Innovationsfonden
FORSKNING, TEKNOLOGI & VÆKST I DANMARK

DRIP

Water efficient industrial food production

Introduction

In 2015, the DRIP partnership was initiated, to set focus on water efficiency in the Danish food sector in response to the call for societal partnerships (INNO+) by Innovation Fund Denmark. The partnership was designed as a triple-helix interdisciplinary innovation partnership and comprised 18 partners including major water end-users from the food and beverage industry, water technology providers, and knowledge partners. The Danish Veterinary and Food Administration and the Danish EPA were associated partners.

The aim of the partnership was to create effective solutions to improve water efficiency in the food industry without compromising food safety. The partnership aimed at a paradigm shift in industrial water efficiency through demonstration and implementation of *water-fit-for-purpose* concepts to use significantly less water of drinking water quality and increasingly use recycled and reclaimed water. Ensuring the quality of water throughout its use is of paramount importance to secure food safety and product quality. Having Danish food and environment authorities as associated partners in the project allowed for a positive co-operation and dialogue with a focus at very early stages on important considerations regarding regulation.

The partnership management was facilitated by the Danish Agriculture and Food Council, working through a governance model consisting of a daily management team, reporting to a steering committee consisting of partner representatives. Funds were allocated to projects and activities by the steering committee in a continuous process, in which water saving projects were developed and matured in open collaborations between the participating partners. The governance model ensured a focused prioritization of the most value-adding activities throughout the life span of the DRIP partnership.

This report documents the results obtained through the DRIP partnership in the period 2015 - 2021.

DRIP Partners and contact persons at the time of DRIP finalization

Partner	Contact person
Alfa Laval	Mikkel Nordkvist
Arla Foods	Bente Østergård Mikkelsen
Aqua Porin	Jörg Vogel
Danish Agriculture and Food Council	Anette Christiansen Hanne Skov Bengaard (Partnership Manager 2015-2020)
Carlsberg	Lars C. Christensen
Danish Crown	Rikke Dencher Aagaard
DTU Food	Lisbeth Truelstrup Hansen
DTU Environment	Hans Jørgen Albrechtsen
Danish Technological Institute	Susanne Støier Chairperson of the Steering Committee (2019-2021)
Grundfos	Wilbert Van De Ven Chairperson of the Steering Committee (2015-2019)
HK Scan	Rasmus Erkstrøm
IN-Water	Martin Andersen
LiqTech	Haris Kadrispahic
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Project acrononym	INNO+VIP/DRIP – Danish Partnership on Resource Efficient Industrial Food Production
Innovation Fund Denmark File no.	152-2014-10
Contact person (project manager)	Karen Sørensen, Danish Agricultural and Food Council/Technological Institute
Administrator	Danish Agricultural and Food Council
Status pr.	31.03.2022
Project duration	01.04.2015-31.12.2021
Other partners	Arla Carlsberg Danish Crown HK Scan TripleNine Alfa Laval Aquaporin Grundfos Liqtech Siemens Tetra Pak Ultraaqua Technological Institute DHI (until 31.12.2017) IN-Water (from 01.01.2018) Copenhagen Business School Technical University of Denmark University of Copenhagen
Project website	www.drippartnership.dk
Total budget	95,404 Mio. DKK
Innovation Fund Denmark grant	49,992 Mio. DKK
Partner co-funding	45,412 Mio. DKK

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A. Executive summary

A.1 Key results and experiences

- **Overall –** Creating new constellations take time. The duration of the DRIP partnership has ensured the formation of new and fruitful collaborations and the transfer of knowledge between partners/stakeholders in the food industry
- **WP1** – Risk assessments formed the base of all decisions of using water fit for purpose at the end users. The association of the national authorities on food and environment ensured focus and transparency in case handling of projects going to full scale implementation in DRIP.
- **WP2** – The business potential of the solutions demonstrated in DRIP is large, and more technology providers have used DRIP as a platform for new business areas. Dissemination of the solutions will be a long-term process, as water saving focus develops at various speeds in the international food industry.
- **WP3** – A project portfolio of 28 projects was developed. Eight projects resulted in full scale implementation. Seven completed pilot projects offer opportunities to move into full scale implementation, while three pre-studies are attractive to bring into pilot phase. In total, water savings of 1.44 Mio. m^3/year or 32 % of the total water consumption at the five end-users have been achieved or demonstrated, see also Table A.1 below.
- **WP4** – Research on technology and industry-based topics showed that further optimizations are possible, as well as it pointed out a need of strategies for implementing new technology for water saving in the various food industry branches, with regards to operation and cleaning strategies

A.2 Major changes in project conditions

During the partnership period, two partners left the partnership. One equipment provider left shortly after the start, while a large knowledge provider left approximately three years into the project, due to structural changes at the company. However, it was possible to relocate the projects and maintain the level of competencies within DRIP as the highly skilled personnel previously employed by the leaving partner relocated to other DRIP partners or stayed involved through the foundation of independent companies.

A mid-term evaluation of the partnership was performed in 2017. On basis of the feedback from the partners, the partnership structure was reorganized, reducing the number of WPs from 9 to 5. Three WPs organizing technical projects were fused into one WP, and a new WP focusing of research to create the knowledge base for projects was formed, to ensure a larger focus on the research part of DRIP. The final evaluation performed close to the partnership finalization concluded that the revised structure working from 2018 onwards was satisfactory for all partners.

A.3 Challenges/opportunities for partnership continuation after the investment period

The established collaborations will continue to create new solutions and projects for the food industry in the future, in short as well as long term. Several research questions and technical projects have been identified and preliminary studies have been conducted within DRIP. These remain to be further explored in future projects or partnerships, together with technical solutions, where further maturation on the knowledge base created within DRIP is expected to ensure full scale implementation in the future.

A.4 End of partnership status in relation to partnership vision and success criteria

Six DRIP success criteria were formulated from the onset of DRIP (in italics):

• *"Water-fit-for-purpose" concepts and closed loop solutions can be applied successfully in the food sector in Denmark within the present or a modified regulatory framework that has been put in place through collaboration with and support to the relevant authorities. Concepts and solutions should be developed with export of technology and food in mind*

All participating end user implemented full scale projects using water fit for purpose. Two focused on treating water to drinking water quality, and two focused on treating water to a quality less than drinking water but fit for purpose at the site. All solutions were supported by risk assessments and three required authority approval. The liaison between DRIP and relevant authorities in the food and environmental area from the start of partnership was unique and ensured a high degree of knowledge sharing and transparency between the end user and authorities at an early stage, which was important for a successful outcome.

• *Best practices on water use/reuse have been identified and implemented in 20-25 Danish Food companies within the existing regulatory framework with reduction in water consumption of 15-30 % and with attractive payback times*

A total of eight smaller water consuming production companies were screened for water saving potential based on initial analysis of available data, a one-day focused walk through of production facilities and preparation of an action plan identifying immediate water saving efforts as well as high and medium prioritized opportunities requiring further analysis. Water savings of up to 20% or 150.000 m3/year were made probable. However, further data and analysis are required to verify potential and attractiveness of the associated business cases.

In addition, three of the DRIP end-users have implemented a total of 11 "best practices" opportunities or "low-hanging fruits" at six different production facilities, identified during the pre-assessments or emerging from the increasing awareness on water savings and water efficiency at the end-users created by DRIP participation. Water savings in the range of 15-25% were achieved at four locations and less than 5% in two locations, see Table A.1 below.

• *Sector specific risk management concepts of safe combination of water source quality, technology solution and purpose of use have been applied and further developed and translated into specific national guides and instructions for a more streamlined industrial water reuse approval process than today's practice*

A series of risk assessments were performed, both in pre-study analysis and for full-scale projects. The development of national guides was not relevant in all cases, as there are large differences in production facilities and production processes applied. However, one pilot project in WP3 developed a water catalogue for the use of treated process water in the meat industry. This can be developed into a national guideline and become integrated in the official control and thereby omit the need for individual exemptions thus serving to facilitate and increase the reuse of water in the meat industry. In one case the full-scale implementation will result in a national guideline for the sector.

• *New innovative water efficient processes, production equipment and integrated technology solutions are developed tested, demonstrated, and documented with lead end users – raising the bar of global best in class – through 6-8 lighthouse projects with resulting reduction in water consumption of 15-30% and with attractive payback times*

A total annual water saving of 905.400 m^3 or 20% of the total consumption at the end users was realized through the complete project portfolio, and a further 535.000 m^3 or 12% water saving potential was demonstrated in several pre-studies, pilot projects and low-hanging fruits identified by DRIP in the pre-assessment phase. The savings for the individual end users are summarized in the Table below.

