real-time are necessary to cope with the challenges of climate change.

Efficient and sustainable wastewater treatment
In Denmark, most wastewater is purified at treatment plants. In the future, the treatment process will be more advanced, incorporating new technologies for the destruction of environmental contaminants and cost-effective extraction of resources in sludge. Furthermore, GHG emissions from treatment plant is a serious challenge to the Danish water sector's target of climate neutrality by 2030 requiring continued research and development.

[13] Water Cycle Denmark: https://watercycledenmark.com/

While some technologies are already implemented in Denmark, others show significant potential in lab and pilot scale. A new report from the Danish Technical Institute indicates[14] that the majority of Danish wastewater treatment plants have not yet made decisions or invested in the so-called fourth treatment stage for wastewater purification, which the EU is expected to require from 2035[15]. Uncertainty about the law and a lack of knowledge about technical solutions are cited as central barriers.

Clean water for green hydrogen production
An emerging field of research is clean water for green hydrogen production. Green hydrogen is produced via electrolysis by using electricity to split water into hydrogen and oxygen. Electrolysis technologies are being developed, tested, and scaled worldwide at a rapid pace. To run electrolysis, renewable energy and water are needed in large quantities, and water for electrolysis must be of extremely high quality. In Denmark, the government has suggested a target of 4-6 GW electrolysis capacity by 2030[16]. To give a sense of the amount of clean water needed, a 1GW electrolysis facility requires the same amount of water as a city of 70,000 people[17]. Research and development are needed to find cost-effective solutions to supply green hydrogen plants with clean water without overloading utility companies and depleting groundwater resources.

7.3 Review of framework conditions

Funding, regulation, and other framework conditions need to be designed to support research environments and the water sector in their endeavors to solve the challenges outlined above.

As a final step in this analysis, a review of framework conditions for water tech research and innovation has been conducted. This review draws on insights from researchers, companies, utilities, and the broader ecosystem, as well as lessons learned from the Netherlands (see case study in Chapter 6).

Danish research strongholds in the field of water technology were gradually established over many years with sufficient funding across all Technology Readiness Levels (TRLs), ambitious regulation of the water sector, and a thriving collaborative ecosystem. However, the analysis indicates that the conditions for water tech research are deteriorating. The current fragmentation of water tech research environments and the challenges described above underscore the need for improved incentives to collaborate on innovative solutions to pressing societal challenges.

If action to strengthen framework conditions is not taken, Denmark risks losing unique know-how and eroding the platform for water tech innovation. Without strong research environments, utility companies are forced to develop and buy solutions abroad, and the national goal to double the export of Danish water technology, as stated in the cross-ministerial Export Strategy for Water[18], might be challenged.

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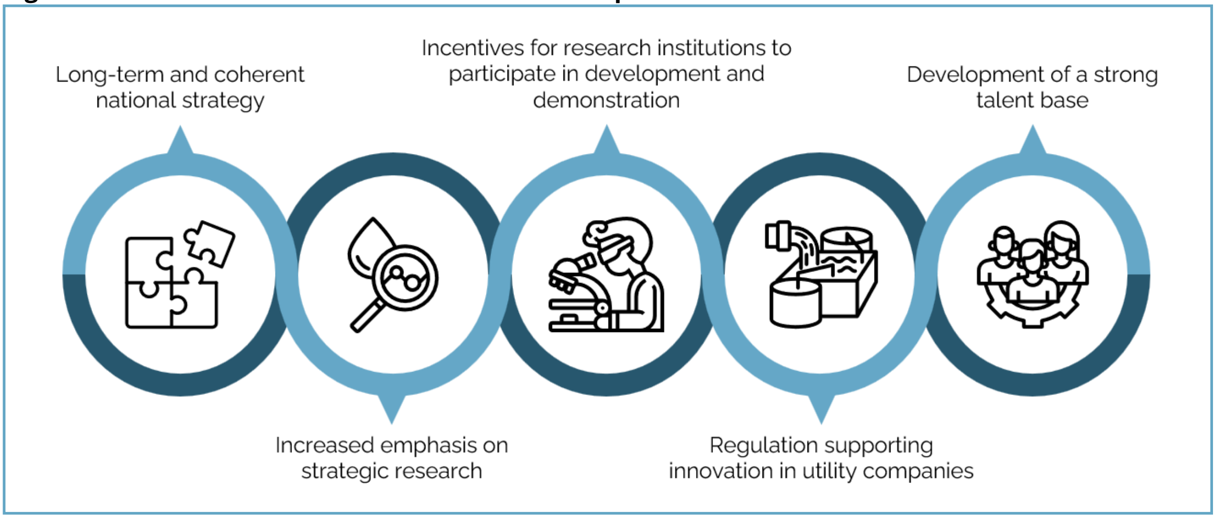
[14] Danish Technical Institute (2023): "Fremtidens spildevandsbehandling".
[15] The traditional three treatment stages include: 1) Mechanical treatment where larger particles and waste are removed from the wastewater; 2) Biological treatment, where microorganisms are used to break down organic material and nutrients in the wastewater; and 3) Chemical treatment where chemicals are used to remove remaining particles and nutrients. The fourth treatment stage may involve various technologies such as biological treatment, ozone treatment, activated carbon filtration, membrane technology, UV disinfection, and is often a combination of several technologies. The purpose of the fourth treatment stage is to remove environmentally harmful substances, such as pharmaceutical residues, hormones, and perfluorinated substances (PFAS), which are not effectively removed in the first three treatment stages.
[16] Danish Ministry of Climate, Energy and Utilities (2021): "The Government's Strategy for Power-to-X".
[17] IRENA (2020): "Green Hydrogen Cost Reduction: Scaling up electrolysers to meet the 1.5° C climate goal".
[18] The goal included in the strategy is to double the export of Danish water technology from 20 billion DKK in 2019 to 40 billion DKK in 2030. The strategy was published in 2021 by the Ministry of Foreign Affairs, the Ministry of Industry, Business and Financial Affairs, and the Ministry of Environment.

Figure 7.2 summarises the findings from the review of framework conditions: Action is needed in five areas.

Figure 7.2. Framework conditions: Five areas for improvement



Source: IRIS Group

A long-term and coherent national strategy to prioritise and unite research efforts

The fragmentation of Danish water tech research environments and the fluctuating priorities in available funding schemes, and thus research focus, call for a long-term and coherent national strategy. Despite possessing world-leading research environments and one of the world's most effective water sectors, Denmark has not been able to establish water technology as a national stronghold, in contrast to the Netherlands. As highlighted in Chapter 6, Wetsus in the Netherlands has successfully united Dutch water tech research around strategic research topics and forged close ties with end-users in the private and utility sector.

Danish water tech research environments require incentives for cross-disciplinary and cross-institutional collaboration, along with a clearer division of labor across research institutions. A national strategy, possibly incorporating a common water campus for PhD students inspired by Wetsus, could eliminate fragmentation and secure long-term commitment to prioritised national challenges.

Furthermore, a national strategy should include a review of funding mechanisms to support increased emphasis on strategic research, improve conditions for research environments to participate in development and demonstration projects, and enhance opportunities for utility companies to engage in research and development. The strategy should also outline a way to secure a solid talent base for water tech research. These issues are elaborated below.

Increased emphasis on strategic research to bridge basic research and innovation

The analysis in Chapter 3 indicates that a funding gap emerged when the Danish Council for Strategic Research was succeeded by the Innovation Fund Denmark in 2014. Although the Innovation Fund Denmark supports activities through Grand Solutions, spanning from strategic research to commercialization and implementation, most Grand Solutions, according to interviewees, are focused on activities at the higher end of the TRL scale. This leaves a funding gap for strategic research (TRL 2-4) compared to available funds for basic research (TRL 1-2) and development and demonstration projects (TRL 5-9).

Another challenge in the current funding landscape, according to interviewees, is that projects granted by the Innovation Fund Denmark and Technology Development and Demonstration Programmes tend to focus on specific technologies and products leaving little funding for systemic research and holistic exploration of the water cycle.