Table A.1*: Summary of water savings achieved and demonstrated in DRIP*

END-USER	Arla	Carlsberg	Danish Crown	HK Scan	TripleNine	Total
Total annual water consumption, m3	**1.600.000**	**750.000**	**1.635.000**	**416.000**	**131.350**	**4.532.350**
DRIP total annual water savings, %	42%	63%	15%	9%	9%	32%
DRIP implemented annual water savings 2015-2021, %	15%	58%	11%	9%	9%	20%
DRIP demonstrated annual water savings beyond 2021, m3	27%	5%	4%		0,2%	12%
DRIP total annual water savings, m3	**673.600**	**475.000**	**240.300**	**39.500**	**12.315**	**1.440.715**
DRIP implemented annual water savings 2015-2021, m3	242.600	435.000	176.300	39.500	12.000	905.400
- Low hanging fruits	*190.000*		*82.500*	*17.000*		*289.500*
- Implemented projects	*22.600*	*435.000*	*15.800*	*22.500*		*495.900*
- Projects under implementation	*30.000*		*78.000*		*12.000*	*120.000*
DRIP demonstrated annual water savings beyond 2021, m3	431.000	40.000	64.000		315	535.315
- Pre-studies	*125.000*	*40.000*	*35.000*			*200.000*
- Pilot projects	*306.000*		*29.000*		*315*	*335.315*

The participating end users each completed five to seven projects (pre-studies, pilot projects or full-scale implementation) of various complexity except HK Scan that only completed one project. In addition, three industry cross-cutting projects were completed of which one was relevant for all end users, one was relevant for the meat industry and one for dairies and breweries.

Of the portfolio, five full-scale implementation projects (Arla-6: CIP-by-measure, Carlsberg-5: Water Recycling Plant, Danish Crown-8: Treated process water for the dehairing process, HK Scan-1: Chicken feet processing line, and TripleNine-5: Innoflot treatment of landing water (with external co-funding from MUDP) are considered to be lighthouse projects characterized to various degree by a solid water and other resource saving potential, technological complexity, innovative new approaches, requirement for authority accept - and all five scalable solutions with a good market potential.

In addition, during the course of DRIP Arla DP has also implemented a major water recycling plant (lighthouse project) reclaiming 7-8% of the effluent from their wastewater treatment plant and reuse it as technical water. Further expansion of this recycling plant – eventually going for a Zero Level Discharge (ZLD) – may include introduction of a pellet reactor treatment to overcome scaling challenges as successfully demonstrated in pilot scale by DRIP (Arla-5).

• *Partner and trade specific business models have been developed, tested, and proven for technology and knowledge providers and the food industries respectively and are internationally transferable*

The development of new trade and partner specific business models proved more difficult and less relevant than anticipated. The solutions developed and demonstrated in the partnership were presented in a series of workshops and webinars. It proved difficult to engage the technology providers in activities aiming at this perspective, as they prefer to approach the international markets through their existing sales channels. Since the technology providers differ greatly in size as well as business models, and some of the larger companies apply different business models between products and markets, the application of centrally developed business models turned out to be irrelevant for the participating companies.

• *Best practices, novel production processes, and technology solutions are transferred and scaled – initially to food processing plants of Danish companies abroad and subsequently to the global industry at large and adapted by other water consuming trades (ingredients, pharmaceuticals, energy etc.)*

The developed solutions have a large potential for scaling into the international market. The development of the specific solutions spanned the time frame of the partnership, and dissemination of the practices, processes and technical solutions into the international market is a long-term focus that will be completed after the finalization of DRIP.

B. Value creation

The **DRIP end users** have all benefitted from implementation of projects with water savings and more water efficient production processes. In total, water savings of almost 1.5 Mio. m^3/year or 33 % of the total water consumption at the five end-users have been achieved or demonstrated. Some of the implemented projects have also led to savings in energy, and thus reduction in CO_2 emissions, as well as in resource consumption (e.g. chemicals). As such, the end users have reduced their operating expenses, in some cases postponed investments or enabled them to increase their production capacity, resulting in an increased competitiveness. Scaling of implemented projects to other production facilities and attractive projects in the DRIP project portfolio not yet implemented offer further opportunities for the end users (and thus for the technology providers) to continue their journey towards more resource efficient production processes and increased competitiveness in accordance with their corporate green strategies and also to contribute to *UN Sustainable Development Goals no.12 Responsible consumption and production* and *no. 6 Water and Sanitation.*

The **DRIP technology providers** have benefitted to a varying degree from their participation. During the course of DRIP, some partners have increased while others have reduced their scope of activities in the partnership e.g.:

- Ultraaqua has benefitted substantially and grown their involvement in DRIP through development and implementation of two new products and establishment of new customer base (Carlsberg, Danish Crown and Arla). Through Carlsberg, links has been created to two Belgian OEM partners that are active in the F&B industry and have generated more than 10 requests for proposal and four contracts with a value close to 6 Mio. DKK and resulted in five new knowledge jobs at Ultraaqua and three jobs at sub-suppliers. Ultraaqua expects a growth in turnover of 30 Mio. DKK and 15 new jobs (including sub suppliers) in a 3–5-year perspective.
- Tetra Pak joined DRIP with the ambition of testing some of their dairy technology solutions in other F&B segments and did that successfully in two pilot projects at Danish Crown being considered for implementation. In continuation, the Tetra Pak approach to the meat industry segment will however be opportunistic rather than strategic.
- Grundfos was envisaged to be major partner in DRIP with their emerging products BIOBOOSTER (MBR reactor) and BACMON (online microbial sensor). Unfortunately, as a result of internal reorganization and prioritization, both BIOBOOSTER and BACMON were discontinued as offerings from Grundfos in 2018. Consequently, Grundfos reduced their engagement in DRIP to a large extent. However, the (industrial) water treatment market remains to be of strategic interest to Grundfos and will be pursued through M&A and is a key focus in the new Industry Division in Grundfos.

The **DRIP knowledge providers** (universities, GTS-institutes, consultants) have also benefitted to a varying degree from their participation:

- Technological Institute increased their scope of activities within DRIP when the other GTS-institute DHI pulled out. Through DRIP, TI has expanded their network in the F&B industry and created a handful of new R&D projects with DRIP end users and other F&B industries as spin-off from their DRIP activities. The changed mindset with respect to food safety and quality risk in connection with water reuse in the meat industry opens for new interesting business opportunities for TI
- IN-Water - a small startup consultant established by senior staff previously employed by DHI who were key in development of DRIP from the beginning – joined DRIP halfway. Continued involvement in DRIP-activities offered a smooth start for IN-Water though the

financing conditions in Innovation Fund Denmark (compared to other knowledge providers) became less attractive. Benefits in terms of new business networks and the sensor supported "CIP-by-measure" concept are important outcomes for IN-Water
- The universities have throughout DRIP (and as envisaged from the very beginning) been challenged by the demand to act as consultants – providing ad-hoc and short-term knowledge input. However, they have strengthened their network with technology providers and DRIP end-users. DRIP has also contributed with co-funding of DRIP relevant Ph.Ds. and Post-doc activities and provided a platform for several M.Sc. and B.Sc. student projects.

DRIP partners have during the course of DRIP already been able to attract additional public investments to continue project activities initiated by or inspired by DRIP. This includes funding from MUDP and EUDP to nine projects within food and beverage, pharmaceuticals and textile industries with public funding of close to 100 Mio. DKK involving ten different DRIP partners.

Further, several DRIP partners have participated actively in activities and project preparations for the AgriFoodTure InnoMission, with various projects targeting resource and climate efficient food processing.

The DRIP project portfolio offers opportunities for continuous investments in realizing the DRIP vision, maturing technological solutions, enhancing market readiness and implementation and securing scalability:

- Three themes (i) Reclaiming water for evaporative cooling towers, (ii) Reuse of cooking water for autoclaves and (iii) treating stick water all represent attractive water, energy and resource saving potentials that however require further development and documentation, which may attract public co-funding (Innovation Fond Denmark, MUDP, EUDP)
- Developing a national guideline for reuse of treated process water in the meat industry, on the basis of the water catalogue developed in DRIP, will speed up implementation of water efficient production processes in the meat industry, which may attract further funding from e.g. The Pig Levy Fund.

Promotion of water efficient best practices, particularly in SMEs, has proven more challenging than envisaged due to low awareness and shortage of resources in the SMEs. A close collaboration between industry associations and consultants supported by a public incentive scheme for conducting water audits/quick scans may be a way forward to identify and accelerate implementation of water efficient best practices in the F&B industry as well as other water consuming industries.

Direct investment by the DRIP partners themselves (end-users, technology, and knowledge providers) are underway to install and bring well proven and documented solutions to the market and scale implementation e.g.

- Carlsberg is evaluating opportunities for the water recycling plant concept in other locations in their network of numerous breweries especially in water scarce areas which will offer business possibilities for several DRIP technology providers
- Danish Crown is considering how the three full scale DRIP solutions implemented in full scale can be introduced in other business locations and how three promising pilot projects can be brought into full scale implementation - in dialogue with the technology providers
- Ultraaqua actively promotes their UV-based product for polishing of treated process water and their filtration unit for reclamation of process water with international OEM partners
- IN-Water actively promotes their sensor based "CIP-by-measure" concept to other Carlsberg and Arla locations in Denmark and abroad and to other dairies and breweries.