The lack of funds for strategic and holistic research can hinder the translation of basic research into innovative technologies and systems. Increased focus and funding for strategic water tech research could be supported by the Innovation Fund Denmark through a dedicated Innomission on water or by incorporating more water research into existing Innomissions[19]. For example, clean water for green hydrogen production could be a substantial part of the MissionGreenFuels partnership.

Incentives for research institutions to participate in development and demonstration projects
A concrete challenge evident from interviews with stakeholders in research environments and at utility companies is that conditions for research institutions to participate in development and demonstration projects are generally not attractive.

Chapter 3 showed that the Environmental Technology Development and Demonstration Programme (MUDP) is the largest public contributor to the development of water technology in Denmark. However, the analysis indicates that MUDP grants are accompanied by high criteria for own financial contributions, limiting the grant amount to 50% of the expenditures. Consequently, water tech research environments are becoming more and more reluctant to participate in MUDP projects. In a similar Danish programme supporting the development of energy technologies (EUDP) [20], research institutions are, in most cases, not considered as companies and are therefore not subject to the provisions on maximum aid intensities in the EU context. EUDP has set a maximum grant amount of 90% of the expenditures.

Unattractive conditions for water tech research environments to participate in development and demonstration activities challenge relationship building between research institutions, utilities, and private companies. Conditions for research institutions to participate in such activities could be improved by aligning funding practices between MUDP and EUDP.

Regulation supporting innovation in utility companies
Utility companies in Denmark are regulated according to a self-supporting principle, allowing companies to charge the price corresponding to necessary costs. However, the current regulation poses a barrier to investing in research and development, with efficiency requirements being a main reason for limited engagement in collaborative research and development activities by utility companies. Another reason for limited involvement in development activities is that national standards for water treatment and operation of treatment plants are not aligned with the ambition of climate neutrality in the water sector by 2030. Several interviewees argue that the ambitious climate target is not possible to reach without regulatory incentives.

Economic regulation in other countries, including the Netherlands, is less strict, allowing utility companies to charge more from consumers than the necessary costs despite the sector being a natural monopoly. Denmark also used to have an end user fee on tap water, legally enforced by "Gebyrloven" (L115 1999), which financed, among other things, large parts of the groundwater mapping conducted in Denmark between 1999-2016.

[19] Four mission-driven green partnerships called Innomissions was launched in 2021 to develop technologies and solutions for the green transition of the Danish society.
[20] Energy Technology Development and Demonstration Programme (EUDP).

Reintroducing a small research and development fee on water supply and/or treatment could be a way to enhance the opportunities for utility companies to invest in research and development.

Development of a strong talent base to power the future water sector

Researchers and stakeholders in the water sector agree that current water tech education activities are insufficient. The analysis indicates a lack of Master's education with a substantial focus on water technology. In interviews, leading researchers explain that it is difficult to attract talented PhD students. Companies and utility operators experience the same issue and express concern that recruiting in the future will be even more difficult if action is not taken.

The analysis points to two main issues: few specialised water tech education courses, and poor funding options for PhD positions. A collaborative approach towards education activities could help build better and more focused water tech courses, drawing on expertise from several research environments. A joint water campus with earmarked PhD funding could educate interdisciplinary PhD students with a comprehensive understanding of the entire water cycle.

A national water tech research strategy should cover all the above aspects.

Inspection of potable water samples

Photo by VIA University College

Appendices

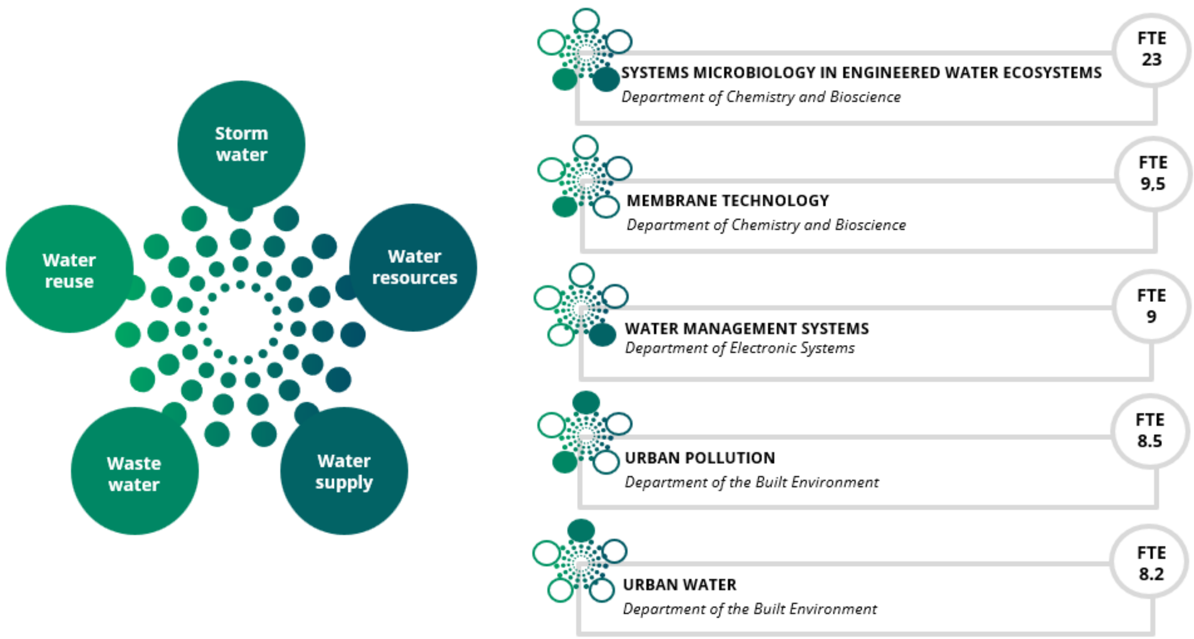
Appendix 1: Danish water tech research environments in details

The following pages contain short descriptions of each of the 17 research environments in Denmark focusing on water tech research (as defined in Chapter 1). All descriptions are organised by institution, and each section begins with a presentation of the institution and how water tech research is organised within it. A figure provides an initial overview of the research environments at each institution, showing the number of Full-Time Equivalent (FTE) researchers and specifying the part(s) of the water cycle that are the focus of their research.

A. Aalborg University (AAU)

At AAU, five research environments across three departments are engaged in water tech research. The number of researchers in the field of water technology has increased over the past five years, and in 2023, the university has nearly 60 FTE researchers within the field.

Water tech research activities at AAU cover a variety of topics related to most parts of the water cycle. Activities span from basic research in microbiology focusing on mapping microorganisms in water systems to applied research on wastewater process engineering and the impact of climate change on water systems in cities.



Systems microbiology in engineered water ecosystems

The research group is embedded at the Center for Microbial Communities and focuses on mapping the ecophysiology and function of different microogranisms in water systems. The research activities have several main research areas:

- Identification, classification, and ecology of microorganisms in engineered ecosystems of activated sludge plants, anaerobic digesters, and related wastewater treatment systems. The researchers apply advanced DNA sequencing, microscopy, and Raman microspectroscopy to identify and describe the various bacteria and their function. The research group is world-leading in the field microbial ecology of wastewater treatment and resource recovery systems. They host the public website "MiDASfieldguide" as an authorative resource in the field.
- Development of models for determining the factors that influence the bacterial composition in water systems, as well as modeling and predicting the future bacterial composition.
- Pioneering novel methodologies and understanding to extract valuable extracellular polymeric substances produced by bacteria in wastewater treatment plants, transforming biosolids into versatile biopolymers applicable in various fields such as biomaterials, bioplastics, and construction materials.
- They are responsible for the development of a map of all microbes in natural and urban habitats across Denmark (Microflora Danica), which also includes all water bodies from groundwater, drinking water, sewers, wastewater treatment plants, streams, lakes to coastal areas.

While primarily engaged in fundamental research to enhance comprehension of microorganisms in water systems and their interactions, the insights garnered from their research have already led to societal impact. The group collaborates extensively with sewage treatment plants in Denmark and abroad, actively monitoring and measuring microbial communities for trouble shooting and informed optimization of the purification process and the recovery of nutrients and energy.