C. Technical and scientific achievements

As part of the mid-term evaluation in Autumn 2017 it was decided to reorganize and simplify the DRIP structure from originally eight work packages to five new work packages including four technical work packages, WP1-WP4, and a partnership management and communication work package, WP5, see Figure C.1. This chapter summarizes the achievements in WP1-WP4.

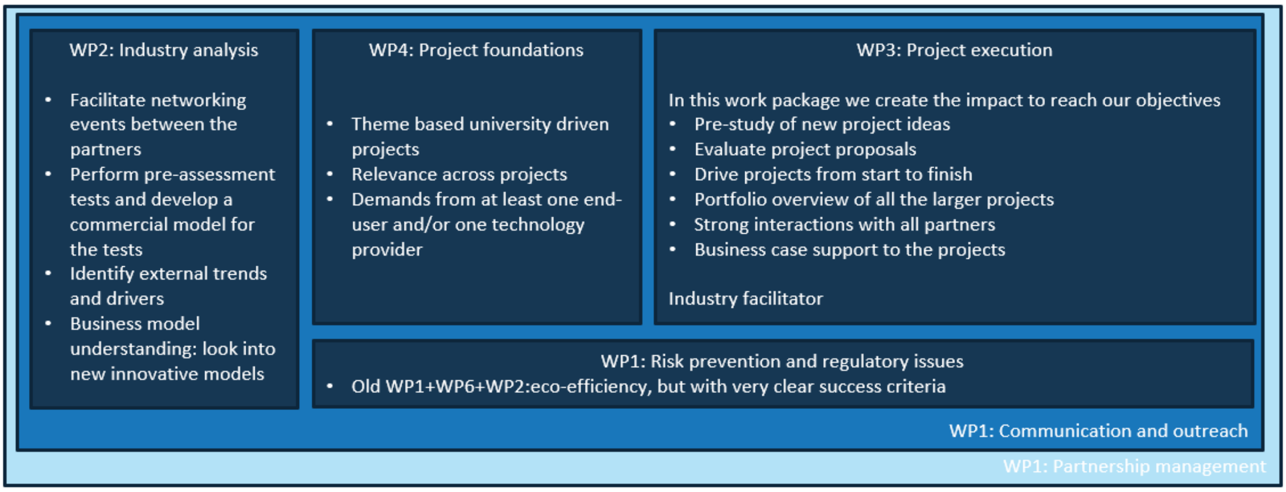

Figure C.1: *Revised DRIP structure established as part of the mid-term evaluation in autumn 2017 and effective from 2018*

C.1 Work package 1 – Risk prevention and regulatory issues[1]

C.1.1 Background and objectives.

A major challenge for reuse of water in the food industry is to ensure that implementation can take place without jeopardizing the safety or quality of food. The overall objective of this work package 1 (WP1) was therefore to develop strategies for how to (a) assess the risks involved in reusing water and (b) manage these risks to satisfy regulatory requirements, which were also being mapped within this work package.

C.1.2 Risk assessments

Activities in WP1 supported technology projects (WP3 Project Execution) by conducting risk assessments for selected projects. A holistic evaluation of the health hazards or spoilage potential associated with the use of the treated water is a pre-requisite for reuse of water in the production, e.g., for cleaning purposes. As risk assessment models exclusively deal with health hazards, it became apparent that we needed to devise an adapted risk assessment approach to evaluate industrial case studies from DRIP-partners. This approach considered the process water type, water treatment method(s), relevant hazards and/or spoiling agents, and final use for the reclaimed water. The general outline of the steps in the risk assessment is shown in the table below.

[1] All references in this section refer to Appendix 1 if not otherwise written

Table C.1. *Content and steps in an adapted general approach for risk assessments of water reuse scenarios. The standard risk assessment method was amended by inclusion of an assessment of reclaimed water quality and the risk of changes to final food product quality (Step 5).*

Step	Activities
1. Description of the reclaimed water (final product)	• What will the water be used for (intended use)? • What is the legal and regulatory framework?
2. Description of the raw material and water treatment system	• Source of the water (including raw material, additives)? • Flow diagram and details of the water treatment system • Mapping of all possible input/contamination sources
3. Identification of potential health hazards	• Biological, chemical and physical hazards • Likelihood of occurrence and severity ranking
4. Evaluation of health hazards	• Effect of water treatment system • Critical Control Points (CCPs) in the water treatment system or later in the processing of the food?
5. Water quality: Reclaimed water stability and impact on food product quality	• Evaluation of the stability of the reclaimed water • Model/measure effects on the final food product quality
6. Monitoring plans	• Selection of parameters to monitor to ensure the reclaimed water meets the expected standard • Setting of Critical Limits (CLs) for control and/or reduction of significant hazards or quality issues
7. Documentation	• Evidence of the system being in compliance?
8. Summary	• Recommendations and conclusions

Using this approach, a total of 12 risk assessments were completed for projects in the WP3 project portfolio. Five of them are included in the completion reports of the relevant projects, see Appendix 1 – one of the risk assessments was relevant for two projects. The other seven risk assessments (all in the meat industry) are confidential and not included in the completion reports of the relevant projects, Appendix 3 Ref. /3.15-3.20, 3.22/.

Two invited presentations were also given at the IFC Water Congress in 2018 and 2021 on the topic of water reuse in the food industry and assessment of the risk, see Appendix 6. An overview of the risk assessment approach is also given in Figure C.2.

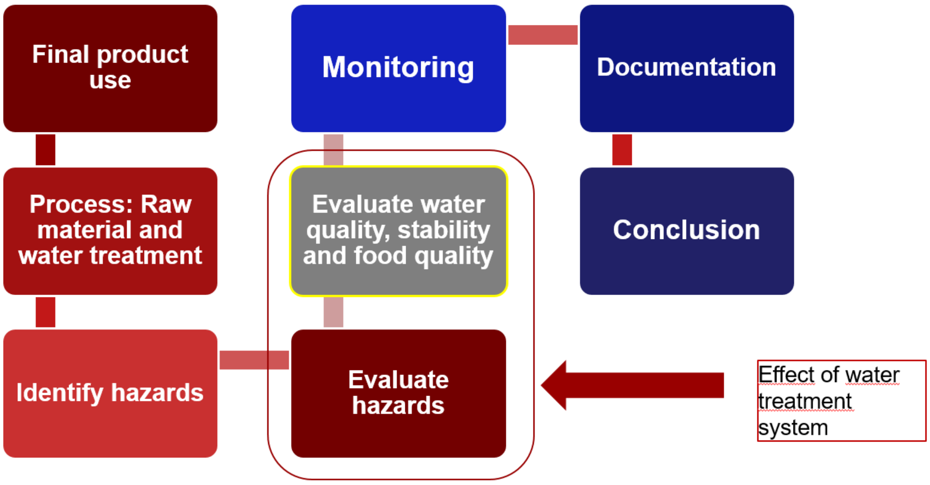

Figure C.2. *Steps in the amended risk assessment for evaluation of risks involved in reuse of water.*

Depending on the specific intended use scenario or the type of input water, the industry might choose to apply a multi-barrier approach by mixing and matching the water treatment processes, which are most suitable for their purpose. Our risk assessments have looked at the effect of biological treatment, membrane bioreactors and ultrafiltration (MBR/UF), reverse osmosis (RO), ultra-violet light and advanced oxidation treatments (UV/AOP), and chlorine dioxide (ClO_2) on the removal of both microbiological and chemical hazards.

Generally, the performed risk assessments showed that biological hazards (virus, bacteria, fungi, parasites) were controlled through the multi-barrier approach used in the water treatment systems (Figure C.3).