Moreover, the group actively participates in collaborative ventures with utility and consultancy companies, focusing on various aspects of the microbiology in resource recovery, bioenergy, and ensuring clean water.

Facts

No. of FTE-researchers (water technology): 23

Funding sources: Basic funding (5%); public funds (10%); private funds (80%); EU (5%); other international sources (0%)

Membrane technology

The membrane technology group is part of the Center for Membrane Technology located at the Department of Chemistry and Bioscience. The group focusing on membranes for water treatment makes up approximately 2/3 of the center in terms of FTE-researchers.

The group's main research activities include:

- Mechanical and chemical separation processes, e.g., for the removal of micropollutants.
- Management and monitoring of functional membranes to avoid clogging.
- Novel membrane technologies, e.g., membrane crystallisation.
- Novel materials to replace petrochemical polymer in membranes.

Research activities range from low to high TRL projects, and the group is engaged in both basic research and support of spinouts.

Facts

No. of FTE-researchers (water technology): 9.5

Funding sources: Basic funding (7%); public funds (29%); private funds (50%); EU (14%); other international sources (0%)

Water management systems

The research group Learning and Decision at Aalborg University's section of Automation & Control carries out research with the overall aim of developing new IT-based methods to improve water management systems. The group has extensive knowledge within advanced mathematical modelling and the development of algoritims for IT-based systems. The research group is among the world's leading enviroments within the field of developing and testing advanced digital water systems. The research activities cover several areas related to water management systems:

- One focal area is pressure management in the water system and the development of smart water systems. Their aim is to devise advanced IT systems empowering pumps in water distribution networks to autonomously regulate water pressure, ensuring consistent pressure levels irrespective of consumption fluctuations.
- Another key area involves the detection of leaks in the water infrastructure. The group formulates sophisticated models and algorithms for managing water pressure in distribution systems, utilizing sensors measuring pressure and flow to pinpoint leaks,

The group has developed mathematical models and a simulation environment for the water infrastructure. The group has established a laboratory environment for testing control solutions for water infrastructre in realistic and physical experiments, which allows the researchers to verify the theoretical solutions.

The group is practice-oriented and aims to develop new control systems that can be used by utility companies to reduce energy consumption and mitigate the impact of leakages. With the Smart Water Infrastruce Lab (described in detail in the following section), the research group has the unique opportunity to test their theoretical models and algorithms in a real-world realistic environment.

Facts

No. of FTE-researchers (water technology): 9

Funding sources: Basic funding (10%); public funds (30%); private funds (60%); EU (0%); other international sources (0%)

Urban Pollution Research Group

The Urban Pollution group is world-leading within wastewater process engineering. The group has deep knowledge of the design and operation of sewer systems and technologies for the prediction, identification, and management of hydrogen sulphide, odors, asset corrision, and water quality.

The systems approach by the group has led to the development of predictive models that are used all over the world to forecasty maintenance, predict asset life, find and optimize solutions to odor and corrosion, dynamic interactions between sewers and treatment plants, and lately also implementing sewer process models as digitil twins for integrated system management.

The second focal area of the group is the quality of stormwater from cities and highways, with a focus on the full spectrum of treatment approaches, ranging from high-tech solutions to nature-based ones. The research encompasses the design of stormwater solutions for whole cities and highway systems, the ecosystem services and recreational services they can give in addition to water treatment, and the development of technologies for advanced chemical and biological treatment of stormwater to meet the latest demands for receiving water quality.

Finally, the identification and treatment of xenobiotics (such as PFAS, heavy metals, and other environmentally hazardous substances) in water systems has become a major research area in the last few years. Today, all PhD positions in the group are committed to one of the above-described research areas.

Facts

No. of FTE-researchers (water technology): 8.5

Funding sources: Basic funding (5%); public funds (20%); private funds (50%); EU (20%); other international sources (5%)

Urban Water Research Group

The Urban Water Research Group at Aalborg University focuses on the impact of climate change on technical water systems in cities. The research group utilises precise weather data to develop models that can predict the stress level on the city's sewage systems in real-time.

They are among the world leaders in their field and conduct cutting-edge research on the combination of fluid dynamics, mathematical models, and machine learning to better manage urban water systems. The research activities have three focal areas:

- Modelling of the technical water systems for better design and management of the systems in real-time. By combining prediction models with digital technologies, the group aims to measure, control, and regulate water intelligently to better control water flow and prevent the number and extent of floods. This improves the effectiveness of existing water infrastructure to mitigate climate change.
- Development of better methods for predicting short-term weather using weather radar and weather models. The research group is a leader in weather radar measurements of rainfall and weather radar nowcasting.
- Measurement of precipitation and water transport through the city's hydrological cycle. The research group utilises a dense-meshed network of urban IoT sensors that can measure the microclimate in the city. The research focus is on both the transport of water discharged and the associated water quality.

The research conducted is very practice-oriented and participates in a variety of collaborative research projects with industries, consulting engineering companies, as well as utilities. The research group has a strong history of collaboration with rainwater and sewage treatment facilities on how to use their prediction models to improve the operations of the facilities in real-time.

The group has also fostered spin-off companies. One example is Dryp A/S, which develops state-of-the-art sensors that can provide real-time data on the quantity and quality of water flowing in the water systems. The group has also developed prediction software that helps prevent pollution from oil extraction around the world.

Facts

No. of FTE-researchers (water technology): 8.2

Funding sources: Basic funding (5%); public funds (55%); private funds (20%); EU (20%); other international sources (0%)

Lab facilities at AAU

Smart Water Infrastructures Laboratory

The smart water infrastructure laboratory is a research facility that enables experimental research in the control and management of water infrastructures in a realistic environment. The laboratory is designed as a modular system that can be configured to emulate Water Distribution Networks, Wastewater Collection, or District Heating Systems. Research activities include infrastructures for water supply, wastewater transport, and leakage identification.

Main applications: This laboratory aims to address problems in the water cycle management with a focus on how control technology can contribute to providing solutions. The lab modularity makes it possible to perform realistic experiments where different network topologies are reproduced, and multiple scenarios are emulated, such as water leakage, transport delays, sewer overflow, stochastic disturbances, or cyberattacks. The test-beds make it possible to test fault detection algorithms, leakage detection, and cyber-robust algorithms in a safe environment.

Types of equipment (examples): The infrastructures considered in the lab comprise water distribution networks, wastewater networks, and district heating and cooling systems. The laboratory is modular, consisting of different moveable blocks with various functionalities, creating the possibility of building miniature infrastructures and testing real-life challenges that cannot be tested in real life. The test-beds are equipped with local data acquisition systems and a central control unit. The flexibility in the control architecture creates a suitable framework for both centralised (SCADA) and decentralised/distributed control strategies.

High-Performance Computing

The research groups at Aalborg University have access to high-performance computing systems that enable them to perform computationally demanding tasks beyond the capability of traditional computing systems. High-performance computing is used to process and analyse large, complex datasets, perform simulations, and run resource-intensive applications.

Access to the high-performance computing system allows the researchers to compute advanced models and algorithms. The applications vary from simulating fluid dynamics to the development of advanced algorithms for optimising pressure in the water system.

The high-performance computing systems consist of a large number of very fast computers tied together in a fast network, which is hosted by the Danish e-Infrastructure Cooperation (DeiC), and access is shared among the Danish universities.

Biological and analytical chemistry laboratories

The research group at the Centre for Microbial Communities has access to labs equipped with a variety of machines and equipment, enabling the group to carry out state-of-the-art chemical and microbiological analyses.

Within the microbiological laboratories, researchers can identify and characterise microorganisms present in any sample, including water. The facility is also outfitted with advanced equipment for microbial whole-genome sequencing, enabling the mapping of novel organisms and their functions while allowing for genome comparisons across diverse samples. There is also access to advanced microscopy, including confocal laser microscopy for visualisation and Raman microspectroscopy for functional analyses. The infrastructure within these fields is state-of-the-art.

Main applications: Analyses of microorganisms based on DNA, RNA, and protein analyses, Bacterial whole-genome sequencing.

Types of equipment (examples): Broad variety of equipment for chemical and microbiological analyses (such as mass spectrometers, nuclear magnetic resonance spectroscopy, high-performance liquid chromatography, microscopes, genome sequencing).

Membrane lab

Main applications: Testing, analysis, and characterisation of membranes.

Types of equipment (examples): The Centre for Membrane Technology has access to a great range of filtration equipment and analytical equipment.

Filtration equipment includes microfiltration and ultrafiltration systems for both polymer and ceramic membranes, nanofiltration systems, a forward osmosis setup, and a membrane distillation pilot system.

Analytical equipment includes tools for the analysis of untreated and treated water samples, as well as tools for membrane coating.

Urban Water Research Group

The Urban Water Research Group at Aalborg University has access to a variety of infrastructure. The research group has established a hydrology lab where researchers can study the behaviour of water in various conditions, measure flow rates, and develop models to understand and predict water-related phenomena such as rainfall patterns and surface water flow.

In addition, the research group has established a computer cluster used to process weather data and perform advanced calculations. The very large and complex datasets mean that the calculations and model developments are extensive, thus requiring access to supercomputers.

Moreover, the Urban Water Research Group manages two weather radars presently and is in the process of establishing a third. The group utilises data from the weather radars to study urban hydrology, climate change impacts, resilience of urban areas to hydrological extremes, and develop online prediction/warning systems.

Urban Pollution Research Group

The Urban Pollution Research Group has access to a laboratory equipped with state-of-the-art analytical equipment, enabling complex chemical and biological analysis of materials and substances relevant to the research focus of the group.

Within this facility, a range of top-end analytical machines is available, including μRaman, micro–Fourier Transform Infrared spectroscopy, Atomic Force Microscopy, Gas Chromatography Mass Spectrometry, Inductive Coupled Plasma Mass Spectrometry, High-Performance Liquid Chromatography, Ion chromatography, and other advanced equipment. This enables diverse material examination, quantification of chemical substances, and the study of dynamic systems at lab scale, pilot scale, and in the field.

Primary applications encompass chemical and biological analysis of substances, detection of anthropogenic substances in water samples, investigation into material degradation of metals, concrete, and plastics, and the assessment of the behaviour of biofilms and dissolved biomass under diverse conditions. The studies are conducted in a system context, such as how biofilms in water systems protect or attack plastic surfaces, or the formation and fate of hydrogen sulfide.

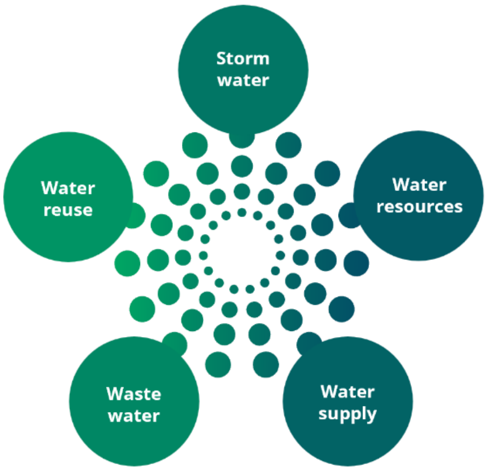
B. Aarhus University (AU)

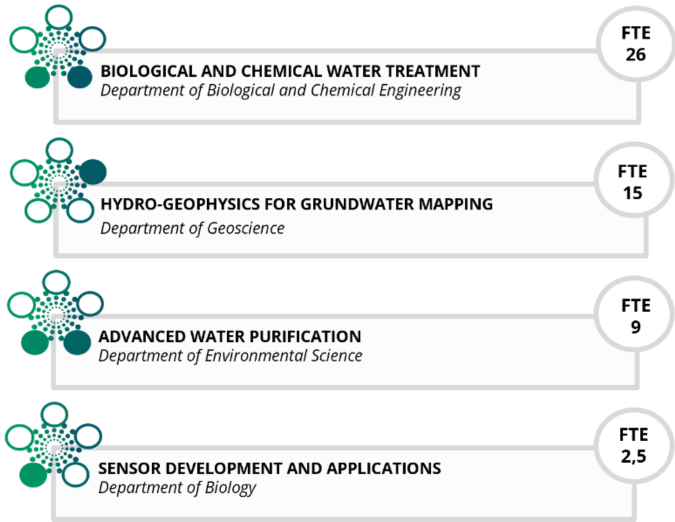
Four departments at Aarhus University (AU) have research groups that focus on water technologies related to the water cycle – specifically, water resources, water supply, and wastewater.

Since 2017, water technology research at AU has been organised around the interdisciplinary Centre for Water Technology (WATEC), which, in addition to the four groups covered in this analysis, also includes research environments focusing on surface water management and constructed wetland treatment technologies.

WATEC is structured to encourage collaboration and synergy across departments, mirroring the university's commitment to multidisciplinary approaches. WATEC aims to develop sustainable water management and technology, contribute to graduate and postgraduate education, and facilitate research at the highest level for the benefit of society and industry.

Except for the Hydro-Geophysics Group, which has been mapping water resources since the 1990s, the water technology research groups at AU are relatively young compared to water technology environments at other Danish universities. In the past ten years, the number of researchers focusing on water technologies for the piped water system has increased significantly.





Biological and chemical water treatment

The research group is located at the Department of Biological and Chemical Engineering and focuses on the chemical and biological treatment of water. The research activities cover water quality, potable water treatment, as well as wastewater treatment.

The research activities are organised into three research groups:

- Resource extraction from wastewater with a focus on new technologies enabling the recovery and valorisation of extracellular polymeric substances from microbial biomasses. The group also focuses on microbial bio-interfaces in biofilms and new strategies to control biofilm growth.
- Advanced biochemical water treatment processes to produce clean water and microbial technologies to remove micropollutants such as pharmaceuticals and biocides. The research group also develops and tests advanced bioanalytical methods to accurately measure toxicants in water.
- Novel chemical approaches for the degradation of environmentally hazardous substances in water with a focus on PFAS removal and degradation. One approach is by developing new biochar-based photocatalytic material that can accelerate the degradation of PFAS.

The research group is part of Aarhus University Centre for Water Technology (WATEC), which works with municipal wastewater treatment, process control, as well as water management. The research group has extensive collaborations with private companies, utilities, as well as other research institutions.

Facts

No. of FTE-researchers (water technology): 26

Funding sources: Basic funding (5%); public funds (36%); private funds (35%); EU (26%); other international sources (15%)

Hydro-Geophysics for grundwater mapping

The Hydro-Geophysics Group at the Department of Geoscience carries out high-level research with the overall aim of developing methods for knowledge-based mapping of the subsurface and modeling water resources.

The group is highly practice-oriented. A key research focus has evolved around geophysical investigations of the subsurface, where large areas are mapped for groundwater resources using helicopters or towed instruments at the surface.

Research activities combine geophysical instrument development with advanced data processing and inversion algorithms and hydrological modeling. The key geophysical methods are airborne and ground-based transient electromagnetic (TEM), induced polarisation and DC, and nuclear magnetic resonance sounding.

The group was established in the 1990s by request from Aarhus Amt (a former regional administrative body), and from 1999-2016 was largely financed through an end-user fee on tap water legally enforced by the "Gebyrloven" (L115 1999).

Today, the Hydro-Geophysics Group at AU is world-leading. The unique strength is that the group covers the entire geophysical value chain. The group builds its own instruments, develops software, and designs interfaces that present mapping results in a user-friendly way. Methods and tools developed by the Hydro-Geophysics Group are requested all over the world. Thus, instruments are designed for non-scientific staff to handle.

The group has fostered several spin-off companies. The largest one is SkyTEM Surveys ApS, which is one of the major players in airborne electromagnetics. SkyTEM and the Hydro-Geophysics Group are currently developing the next generation equipment called SuperTEM, supported by a large grant from the Innovation Fund Denmark.

Facts

No. of FTE-researchers (water technology): 15

Funding sources: Basic funding (25%); public funds (30%); private funds (20%); EU (10%); other international sources (15%)

Advanced water purification

The research group for advanced water purification is situated at the Department of Environmental Science (Roskilde Campus) and is dedicated to water purification, primarily focusing on wastewater but also extending to drinking water.