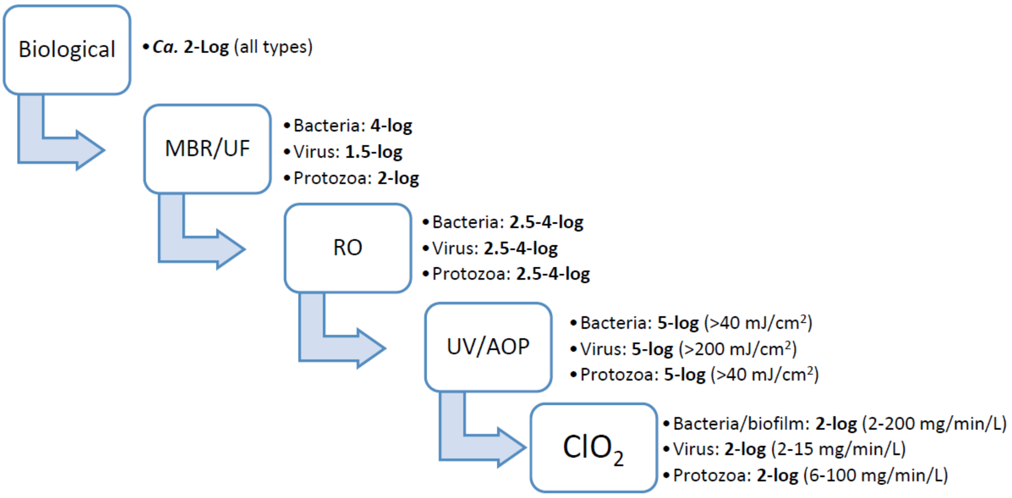

Figure C.3. *Example of the log reduction values that can be expected for a multi-barrier water treatment plant. Every log reduction corresponds to a reduction/kill of the microorganism. (From the Carlsberg TWM report and based on values from published literature and WHO, 2017[2]).*

[2] WHO. 2017. Potable reuse - Guidance for Producing Safe Drinking-Water," World Health Organisation. Geneva. Licence: CC BY-NC-SA 3.0 IGO.

A similar approach was used to model or evaluate the removal of identified chemical hazards, see Figure C.4. Information about all chemicals (ingredients, cleaning agents, sanitizers, etc.) was first collected along with information about the approximate annual consumption and knowledge of the planned water treatment system. This allowed for calculations of the expected removal in each step in the multi-barrier treatment system.

Due to the variety of chemical compounds that can potentially be found in the source water (i.e., untreated process water going to the water treatment system for later reuse), the risk assessments of chemical hazards suffered from uncertainties and more research is needed to validate the models used to calculate removal in the treatment system. However, generally all chemistry of concern were projected to be handled. An interesting outcome of this risk assessment work was that the industrial partners became aware of their chemistry use. Moreover, as water no longer is looked upon as a "throw-away" commodity, some partners are beginning to question whether all the chemistry is needed.

The amended risk assessment approach included an investigation of whether the reuse of water would impact the quality of the final product. In all cases it was found that such quality changes would be negligible. The risk assessment also needed to consider if storage of the source or treated reuse water could constitute a quality issue.

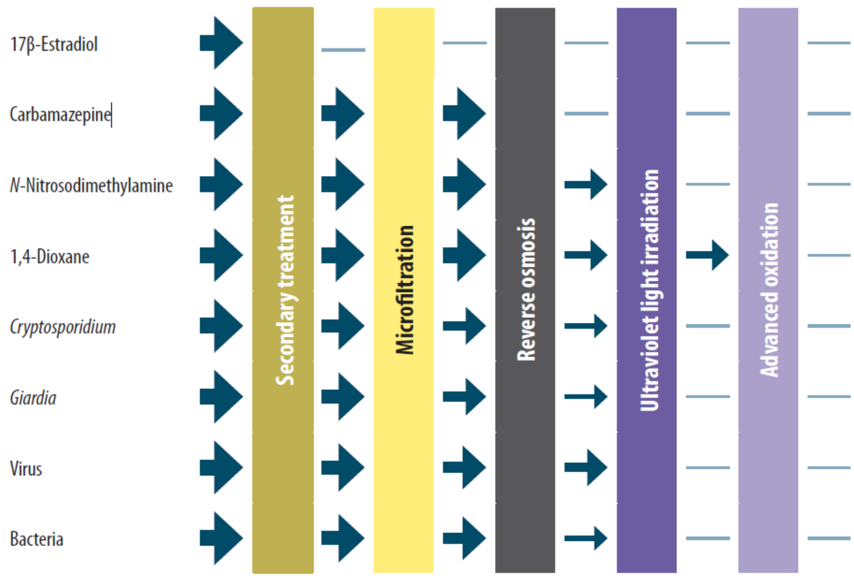

Figure C.4. *Concept of multi-barrier removal of microbial and chemical hazards in advanced water treatment systems (from WHO, 2017).*

Microbial regrowth potential was documented by DMRI, KU and DTU Environment, and the establishment of guidelines for "shelf-life" is needed to prevent "spoiled" water from compromising the quality of cleaning or the food product itself.

Managing the risks, water treatment systems and documentation: Documentation of the performance of the water treatment methods (potential CCPs) and management of physical, chemical or biological hazards is paramount to ensure final product quality and safety.

The risk assessments exemplify how food safety relies on the multi-barrier treatment, and management of the risks therefore depend on each step performing within its specifications.

This is typically done via online measurements of pressure, temperature, turbidity, conductivity, chemical oxygen demand (COD) and so on. Documentation of the water treatment system working would together with a regular monitoring program feed into the industry's Hazard Analysis and Critical Control Points (HACCP) plan. Future research is needed on how to best monitor that the system is in compliance and digital integration with "go/no go" decisions within the HACCP or food safety management program.

Legislation and regulatory framework. To map opportunities, challenges and approaches for managing food safety in water reuse scenarios, the regulatory framework in Denmark and the EU were elucidated in each of the risk assessments. Throughout the DRIP project, regular communications took place with the competent authority in Denmark, Danish Veterinary and Food Administration (DFVA), who is in charge of approving HACCP plans and administering the Hygiene Directive (EU 852/2004). In principle, drinking water must be used in food plants. However, the law gives some provisions for reuse schemes, which can be approved by the competent authority if it is presented with convincing documentation that food safety is not at risk. Advances in the DRIP project have led to a better understanding of the required documentation and what is possible within the legal framework. This is reflected in the risk assessments.

Water reuse in other countries including their regulatory framework may also be of interest for partners as would non-regulatory issues that could act as possible barriers for industrial reuse of water. Both aspects were mapped and presented in separate reports (Danish Agricultural Council. Undated a), Danish Agricultural Council. Undated b)).

Partners within DRIP also participated in the work on EU standards on Best Available Techniques (BREF standards). In cooperation with the Danish Environmental Protection Agency (DEPA) conclusions on inventory of water consumption and water reuse were included (EU 2019/2031)[3]. The efforts including the learnings from DRIP will continue in the current work with defining BREF standard for slaughterhouse and fishmeal production. An EU standard on water reuse in agricultural irrigation was also published during the DRIP project period (see below). While not directly relevant for the post-harvest DRIP partners, there are important considerations of which parameters should be monitored to determine if the water is fit-for-purpose, e.g., as irrigation water in the production of vegetables.

Work completed in WP1 lay the foundation for the development of national guides for the reuse of water with full-scale water treatment systems being implemented at two of the DRIP partners (Danish Crown, Horsens, and Carlsberg, Fredericia) in 2021. A national guide for water reuse in the dairy industry has been underway for some time under the leadership of the Danish Agriculture and Food Council (DAFC). DRIP has created the foundation for a guide for other segments of the food industry, notably in the meat industry based on the outcome of the project *WP3-Industry-2: Water catalogue for the use of treated process water in the meat industry*, Appendix 3, Ref. /3.29/. All national guides must be assessed by DFVA, before they can become integrated in the official control and thereby omit the need for individual exemptions thus serving to facilitate and increase the reuse of water in the food industry.

[3] EU 2019/2031. COMMISSION IMPLEMENTING DECISION (EU) 2019/2031 of 12 November 2019 establishing best available techniques (BAT) conclusions for the food, drink and milk industries, under Directive 2010/75/EU of the European Parliament and of the Council

C.1.3 Other WP1 deliverables

Task 1.2 Sensors and Task 1.3 PAT modelling

The elements have been incorporated into WP3 and WP4 projects and will not be discussed here.

Task 1.4 Mapping of national and EU regulations

A draft report was prepared by Danish Veterinary and Food Administration (DVFA), however, it was not released due to a change in the communication strategy. The agency has decided to focus on self-help tools (værktøjer til hjælp til selvhjælp) on their internet-based communication platform. DVFA therefore plans to launch a web page: Alt om vand (all about water), which will contain references to the relevant legislation and content such as risk assessment tips & tricks for the food industry. The plan is that "lessons learned" from the different DRIP projects will be reflected in DFVA's material.

Task 1.5 Mapping of regulations in 3rd countries

The report submitted by Danish Agricultural and Food Council (DAFC) contains information from USA, China, Australia, Canada, and Israel (Danish Agricultural Council. Undated a))

Task 1.6. Mapping of non-regulatory barriers

A summary note of important consideration was submitted by DAFC (Danish Agricultural Council. Undated b)).

Task 1.7. Supporting the BREF work

This work was led by DAFC. See above for more details.

Task 1.8. EU standards on water reuse

This work was primarily related to the new guidelines on using recycled water in irrigation (primary food production) and did not involve DRIP partners. The work was however, presented in meetings and served as an inspiration for risk management of issues in industrial water reuse. This work has ended and is published as an EU regulation (EU 2020/741)[4].