Technically, the group specialises in the removal of organic micropollutants, including pharmaceuticals, personal care compounds, biocides, flame retardants, and more, from water. All technologies with the potential to eliminate micropollutants (biological, sorptive (GAC), and reactive (ozone)) are of interest to the group, with a particular emphasis on biofilm technologies. These technologies aim to degrade and metabolise organic micropollutants using reactors of various formats.

Facts

No. of FTE-researchers (water technology): 9

Funding sources: Basic funding (0%); public funds (30%); private funds (0%); EU (60%); other international sources (10%)

Sensor development and applications

The sensor group at the Department of Biology develops advanced sensing tools for measuring biological and chemical substances in water. Historically, the group has developed and applied sensor technology in surface water and wetlands. Today, approximately one-third of the research (around 2.5 FTE) focuses on sensor applications for the piped water system.

Two main sensor technologies are in focus:

- Optical sensors for multiple analytes, including O2, pH, temperature, several ions, etc. Optical sensors can make chemical conditions visible in 2D.
- Electrochemical micro-sensors for the detection of dissolved gas or other molecules. Electrochemical sensor signals are generated based on the oxidation/reduction of the target molecule in the electrode.

A third but minor research area is biosensors.

Most of the sensors developed by the group are used for the analysis of wastewater. A unique position, relative to other labs around the world, is that the group develops sensors to be functional in complex natural environments such as wastewater treatment plants.

Facts

No. of FTE-researchers (water technology): 2.5

Funding sources: Basic funding (5%); public funds (38%); private funds (57%); EU (0%); other international sources (0%)

Lab facilities at AU

Laboratories at the Department of Biological and Chemical Engineering

The researchers at the Department of Biological and Chemical Engineering have access to several laboratories equipped with a diverse range of cutting-edge machinery enabling the research group to conduct an extensive array of analyses, primarily focusing on chemical and biological detection in water samples.

Main applications encompass chemical and biological detection and analysis of substances in water samples, such as micro-pollutants, pesticides, analysing compounds, determining structures, and identifying substances in water samples, and analysis of biofilms. Chemical analyses of microorganisms in water, as well as DNA and protein-based analysis.

Types of equipment (examples): Various equipment for chemical and biological analysis, such as targeted and non-targeted mass spectrometers, nuclear magnetic resonance spectroscopy, etc.

Moreover, the research group has access to the WATEC Sensor Laboratory, housing cutting-edge micro-sensors designed for detecting dissolved gases and various molecules. These state-of-the-art sensors are primarily employed for wastewater analysis, enabling remarkably precise measurements and analytical profiling.

The primary applications include the detection of contaminants like heavy metals, organic compounds, and toxic substances, as well as facilitating biological process control. We conduct online, real-time analyses of substances such as NO3, H2S, O2, NH4, N2O, and CO2, or phosphate levels, optimising biological processes for enhanced efficiency.

The laboratory's equipment comprises an array of specialised tools, including electrochemical micro-sensors like CO2 sensors, NO2 biosensors, and VFA sensors. Additionally, optical sensors, fiber-based sensors, planar sensor foils, and particle-based sensors contribute to our comprehensive analytical capabilities.

Water purification lab at Roskilde Campus

Main applications: Measuring organic micro-pollutants in water.

Types of equipment (examples): High-resolution mass spectrometry for structural elucidation, metabolomics, and non-target studies. 2 HPLC-MS/MS for quantifying trace amounts of organic micropollutants, especially pharmaceuticals, biocides, pesticides, etc. Various infrastructure to study new water treatment technologies such as moving bed biofilm reactors, porous medium biofilm reactors (biofilters), ozonation, granulated activated carbon, and sludge reactors.

Instruments for groundwater mapping

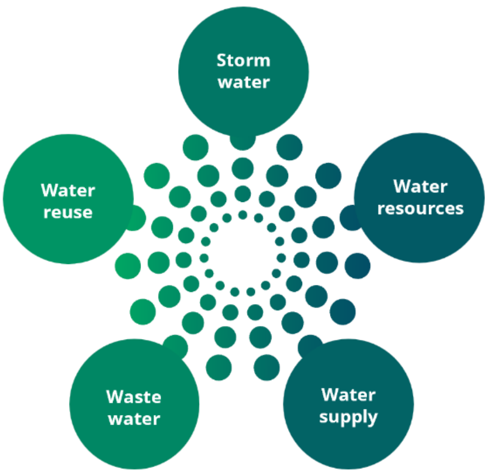
Main applications: Mapping of the subsurface and modelling of groundwater water resources.

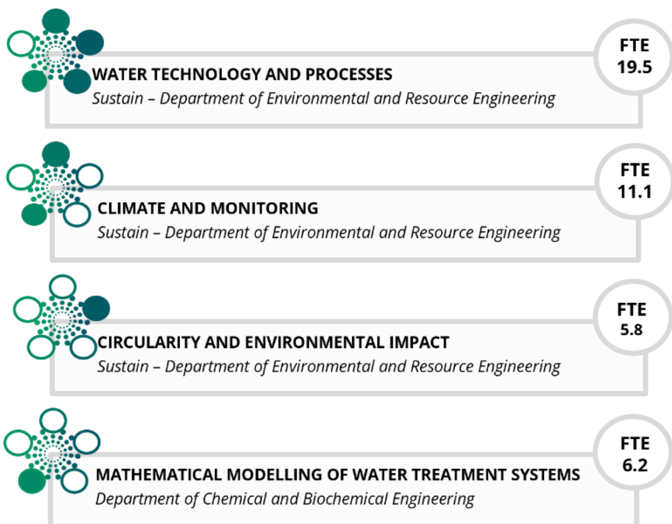
Types of equipment (examples): Magnetometers, ground-based transient electromagnetics (TEM), airborne electromagnetics (SkyTEM), induced polarization (IP), and magnetic resonance sounding (MRS) / surface nuclear magnetic resonance (NMR). Some of these instruments are the results of in-house research and development, while others are off-the-shelf geophysical instruments. In addition to physical instruments, the group has specialised software for processing electrical and electromagnetic geophysical data.

C. Technical University of Denmark (DTU)

Most research in water technology at DTU is concentrated at DTU Sustain, where three out of seven sections focus on theoretical, as well as experimental and computational research within topics related to the water cycle, and several of the other sections also carry out some water-related research (e.g. sanitation in the arctics, P-recovery from wastewater sludge, and life cycle assessment of technological systems).

The research in the three sections is mostly multidisciplinary, and many activities involve researchers from more than one of the sections, as well as colleagues from other departments, especially DTU Compute, DTU Aqua, DTU Space, and DTU Chemical Engineering.





Water Technology and Processes

The section focuses on the treatment of water and residual streams in urban and industrial settings. Processes and technologies are considered in different parts of the water cycle, including source water, potable water, residual water, drainage water, and stormwater. The main aim of the section is to contribute to the transition to greener and more circular solutions in the water sector.

The research in the section is structured around four main areas:

- Micro-pollutant removal processes, including management and treatment technologies for organic micropollutants in source waters, wastewaters, and in water supply (i.e. pesticides and PFAS).
- Development of membranes and advanced materials for membranes, including catalysis aiming at increasing the effectiveness of membranes through the use of enzymes. The research also focuses on microbial electrochemistry, which enables the transition of microorganisms to new proteins such as amino acids.
- Microbial technology, including biological transformation of pollutants and biofilms and bio-aggregates for water treatment.
- Urban water, including distribution and collection systems, monitoring and control system analysis, as well as modelling and digitalisation of water systems. The research also encompasses the issue of how materials in the distribution system (such as plastic and substances used for the removal of micropollutants) affect water quality.

Facts

No. of FTE-researchers (water technology): 19.5

Sources of funding: Basic funding (10%); public funds (57%); private funds (19%); EU (12%); other international sources (2%)

Climate and Monitoring

The research in the section covers various aspects of climate change and its impacts on water-related issues. Two of the three distinct research groups in the section have a specific focus on water technology, namely 1) Water management on urban and catchment scales and 2) Monitoring of greenhouse gas (GHG) fluxes, impacts, and mitigation.