Task 1.9. Generic HACCP plans and documentation to the local authorities

Important lessons were obtained during the DRIP project regarding the need for and possible types of documentation pertaining to food safety. In general, one or several steps in the multi-barrier water treatment train are prone to become critical control points (CCPs) to safeguard food safety. The risk assessments help to identify these CCPs and identification of operational parameters such as pressure, conductivity, pH and so, which can be monitored to make sure that CCP is in control and working within specifications. The reader is referred to the individual risk assessment reports for more information.

S. Knøchel (KU Food) has participated in the water/food expert group created by WHO/FAO in 2017 (Bilthoven, Netherlands) and 2018 (Rome, Italy). The expert group has made a background report (confidential) which was later presented for CODEX where the need of a

[4] Regulation (EU) 2020/741 of the European Parliament and of the Council of 25 May 2020 on minimum requirements for water reuse, https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1598957517761&uri=CELEX:32020R0741).

"Water-fit-for-use" concept in a food production context and the use of HACCP/quality assurance programs was elaborated and possibilities and challenges pointed out. The focus was only on microbiology. During this process, project material from our group and some of the partners, incl. The Danish Veterinary and Food Administration and The Danish Agriculture and Food Council, was helpful background material in the discussions.

Task 1.10. Development of national guidelines

Work on general guidelines for how to make a generic risk assessment and HACCP is in its infancy, however, important lessons were made during the DRIP project as is reflected in this final report. DFVA is using information from DRIP to create their web page "alt om vand", which will set the foundation for national guidelines.

C.1.4 Conclusions and future directions.

- An amended risk assessment approach was developed and applied within the DRIP project to determine if the proposed/projected water treatment systems would provide control with identified hazards including those related to quality changes.
- Use of the risk assessment approach showed that it should be possible to provide a water quality suitable for the intended reuse, e.g., cleaning.
- Routine monitoring for HACCP purposes can be covered by online sensors to document that the individual steps are running as per their specifications.
- The legal framework in Denmark permits reuse of water provided it can be documented that food safety is not compromised.
- Other countries, EU and third countries, have similar provisions in their legislation.
- Initial survey of non-regulatory barriers did not identify major barriers. Sustainability agenda may also help.

Future work should look at:

- Validation of models used to predict the removal of microbiology and chemistry.
- Studies of full-scale systems to elucidate if water quality changes over time – also in the industrial distribution system.
- What quality parameters are essential to determine if water is fit-for-purpose.
- Suitable sensors for more detailed information about the water quality and their integration into HACCP programs (digital integration).
- Continued development of best practise for the industry.

C.2 Work package 2- Industry analysis[5]

C.2.1 Background and objectives

The overall objectives of Work Package 2 (WP2) included (i) substantially reduced water consumption through identification and sector wide implementation of best practice solutions, (ii) development and testing of generic business case templates and business models to support investment decisions, and (iii) cooperative efforts to commercialize and disseminate technology solutions in the food processing sector and other water consuming industrial sectors.

[5] All references in this section refer to Appendix 2 if not otherwise written

C.2.2 Summary of work package deliverables

To fulfill the objectives, WP2 included a number of tasks the outcomes of which are summarized below.

Task 2.1 – Pre-assessments

A total of 9 pre-assessments were carried out in the participating food-sector industries (five Danish Crown sites (Horsens, Tulip-Vejle, Holsted, Aalborg, and Tulip-Aalborg) and one site each for Carlsberg (Fredericia), Arla Food Ingredients (Nr.Vium), HK Scan (Vinderup) and TripleNine (Thyborøn). The aim was to identify present water use, consumption patterns and practices, as well as realistic water saving targets and specific technology scenarios that may lead to substantially reduced water consumption in accordance with DRIP success criteria, including introduction of "water-fit-for-purpose" concepts and solutions and overall reduction in water consumptions of 15-30%.

A water audit of the individual sites was the backbone of each pre-assessment. The audit had two functions; firstly, to determine water uses and to determine which end uses were metered, and secondly to give a further understanding of the individual production processes at the site. Possible scenarios for improved water efficiency were pre-assessed based on the water audit and the so-called 6R approach, see Figure C.5. The most obvious and straightforward scenarios could be implemented immediately ("low-hanging-fruits"). Others – more advanced scenarios – were referred to further analysis, prioritization and possible implementation in *WP3 - Project Execution*, see Table C.2.

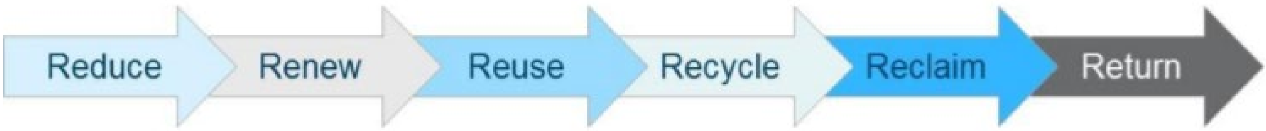

Figure C.5*: 6R approach - Prioritized route to reduced and more efficient industrial water use. Reduce: through (simple) better in-house water management schemes; Renew: introducing more water efficient technologies; Reuse/Recycle: Direct reuse in other processes with lower water quality demands or recycle in the same process; Reclaim: Treatment of process stream to required quality and reuse/recycle in the same or other processes; Return: Discharging remaining wastewater to own or municipal wastewater treatment plant.*

The detailed outcomes of the pre-assessments are available in nine pre-assessment reports, /Ref. 2.1-2.9/. The pre-assessments enabled matching of the individual end-users with technology providers in the partnership and identified where possibly strong business cases for both exist and thus supported prioritization of scenarios to be further analyzed in WP3 – in total 28 scenarios/projects.

Table C.2*: Nos. of identified scenarios for improved water efficiency in the pre-assessments*

Site	Reduce	Renew	Reuse/ Recycle	Reclaim	Return	Total
Carlsberg (Fredericia)	3	2	3	2	1	11
Arla (Nr.Vium)	2	1	3	6	1	13
TripleNine (Thyborøn)	2	7	2	6	2	19
Danish Crown (Horsens)	1	7	12	5	2	27
Danish Crown/Tulip (Vejle)	5	4	3	1	1	14
Danish Crown (Holsted)	1	1	4			6
Danish Crown (Aalborg)	4		2			6
Danish Crown/Tulip (Aalborg)	2	4	5			11
HK Scan (Vinderup)	4	3	3	1	1	12
Total	**24**	**29**	**37**	**21**	**8**	**119**

Task 2.2 – Review of international state-of-the-art innovation trends including identification of best practice solutions for the four food sectors

Based on a combination of literature review, commercial and scientific contacts and innovation ideas among the DRIP partners, review papers on water efficient production processes were prepared for each of the four food sectors, /Ref. 2.10-2.13/.

The review papers included in various degree of details an overview of the manufacturing processes in the sector; water quality demands for production; water efficient cleaning technologies; and end-of-pipe wastewater treatment and reuse technologies. The review papers for dairy and meat industry also included general and specific best practices considerations and examples of decentralized water-fit-for purpose closed loop solutions. The review papers supported the development and prioritization of the project portfolio in *WP3 – Project Execution* as well as development of the quick scan water efficiency assessment and actual quick-scans of food sector companies outside the partnership, Task 2.3 and Task 2.4 respectively.

Task 2.3 – Quick-scan water efficiency assessments

A methodology for rapid water efficiency assessment (a quick-scan) of production facilities of SMEs or part of production facilities of bigger companies was developed and tested. Each quick scan comprised:

- a preparatory phase (telephone interview, submission and return of questionnaires, prior analysis of submitted data)
- one day company visit (introduction to and purpose of quick scan)
- a water and resource efficiency focused walkthrough of production facilities
- debriefing and need for additional data/information

- preparation and presentation of an action plan identifying immediate water saving efforts as well as high and medium prioritized opportunities requiring further analysis.

The methodology is supported by two types of questionnaires – a sector specific questionnaire based on the best practices document prepared in Task 2.2 and a generic questionnaire including basic company information including data on type of water sources, total annual water consumption, water uses (cooling, water treatment, process water, cleaning etc.), water prices and degree of any water reuse. The action plan priorities are based on the guiding principles shown in Fig. C.6.