The first group has a strong track record in research into the design and modelling of sewage systems. Historically, the research at DTU has had a significant impact on the planning and design of sewerage in Denmark through the translation of system research into policy, as well as practical guidelines sanctioned by the Danish Engineering Society and used by utilities and consultants in the sector. Today, key aspects of the research include utilising and further developing new data sources, as well as using AI and digital technologies (such as digital twins), to develop new solutions that can be used for monitoring and forecasting the impacts of extreme weather phenomena on sewage systems in cities (in cooperation with the Danish Meteorological Institute). The group also investigates how cities can redesign water infrastructure to deal with both extreme weather and sustainability goals, considering both nature-based solutions and real-time control. Finally, the group conducts leading research (in collaboration with DTU Space) in the development of remote sensing and drone technologies used for monitoring, e.g., leakages and water levels.

The second group carries out leading research in methods and technologies (e.g., sensor systems) used for the quantification and measurement of GHG emissions, as well as technologies that can be used to avoid GHG emissions at the level of both technical systems and cities. The group has a strong focus on modelling GHG emissions, which, together with the data collected from sensor-based measurement systems, can be used to quantify the effectiveness of mitigation measures used at the level of wastewater treatment plants and urban water systems on a broader scale. Moreover, the research aims to develop systems that can be used for monitoring GHG emissions at a national scale based on tall-tower flux measurements at the landscape and urban scales.

Facts

No. of FTE-researchers (water technology): 11.1

Sources of funding: Basic funding (10%); public funds (57%); private funds (19%); EU (12%); other international sources (2%)

Circularity and Environmental Impact

The section aims to provide solutions to environmental and societal challenges related to circularity, chemicals, and water quality. Concerning research into water cycle issues, the main research areas are:

- Risk mitigation of groundwater and surface water contamination – covering the investigation, quantification, and assessment of key natural and anthropogenic processes affecting surface water and groundwater quality through laboratory, field, and modelling studies at various scales. The research also covers remediation technologies.
- Identification, quantification, environmental impact, and solutions concerning chemicals, such as micro-/nanoplastics, in the water environment.
- Implications of micro-pollutants (such as PFAS) and chemicals for regulation and consumer safety.

The section holds an internationally unique combination of in-depth theoretical and experimental process understanding, advanced technology assessment tools, and insights into societal and regulatory challenges. It combines detailed lab- and field-based experimental approaches at the fundamental level with process modelling and system-level assessment. The section contributes to new legislation, guidelines for testing water contamination, tools for risk assessment, as well as technologies for remedial actions.

Facts

No. of FTE-researchers (water technology): 5.8

Sources of funding: Basic funding (10%); public funds (57%); private funds (19%); EU (12%); other international sources (2%)

Mathematical modelling of water treatment systems

The Process and Systems Engineering Center (PROSYS) at the Department of Chemical and Biochemical Engineering specialises in mathematical modelling and computer simulation in relation to water treatment and resource recovery systems.

The group develops and assembles mathematical tools to assess and predict the impact of various changes at municipal and industrial treatment plants, including:

- Altered operating procedures
- Effect of varying sludge management strategies
- Occurrence and fate of new substances in the water (e.g. micropollutants)
- Feasibility assessment of novel processes, for example, related to the removal of emerging contaminants (e.g. N_2O)

The group develops its own software, mainly on a Matlab-Simulink platform. Models are shared via an online platform in collaboration between PROSYS at DTU and the IEA division at Lund University to altruistically distribute water models developed in research projects.

Facts

No. of FTE-researchers (water technology): 6

Sources of funding: Basic funding (10%); public funds (90%); private funds (0%); EU (0%); other international sources (0%)

Lab facilities at DTU

DTU Sustain

DTU Sustain houses a multitude of general and specialised environmental laboratories, with some of them located in a new laboratory building that opened in 2023. The general lab is equipped with a broad range of machinery, equipment, and clean rooms that enable a very broad range of environmental analyses, including the identification of substances such as micropollutants, including pesticides and pharmaceuticals, at all environmentally relevant concentrations. The environmental analytical laboratory houses a wide range of instruments, including continuous flow analysers (CFA) for nutrients, conventional and single-particle ICP-MS systems for metals, two LC-MS/MS systems for polar chemicals and PFAS, several GC-MS systems, including a high-end autosampler coupled to GC-QQQ, as well as CRDS instrumentation for gaseous flux and emission quantification.

Moreover, the department has several more specialised labs for chemical analyses, the design and production of membranes, and the measurement of greenhouse gases, including a mobile analytical lab that is used in the field to measure atmospheric levels of methane and nitrous oxide emissions and quantify emission rates, respectively.

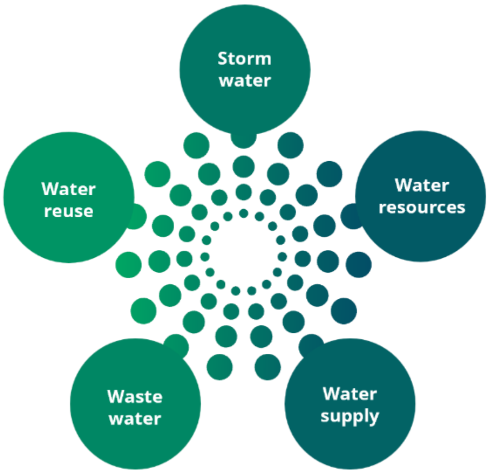
Main applications: Chemical analyses of micro-pollutants, risk assessment, development of new membranes, testing of membranes/filters in wastewater processes, detection of micro-/nanoplastics in water samples, monitoring of greenhouse gas emissions.

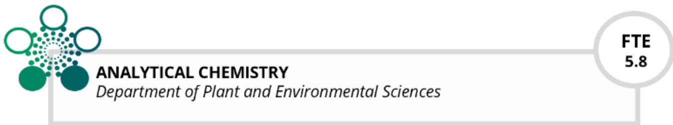
Types of equipment (examples): General equipment for chemical and microbiological analyses (such as spectrometers and plate readers); electrospinning machines for the fabrication of membranes in pilot scale; reactors for the investigation of biochemical processes related to different water types, from drinking water to wastewater; sensor systems, tall towers, and a mobile lab for measurements of greenhouse gases at the local level; drones designed for monitoring, e.g., water levels or contaminant plumes.

DTU Sustain also hosts computing servers to support data analysis and model simulations with licensed software. On a central level, DTU Sustain also taps into the cluster computing facilities at the DTU Computing Center (DCC).

D. University of Copenhagen (KU)

The University of Copenhagen is home to world-leading environmental research. However, many water-related research areas at the university fall outside the scope of this analysis (e.g., surface water, percolation issues, nature-based solutions, etc.). Nevertheless, one research environment is highly relevant to the piped water system: Analytical Chemistry at the Department of Plant and Environmental Sciences.





Analytical Chemistry

The Analytical Chemistry group at the Department of Plant and Environmental Sciences conducts fundamental research in advanced analytical chemistry and signal processing. They develop novel analytical platforms and strategies for automated signal processing, such as workflows for suspect- and non-target screening analysis of any sample matrix but with a focus on environmental samples such as ground-, drinking-, surface-, and wastewater.

From 2016-2020, much research activity within environmental monitoring focused on the chemical impact assessment of soil and sediment contamination, driven by a large Innovation Fund Denmark (IFD) project called GANDALF. Since 2019, VANDALF and recently other projects such as the IFD project AquaPlexus and the EU projects D4RunOFF and PARC have built on the work of GANDALF but with a specific focus on water.

In VANDALF, the approach is to link technology-specific but otherwise unbiased and non-targeted chemical detections (chemical fingerprints) with sets of relevant toxicological endpoints (toxicological fingerprints) to identify which chemicals or groups of chemicals can explain the toxicity. The overall vision is to develop and implement flexible and dynamic effect-based tools to identify the chemicals causing 95-99% of toxicity in effluent water. In AquaPlexus, D4RunOff, and PARC, as well as smaller projects with Danish and international water utilities, the focus is on chemical fingerprinting analysis of surface and drinking water to better understand pollution sources and the effects of remediation strategies on the chemical fingerprint.

Facts

No. of FTE-researchers (water technology): 5.8

Funding sources: Basic funding (10%); public funds (50%); private funds (25%); EU (15%); other international sources (0%)

Lab facilities at KU

Research Center for Advanced Analytical Chemistry

The Faculty of SCIENCE houses a research centre for Advanced Analytical Chemistry. The centre combines advanced analytical chemistry, signal processing, and statistical modelling into chemical fingerprinting and metabolomics. The main applications include research in state-of-the-art analytical methods and the development of protocols for the analysis of complex mixtures of compounds (chemical fingerprinting). The centre has recently received funding to build a centre for effect-directed analyses, where a heavy upgrade on the analytical facilities has been made, and a new investment in automated toxicological test systems.

Types of equipment (examples): Analytical platforms include liquid-, supercritical- and gas chromatography methods often hyphenated to high-resolution mass spectrometry detection (HRMS). A large focus of the group is ultra-high-performance separations using multi-dimensional gas and liquid chromatography with mass spectrometry and ion mobility spectroscopy detection. A semi-automated system for high-throughput effect-directed analysis is currently being set up, financed by an NNF infrastructure grant (Contaminomics).

E. University of Southern Denmark (SDU)

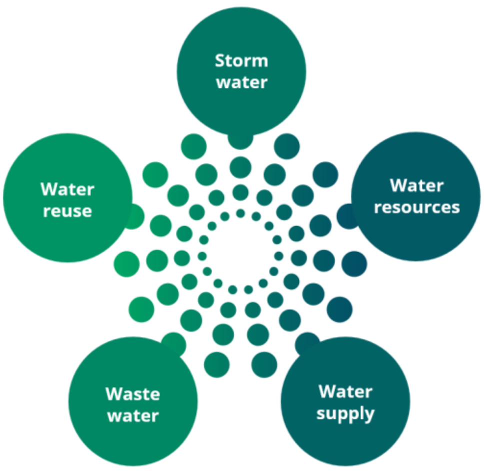
The University of Southern Denmark (SDU) conducts research within the water and wastewater domain, focusing on water quality, sustainability, and monitoring systems. SDU does not host sections or research groups with water technology as the main domain. However, several SDU researchers at the Faculty of Engineering and the Faculty of Science possess deep knowledge in research and technology relevant to water tech solutions, with approximately 25 researchers (corresponding to 7-8 FTE) currently engaged in water tech research and projects.

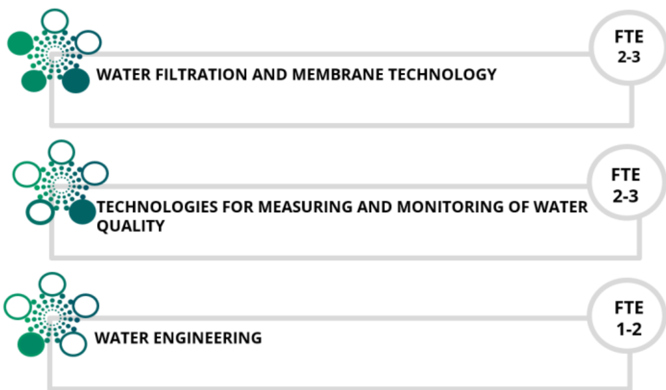
Moreover, the field has gained momentum at SDU after a period of decline. SDU collaborates with a number of utilities in the Region of Southern Denmark and is also involved in many international projects.

Research within water tech primarily takes place at five institutes: Department of Green Technology; Mads Clausen Institute; Department of Mechanical and Electrical Engineering; Department of Biology; Department of Physics.

The research can be grouped into three broad themes:

- Water filtration and membrane technology.
- Technologies for measuring and monitoring of water quality.
- Water system engineering and modelling.





Water filtration and membrane technology

A relatively high share of SDU's water tech research focuses on water treatment technologies, including the development of advanced materials and processes for water purification, waste reduction, the reuse of wastewater, and the conversion of waste. The most prominent area of research is the development of membrane technologies, spanning from the nano to the macroscale, with a focus on enhancing efficiency in wastewater treatment, irrigation, and potable water production.

The research at SDU encompasses the following areas:

- Membrane technologies for wastewater, irrigation water, and drinking water (including facilities for testing and development of membrane technologies in pilot scale).
- Water cleaning technologies such as photocatalysis and sonochemistry, aiming to decompose pollutants without the addition of chemicals.
- New materials for water filters, including tetrapods, and the development of membranes for selective contaminant removal.
- Water and sludge treatment, involving the use of membrane technologies to remove a wide range of contaminants from various water sources.
- Innovative wastewater and sludge treatment strategies, including the reuse of industrial wastewater and the conversion of waste and sludge into energy and valuable resources.

Facts

No. of FTE-researchers (water technology): 2-3

Funding sources: Basic funding (5%); public funds (70%); private funds (15%); EU (10%); other international sources (0%)

Technologies for measuring and monitoring of water quality

SDU possess expertise in sensor technology and has developed comprehensive systems for online monitoring and detection of micro-pollutants and harmful chemicals in potable water in real-time. SDU is also involved in developing sensors for sewerage systems and measuring GHG-emissions at purifiers.

At the lab level, SDU has cultivated expertise in the precise measurement of environmentally harmful substances, specializing in xenobiotics detection in water and sludge using advanced analytical methods. SDU has also devised techniques for detecting and quantifying nutrients, pathogens, xenobiotics, organic and inorganic compounds, as well as micro- and nanoplastics in drinking water.

Finally, SDU engages in interdisciplinary research within aquatic biology and chemistry to comprehend the composition of wastewater and process water, aiming to develop insights into nutrient dynamics and continiminant behavior.

Facts

No. of FTE-researchers (water technology): 2-3

Funding sources: Basic funding (5%); public funds (70%); private funds (15%); EU (10%); other international sources (0%)

Water engineering

The last research area encompasses the design and modelling of water systems. Key themes include:

- Computer models for the design and optimization of sewerage systems, considering current needs and future climate scenarios.
- Models for material flows in urban environments, including greenhouse gas emissions from wastewater treatment facilities.
- Designing resilient and sustainable urban water systems, including everything from the dimensioning and material choice for sewer systems to their construction and maintenance.
- Sustainable sewer systems that prioritize the minimization of environmental impact while maximizing cleaning efficiency.

Facts

No. of FTE-researchers (water technology): 1-2

Funding sources: Basic funding (5%); public funds (70%); private funds (15%); EU (10%); other international sources (0%)

Lab facilities at SDU

Smart Water Infrastructures Laboratory

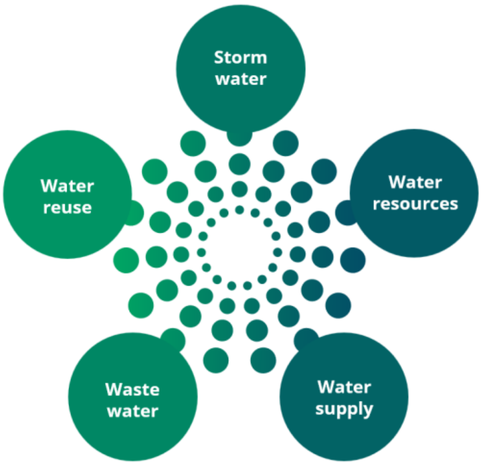
There are no specific water technology labs at SDU, but the university hosts a number of advanced research facilities that are used for water technology research.

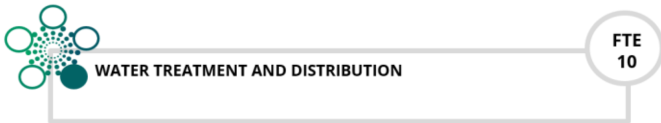
Main applications: High-quality and accurate chemical and physical analysis. Characterisation and verification of sensing solutions (upcoming). State-of-the-art imaging of material, structural, biological, and chemical characteristics. Sample preparation and clean-up for qualitative, as well as quantitative analyses of diverse water sample types. Prototyping and fabrication of portable water solutions.