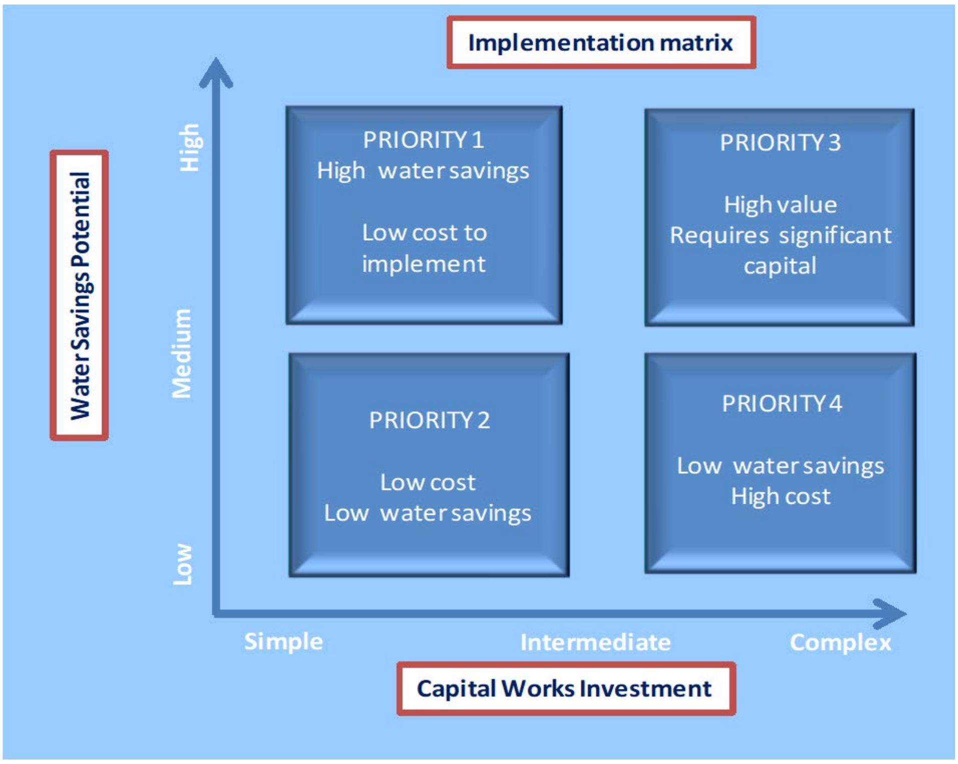

Figure C.6: *Guiding principles for priorities in action plan recommendations in quick-scans*

Task 2.4 – Implementation of best practice solutions in the four food sectors

Originally, the intention was to conduct quick-scan visits to 20-25 food sector SMEs outside the partnership with a view to identifying opportunities for implementation of best practices solutions for water savings and reuse. An introductory folder was prepared, /Ref. 2.14/.

In practice, the goal of 20-25 company was not achieved. It proved much more difficult than anticipated to identify interested SMEs simply because water efficiency and awareness were not very high on their agenda. As a result, the Steering Committee decided to allocate less funding to this task and to revise the target to 10 SMEs. During the later phase of DRIP restricted access to the food companies due to Covid further hampered this activity. Consequently, only a total of eight quick scans were conducted, see Table C.3. Dialogue was initiated with three additional companies but it has not been possible to conduct these quick scans before the completion of DRIP by end of 2021.

The conducted quick-scans are documented in confidential reports, /Ref. 2.15-2.22/, which each contains a prioritized action plan for more water efficient production processes and other water related actions that may save energy, chemicals and operational costs.

Table C.3: *Quick scan water efficiency assessments – conducted and potential water savings*

Company	Trade	Conducted (month/year)	Water consumption (m^3/year)	Potential water savings in prioritized activities (%)	Potential water savings in prioritized activities (m^3/year)
Conducted:					
Prime Ocean A/S (Skagen)	Fish processing	9/2018	41,000	30-40%	12-16,000
Jeka Group A/S	Fish processing	6/2020	99,000	20-30%	20-30,000
Ingstrup Mejeri A/S	Dairy	9/2018 og 6/2019	10,000	15-20%	1-2,000
Thise Mejeri Amba (Thise)	Dairy	2/2020	174,000	20-30%	35-50,000
Them Andelsmejeri	Dairy	11/2021	100,000	20-30%	20-30,000
Globus Wine A/S (Køge)	Bottlery	6/2019	45,000	20-30%	9-13,000
Ardo A/S (Orehoved)	Frozen fruits, vegetables,	8/2021	57,000	30-40%	17-23,000
ZPD A/S (Esbjerg)	Nutrition	10/2021	67,000	30-40%	20-25,000
Potential:					
DanRoots A/S (Bjerringbro)	Horticulture				
Dan Cake A/S (Give)	Bakery				
DSM (Esbjerg)	Nutrition				
Total			**634,000**	**20-30%**	**135-189,000**

Prioritized activities that address water savings include:

- Installation of water meters for continuous monitoring and control of water consumption and benchmarking of individual processes – suggested for all eight companies as priority 1 – up to 20% water savings
- Increased focus on water efficiency and systematic integration in company management systems – suggested for all eight companies as priority 1 or 2 – up to 5% water savings
- Optimization of CIP plants and introduction of CIP-by measure approaches – suggested for four companies as priority 1, 2 or 3 – 10-20% water savings
- Introducing more water efficient equipment and operations in terms of improved flushing nozzles, constant flow valves, and water efficient flushing heads for tank cleaning – suggested in five companies, priority 1 or 2 – few-20% water savings

- Various water reclamation, recycling or reuse approaches – suggested in five companies as priority 1, 2 or 3 – 5-30% water savings

The range of potential water savings in Table C.3 is indicative – but from experience – achievable. However, further data and analysis are required to verify potential and attractiveness of the associated business cases.

Task 2.5 – Cross-cutting applications of new water reuse/treatment technology solutions

This task was intended to focus on developing new water reuse/treatment solutions for upgrading relatively pure process water sources from the production containing only trace amounts of contaminants to high quality water that can be reused in e.g. steam boilers or as cooling tower make-up water.

An analytical platform for measuring composition of relatively clean water streams was established in *WP4 – Project Foundation* (Task 4.4) and presented at the annual workshop of DRIP in 2018. In *WP3 – Project Execution,* the cross-cutting project (WP3-Industry-3) at Arla and Carlsberg has focused on the characterization and removal of low-level bio-effluent organic matter, growth potential and specific compounds in pure and ultrapure water streams intended for reuse, see Appendix 3 /Ref. 3.30/.

Another cross-cutting project (WP3-Industry-1) at Danish Crown Food in Svenstrup addressed the opportunity for reclaiming water for evaporative cooling towers, also relevant for the other DRIP end users, see Appendix 3 /Ref. 3.28/

Task 2.6 – Cross cutting applications of new cleaning technology solutions and concepts

Cleaning of production equipment often uses volumes of water as well as chemicals and energy. New CIP (Cleaning-In-Place) technology solutions and concepts have been tested in WP3 – Project Execution and in WP4 – Project Foundation, outcomes of which are reported under those work packages.

Replacing the traditional "cleaning-by-recipé" concept by a "cleaning-by-measure" concept was investigated in three different food sector projects in WP3 at Carlsberg, Arla (Arinco site) and TripleNine. The concept was based on a combination of sensors known as Opti^{2}Clean from the French company Elodys. The sensors monitor the composition of CIP fluids and determine the effectiveness of the cleaning in real time based on a comparison of the sensor signals on the CIP departure and return lines. The sensors do not tell if the equipment is in fact clean - but it identifies when no further effect of rinsing and/or circulation was obtained and potential savings reported.

The testing was successful at Carlsberg and Arla (Arinco). Substantial reductions in water, chemical and electricity consumption as well as CIP time were documented. The new concept was presented and discussed at a DRIP workshop in October 2021. Implementation of the proposed solution is ongoing at the Arla (Arinco) site in autumn 2021.

At TripleNine, the tests were unsuccessful as the data logging system did not work as intended. Therefore, it is not possible to draw any conclusions whether the CIP-by-measure concept and the application of Opti^{2}Clean (UV/IR) sensors is possible in the fish meal industry.

Task 2.7 – Literature review and analysis of current practices and underlying drivers/determinants for business models selection

In spite of the rise in awareness of water efficiency and the true cost of water, the investments in water efficient technological solution in industrial production are currently much lower that e.g., in energy efficient solutions. Furthermore, water management is often perceived as fairly complex due to regulation (food safety standards), operations (interference with manufacturing), and costs (fairly expensive).

On this background, Copenhagen Business School (CBS) conducted two international surveys during 2015 (the first during Spring financed by Danish Environmental Protection Agency as part of the pilot project *Water-efficient dairies* and the second during Autumn financed by DRIP) to obtain insights into the business priorities, competitiveness factors, and approaches towards water management internally within the European food sector. In total, responses were received from 497 food companies (breweries, dairies, and meat) from Denmark, France, Germany, Italy, Netherlands, Spain and UK. The large majority of respondents represented small enterprises. Detailed outcome of this task is reported in /Ref. 2.23/ and also published scientifically, Appendix 6 (Pedersen et al., 2017).

The main findings from the surveys were:

- Companies in the food sector are dominated by a strong production/operations mindset. New water activities therefore have to be designed and implemented in close collaboration with internal production/operations.
- Water related activities are often at the policy-level (communication, goal-setting etc.). Water management is less likely to be part of recognition/rewards, employee training, partnerships etc.
- Neither direct customers nor end consumers are expected to react negatively to water reuse. Therefore, there is little support to the view that new types of water reuse will inspire consumer boycotts etc.
- Key external stakeholders (customers and investors) do not pay special interest to water issues.
- Competition in the marketplace limits investments in water technology.
- The relative emphasis on business cases as well as the maximum accepted payback time of new investments influences the average level of water management activity.
- The optimal water project is easy to understand, can be introduced quickly, and pays off within a reasonable timeframe. Projects not meeting these criteria are difficult to sell within the organization.

The findings in this survey are interesting in the sense that they were valid in 2015 but are contradicted by the achievements in DRIP by end of 2021. Thus, one important outcome of DRIP is a changed mindset among DRIP end users concerning possibilities embedded in improved internal water management – an outcome that is possibly also seen internationally and would be reflected if a similar survey be conducted in 2022.
The CBS survey is also in agreement with the findings in the WP1 DAFC report that there are not any non-regulatory barriers to water reuse, see Appendix 1 DAFC (Danish Agricultural Council. Undated b)).

Task 2.8 – Development of (new) business models

Management and operation of water efficient technological solutions in the food processing industry may be highly complex and require in-depth technical skills and experiences that eventually could be established in-house, outsourced to external partners or a combination of those two approaches.

During fall 2015 and spring 2016, CBS designed and implemented sixteen qualitative interviews with managers from the Danish food and beverage industry. The interviews examined in depth how companies internally work with water management. Moreover, the interviews provided insight into how business practitioners perceive internal and external barriers for strengthening the water management efforts within the organization. The interviews included in total two dairies, six breweries, two meat and one fish processing company as well as four technology companies, all from Denmark.

On this basis, CBS has proposed four business models appropriate for the Danish food and beverage industry:

- The "All-In" business model: This model is the most commonly seen among the DRIP partners and other interviewed companies. It addresses companies aimed for a bulk market, and which have a direct purchase-and-ownership approach to investments. It focuses on the core production or service activities of the companies, and suggests an investment strategy in water efficiency and technology via the companies' own equity or loan-taking, they can afford.
- The "Buy-In" business model: This model addresses the small companies such as micro-breweries targeting a branded market, and with little or no equity or loan opportunities and therefore rents capacity from other colleagues. It focuses on building up the core production or service activities of these companies through partnerships with the larger companies, and suggests an alliance strategy with the host company, which invests in water efficiency and technology via their preferred business model.
- The "Job-Done" business model: This model addresses all sizes of companies either targeted bulk or branded markets or both. It is generally based on performance contracting, executed through partnership between the company and the technology provider, and based on a medium- or long-term contract of cooperation. It suggests dividing the tasks between core production activities executed by the host companies and the externalized services provided by the technology provider. The investment strategy for water efficiency and technology laid out in this model is based on a shared ownership between the host company and the technology provider during the contract period. This is done in order to avoid the here-and-now intensive investment capital for the host organization and to secure more jobs for technology providers in the long run. The partnership can stretch the total investment over the years of the contract in order to strengthen the collaborating companies' investments/sales via the collaboration, where each of the partners do what it is best at.
- The "Hybrid" business model: This model addresses all sizes of companies either targeted bulk or branded markets or both. In this model the company chooses parts of the above business models case by case dependent, in order to get the best solution for the company in an overall perspective. Basically, each company may have one of the other business models as their core model and when investing in water technology equipment and/or efficiency-making, they "shop" partial bits from the other business models suggested.

The detailed outcome of this task is reported in /Ref. 2.24/.

Task 2.9 – Test and validation of business models on likely partnerships

The recommendations of Task 2.7 and 2.8 were discussed at a couple of workshops during 2016. The topic had only little traction among the DRIP food industries and technology providers, because the technological solutions were not properly identified or tested at that stage. Even during the later phases of DRIP, the business model theme did not emerge as important or of particular interest to the DRIP partners. As indicated above the "All-in" business model is the preference of the DRIP food industries and has also been chosen in those projects that have been implemented in full scale in the DRIP project portfolio in WP3. Consequently, no further testing and validation of business models have been carried out.

Task 2.10 Testing and elaboration of generic business case templates and check lists for the food sector

Projects to be executed in WP3 – Project Execution were primarily prioritized according to their water saving potentials, their business attractiveness in terms of return on investment and their market potential (market readiness and scalability). Hence, to support the prioritization process in the DRIP project portfolio, all funding applications should include a preliminary assessment of water saving potential and a preliminary business case assessment. For the latter, a business case template including check list for costs to be included was developed, /Ref.2.25/.

In practice, the template was used only in a few projects. Most business case assessment in pilot projects were pretty simple – based on (rough) estimates of CAPEX and associated savings in OPEX due to reduced water consumption and possible savings in other resources (e.g. chemicals and energy). With respect to full scale implementation projects, investment decisions were based on requirements/standards of the individual end user partners.

As a consequence, Task 3.3 in WP3 of the revised Project Plan was never initiated.

Task 2.11 – Commercialization of technological capabilities

This task was intended to develop business plan(s) for the partnership to commercialize and scale-up technological solutions developed during the course of DRIP. The focus was on (i) those technological solutions that combine technologies from two or more DRIP partners and (ii) how DRIP as a platform and partnership can add value to the commercialization of those solutions that are based on technology from one DRIP partner only.

The DRIP partnership was approached by the Danish Trade Council in Chicago in 2017 offering assistance to promote DRIP solutions on the US market through establishment of a Danish Industrial Water Platform (building on the success of the Danish Water Technology Alliance focusing on water utilities). The platform should provide access to US customers through 2-3 annual market visits (Great Lakes area, California, and Texas), attracting America customer delegations on fact-finding and demonstration trips to Denmark, and help platform members understand key regulatory and commercial drivers in food processing market.

Three DRIP partners participated in a pilot market visit to Wisconsin in January 2017. For other DRIP partners the food processing market in US was already an important market. While the DRIP partners consider DRIP as very valuable in developing business opportunities further, the real value only emerges when concrete new technological solutions have been developed, tested and documented and thus can be promoted through seminars and workshops in US and demonstrated through site visits to the DRIP food industry partners in Denmark. In that context, DRIP had not progressed sufficiently in 2017, and the platform was not launched. A similar initiative from the Danish Trade Council in Sydney, Australia in 2020 was also turned down – in this case primarily because Australia is a remote and not prioritized market for participating DRIP partners.

An initial market analysis was carried out by DRIP management in early 2019 to support development of business plans and suggest a preliminary market prioritization, /Ref. 2.26/. In this context, the following commercial considerations were valid:

- Project opportunities at other production facilities of DRIP end-users in Denmark and abroad
- Project opportunities with existing key accounts of DRIP technology providers in Denmark and abroad
- Attractive F & B markets in general where Danish competitiveness is high

Different background information was applied in this analysis, including:

- Mapping of international production facilities of DRIP end users based on annual reports, web pages etc.
- Global Water Intelligence market reports including (i) Water for Food and Beverage – Opportunities in water efficiency and gaining value from wastewater, 2012 and (ii) Global Water Intelligence: Industrial Water Technology Markets, 2015
- DI (Confederation of Danish Industries) Global Water Market Analysis, 2018

The analysis showed that the five DRIP food industry partners had more than 170 production facilities in 140 countries outside Denmark. More than 100 production facilities were located in only four countries (United Kingdom, Sweden, China, and Germany). TripleNine had only one production facility outside Denmark (in Norway).

On the basis of above three analyses a preliminary market prioritization was suggested:

- First priority: those countries that appear in top-12 in all three analyses - Germany, France, United Kingdom, China – industrial water use is 75-80 % of the total water withdrawal in Germany, France and United Kingdom
- Second priority: those countries that appear in top 12 in two of the three analyses – Sweden, USA, Canada, Australia – industrial water use is >50% of total water withdrawal in Sweden and Canada
- Third priority: those obvious missing that need to be considered – e.g. India.

Among the first priority countries China may be subject to discussion – the market attractiveness is obvious, but the Danish competitiveness is challenged and China is far away. Some companies think that China is a "must be" market, others think the opposite. DRIP solutions for breweries may be an opportunity in China with 27 Carlsberg owned breweries.

The market analysis was discussed at a Steering Committee meeting in Spring 2019. The SC found that it was premature to develop business plan(s) before DRIP solutions were tested and documented in full scale. Then priority would be selling the solutions to other DRIP food partner locations in Denmark and abroad, followed by markets in Europe and US where their local representatives have adequate competencies to sell the solutions.

In conclusion, no further activity was carried out under this task. Development of business plans and market initiatives directed at other non-food sectors (Task 2.12 in project plan) were not initiated or prioritized for the same reason.

C.3. Work package 3 – Project execution[6]

C.3.1 Background and objectives

The overall objective of Work Package 3 (WP3) was to develop, test, document and demonstrate a project portfolio comprising promising scenarios for water savings and reuse. This was based on the pre-assessments of WP2 and novel ideas identified subsequently. The project portfolio was developed sequentially – as 1) pre-studies, 2) pilot projects, and 3) full-scale implementation projects. Minor pre-studies were launched by the DRIP partnership management – all other project stages were prepared by partners, reviewed by partnership management and approved by the DRIP Steering Committee based on a standardized approach and a standard proposal and reporting format including regular status report and completion reports, see Fig. C.7 and /Ref. 3.1/.