Types of equipment/facilities (examples): Danish Molecular Biomedical Imaging Center (DAMBIC); Center for Materials Analysis and Characterisation (C:MAC); new national infrastructure (NANOCHEM) for chemical imaging and sensing solutions (upcoming); chemistry laboratories including facilities such as gas chromatography–mass spectrometry (GC–MS), liquid chromatography-triple quadrupole mass spectrometry (LC-TQ-MS), liquid chromatography-time-of-flight mass spectrometry (LC-QToF-MS), atomic absorption spectroscopy (AAS), Fourier-transform infrared spectroscopy (FTIR), and Raman spectroscope; tools/equipment for nano and micro fabrication of membranes.

F. VIA University College

VIA University College is one of six university colleges in Denmark, located in Jutland and consisting of a total of eight campuses. The research at VIA focuses on healthcare, technology, business, and design. At the Horsens Campus, VIA has established a Research Centre for Built Environment, Climate, Water Technology, and Digitalisation. The centre carries out applied research with the aim of developing sustainable solutions to environmental and climate challenges in partnerships with companies, authorities, and utilities. One of the four research groups is specialized in water technology.





Water Treatment and distribution (VIA University College)

The research programme for Water Technology covers all aspects of the water cycle, from groundwater entering the drilling to the point where water is tapped by households and industries. The main areas of expertise of the programme are drinking water production and distribution.

Within these areas, the programme is involved in several research projects covering the effects of microbiological processes (such as biofilm) on water quality – an area which is unique for the Danish water distribution system (as opposed to the use of chlorine in most countries). Other research projects in the programme focus on how different kinds of water resources and the composition of the distribution system interact with optimal utility design (such as filter design, use of filter tanks, pressure gauges, and composition of pumps). The aim is to increase the effectiveness of utilities (which are often oversized due to a lack of knowledge of how design should be adapted to water sources), reduce investment costs, and improve sustainability in operation and distribution through cuts in energy consumption, etc.

The programme is practice-oriented and carries out projects in close cooperation with companies and utilities. The centre also develops pilots and facilities that can be used for test and demonstration in collaborative projects. One of its main contributions is a so-called "mobile water works" – a pilot line (located in a container) that is used for testing new components and equipment in a safe environment.

Facts

No. of FTE (water technology): 10

Sources of funding: Basic funding (40%); public funds (40%); private funds (15%); EU (5%); other international sources (0%)

Lab facilities at VIA University College

As a young research environment with a high focus on applied research and practical experiments in the field, VIA University College has not heavily invested in advanced research facilities on campus. Research infrastructure at VIA consists of a relatively modestly equipped water technology lab and a mobile container used for pilot tests at water works.

Water Technology Lab at VIA University College

Main applications: Chemical and microbiological analyses of drinking water; lab and bench-scale setups for documentation of water treatment processes.

Types of equipment (examples): Spectrophotometers, microscopes, plate readers for quantification of biological and chemical assays, flow benches, sensor systems, and electrodes for documentation of water quality and processes in water supply utilities.

The mobile water works

Main applications: Test of new tools/technologies for water treatment and for monitoring water processes.

Types of equipment (examples): A flexible water utility in a pilot scale build on modular principles in a container.

Appendix 2: Informants

Research environments

Name	Position	Organisation
Anders Vest Christiansen	Professor	AU, Geoscience
Cees Buismand	Founder and member of the executive board	Wetsus
Claus Helix-Nielsen	Professor	DTU Sustain, Department of Environmental and Resource Engineering
Ditte Andreasen Søborg	MSc Biotechnology	VIA University College
Hans-Jørgen Albrechtsen	Professor	DTU, Water Technology & Processes
Jan H. Christensen	Professor	KU, Department of Plant and Environmental Sciences
Jens Ejbye Schmidt	Professor	SDU, Department of Green Technology
Jes Vollertsen	Professor	AAU, Construction, City and Environment
Kai Bester	Professor	AU, Environmental Science
Klaus Koren	Associate Professor	AU, Biology
Krist V. Gernaey	Professor	DTU, Department of Chemical and Biochemial Engineer-ing
Lasse Rosendahl	PhD Mech Eng	AAU, Energy
Lars Ditlev Ottosen	Professor	AU, Centre for Water Technology
Merle de Kreuk	Head of department	TU Delft, Department of Water Management
Michael Rasmussen	Professor	AAU, Construction, City and Environment
Morten Lykkegaard Chri-stensen	Associate Professor	AAU, Department of Chemistry and Bioscience
Per Halkjær Nielsen	Professor	AAU, Department of Chemistry and Bioscience
Peter Steen Mikkelsen	Professor	DTU, Department of Environmental and Resource Engi-neering
Rafal Wisniewski	Professor	AAU, Department of Electronic Systems
Theis Raaschou Andersen	Head of Research	VIA University College

Private companies

Name	Position	Organisation
Dennis Trolle	CEO	Water Web Tools
Flemming Hedegaard	Director	Grundfos
Lars Enevoldsen	Senior Vice President	Kamstrup
Mads Warming	Senior Consultant	Danfoss
Michael Ramlau-Hansen	Marketing Manager	AKV Holding
Ole Fritz Adeler	CEO	Envidan
Peter Holme Jensen	CIO	Aquaporin
Søren Porsgaard	CEO	SulfiLogger

Utility companies

Name	Position	Organisation
Claus Homann	CSO	Aarhus Water
Christian Schou	Project Manager	Aarhus Water, Water Living Lab
Liselotte Clausen	Senior Consultant	HOFOR
Mads Leth	CEO	VandCenter Syd
Per Overgaard Pedersen	Chief Engineer	Aarhus ReWater

RTOs and ecosystem agents

Name	Position	Organisation
Anders Leichti	CTO	DHI Group
Caroline Kragelund Rickers	Head of Water Section	Danish Technological Institute
Helle Katrine Andersen	Sekretariatschef	DANVA
Jesper Dannisøe	Director	Danish Water Forum
Lars Holmegaard	Director	Klimatorium
Michael Johansen	Development	CLEAN
Miriam Feilberg	Fagleder	DANVA
Thomas Mikkelsen	Project Manager	CLEAN
Ulla Sparre	CEO	Water Valley Denmark

Appendix 3: Key words and topics included in the funding and bibliometric analysis

Funding analysis

Research area	Keywords included in the analysis
Water technology	Vand, spildevand, kloak, renseanlæg, afløbssystem, pfas, miljøfremmende stoffer, faskine, overløb, regn, water, sewer, waste water, waste water treatment plant, drainage syste, environmental pollutants, environmental contaminants, fascine, overflow, rain
Wind technology	Vind, offshore, vindenergi, mølle, vinge, tårn, composi, nacel, wind, mill, blade, turbin, tower, rotor
Robotics	Robot, cobot, drone, auto

Bibliometric analysis

Research area	Example of topics included in the analysis
Water resources (26 topics)	“Monitoring Network|Groundwater Monitoring|Groundwater Level Data”; “Conformal Mapping|Flow Nets|Analytical Solution”; “Monitoring Network|Groundwater Monitoring|Groundwater Level Data”; “Groundwater Extraction|Recharge|Water Resources”; “Groundwater Recharge|Water|Stored Water”
Water supply (71 topics)	“Airflow|Water Distribution Systems|Consumption Patterns”; “Station|Pumping|Centrifugal Pumps”; “Leak Detection|Leakage|Water Distribution Systems”; “Water Resources|Grid Management|Optimal Allocation”; “Drinking Water|Water Distribution Systems|Legionella”; “Biofilm|Biofiltration|Drinking Water”
Wastewater (66 topics)	“Wastewater Treatment|Ceramic Membranes|Microfiltration”; “Activated Sludge|Feast|Sewage”; “Wastewater|Sewage Systems|Dimethylamines”; “Activated Sludge|Anaerobic Digestion|Pretreatment”; “Wastewater|Advanced Wastewater Treatment|Fenton's Reagent”; “Nutrient Removal|Wastewater Treatment|Activated Sludge”
Stormwater (35 topics)	“Urban Water|Climate Change|Stormwater Management”; “Stormwater|Green Infrastructure|Water”; “Climate Change|Instream Flow|Water Quality Management”; “Catchment Area (Hydrology)|Rain Gages|Flood Forecasting”

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