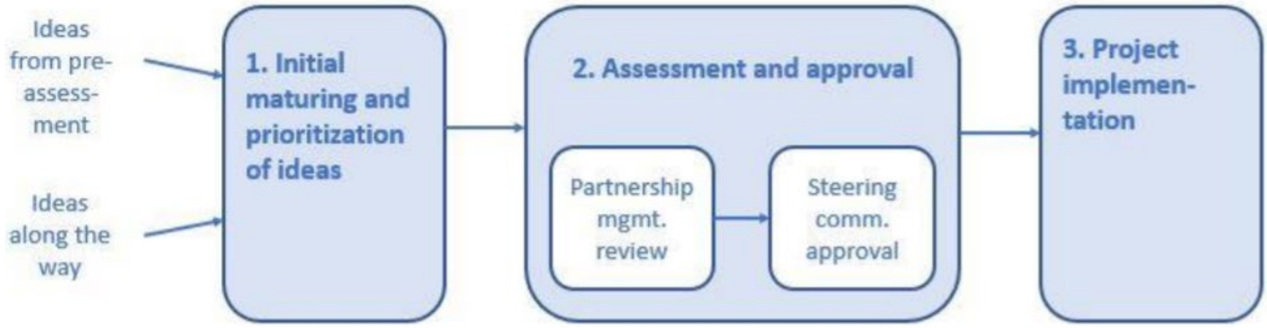

Figure C.7: *Project portfolio development approach*

C.3.2 Summary of work package deliverables

Task 3.1 Execution of technology testing and documentation projects

Project portfolio overview

During the early stage of DRIP in 2015-2017 and following the pre-assessments in WP2, projects were launched on an individual basis. As part of the mid-term evaluation in Q4 2017, identified project ideas and pre-study projects were thoroughly reviewed to mature the project portfolio. Projects were prioritized by the participating end-users (food industries) followed by a matchmaking effort identifying interested technology and knowledge partners. This review was actually a Task 3.2 activity but better described here.

The outcome was a project portfolio comprising more than 20 projects. Few of these project ideas were abandoned after initial testing. During the later stages of DRIP additional promising project ideas were identified and subsequently included in the project portfolio. This resulted in a project portfolio comprising a total of 28 projects. Table C.4 provides a list of the individual projects and partner participation. The number of projects at the individual end-

[6] All references in this section refer to Appendix 3 if not otherwise written

Table C.4: Partner participation in WP3 project portfolio

Central role	C (green)
Minor role	M (orange)

Project title	Type of project	Arla	Carlsberg	Danish Crown	HK Scan	TripleNine	L&F	Alfa Laval	Aquaporin	Grundfos	Liqtech	Siemens	Tetraoak	Ultraaqua	DMRI	TI	IN-Water	DHI	DTU Env.	DTU Food	DTU Kemiteknik	KU	CBS
Arla																							
WP3-Arla-1: HighQ - Upgrading of treated process wastewater to high quality utility water	Pilot	C						C		C			M	M		C		M	M	M		C	
WP3-Arla-2: Backwash water from groundwater sand filters	Pilot	C									C								C				
WP3-Arla-3: Identification, removal and recovery of waste stream substances at Arla DP and Nr. Vium Dairy	Full scale trials	C										M				C							
WP3-Arla-4: Evaluation of heat pumps and direct heat exchange in water projects	Pre-study	C						M								C							
WP3-Arla-5: Applicable pretreatment of wastewater for reverse osmosis recovery	Pilot	C						M								C							
WP3-Arla-6: CIP by measures, phase 2	Full scale trials	C															C						
Carlsberg																							
WP3-Carlsberg-1: Reduction of water / chemical using burst cleaning technique in fermenters	Full scale trials		C					C															
WP3-Carlsberg-2: Beverage water solution	Pilot		C										C					M					
WP3-Carlsberg-3: Identification and overcoming barriers for water reclamation and reuse in Carlsberg Fredericia	Pre-study		C							C				M		M	C	M	M	M		M	
WP3-Carlsberg-4:Experimental verification of detailed AOP design for RO permeate polishing	Pilot		C											C					C	M			
WP3-Carlsberg-5: Recycle water quality - Full scale assessment, on/off-line control and QA	Full scale support		C							C		C		C					C	C			
WP3-Carlsberg-6: CIP by measures	Pre-study		C														C						
Danish Crown																							
WP3-Danish Crown-1: Concentration of stick water from fat melting	Pilot			C									C		C			M	M				
WP3-Danish Crown-2: Removal of blood from slaughterhouse process water	Pilot			C									C		C					M			
WP3-Danish Crown-3: Treated process water for the dehairing process	Pilot			C										C	C					M		M	
WP3-Danish Crown-4: Reuse of tripe cooling water for cleaning of stomachs	Pilot			C											C								
WP3-Danish Crown-5: Recycling of rinse water from gut conveyor	Pilot			C											C					M			
WP3-Danish Crown-7: Reuse of cooking water from autoclaves	Pre-study			C				M						C	C	C	C			M			
WP3-Danish Crown-8: Treated process water for the dehairing process - full scale project	Full scale			C				M				M		C	C								
HK Scan																							
WP3-HK Scan-1: Upcycling of water in the chicken feet processing line	Full scale				C									M	C			M	M				
Triple Nine																							
WP3-TripleNine-1: Avoiding overfoaming during CIP of evaporators	Pre-study					C		M			M		M				C						
WP3-TripleNine-3: Removal of TVN from stick water and controlled struvite precipitation	Pilot					C					M					C	M						
WP3-TripleNine-4:Concentration of products from floor water and landing water	Pilot					C					M					C							
WP3-TripleNine-5: Regulatory challenges in use of reclaimed water and foam from the landing water	Full scale support					C										M				C			
WP3-TripleNine-6: CIP optimization	Pilot					C						M				C	M						
Industry cross cutting projects																							
WP3-Industry-1: Recycled water for evaporative cooling towers (Tulip)	Pilot	M	M	C	M	M				C		C		C	M				M				
WP3-Industry-2: Water catalogue for use of treated process water in the meat industry	Pre-study			C	M									C	C					M			
WP3-Industry-3: Characterization and removal of low-level bio-effluent organic matter, growth potential and specific compounds in pure and ultrapure water streams intended for reuse	Pilot	M	M											C					C				

users are, with the exception of HK Scan, fairly evenly distributed (five to seven projects at each end-user). At Arla, the projects have been conducted at two different locations and at Danish Crown at four different locations plus one more location where “low-hanging fruits” have been harvested.

Among the seven technology providers, Ultraaqua has been comprehensively involved participating in 11 projects (and with a central role in 8) and benefitting already commercially from DRIP participation. Also, Alfa Laval and Tetra Pak have been substantially involved in seven and five projects respectively. Aquaporin was involved in the early exploration of some

project ideas but they were not included in the project portfolio as their technologies at that stage were less mature than the requirements among DRIP end-users. Ultraaqua, Siemens, Grundfos and Alfa Laval have all delivered technological solutions or equipment to full scale scale implementation of projects in the DRIP project portfolio.

Among the knowledge providers (universities, GTS-institutes and consultants), Technological Institute, DMRI, DTU Environment and DTU Food have all been substantially involved, in 9-10 projects each. IN-Water, a start-up consultant that became a DRIP partner when DHI pulled out of DRIP by end of 2017, has participated in seven projects.

At end-user level, some of the projects were linked. Either they addressed the same challenges - two projects at Arla (WP3-Arla-1 and 5) and two projects at Triple Nine (WP3-TripleNine-1 and 6) - or they comprised different stages of the same project - three projects at Carlsberg (WP3-Carlsberg-3, 4 and 5), two projects at Danish Crown (WP3-Danish Crown-3 and 5), and two projects at Triple Nine (WP3-TripleNine-4 and 5).

Of the 28 projects, 5 are pre-studies, 16 are pilot projects and 7 are full scale projects (including full scale trials and support to full scale projects), see Table C.5. One of the full-scale trial projects (WP3-Carlsberg-1) was unsuccessful, while two of the pilot projects (at Danish Crown) have subsequently been implemented in full scale (WP3-Danish Crown-4 and 5). Thus, in total eight projects resulted in full scale implementation. Seven completed pilot projects offer opportunities to move into full scale implementation while three of the pre-studies are attractive to bring into pilot phase. Two cross-cutting pilot projects (WP3-Industry-2 and 3) are of a different supportive nature that will facilitate concrete full-scale implementation of projects.

Table C.5: *Project types in DRIP project portfolio at the participating end-users*

End-user	Pre-studies	Pilot projects	Full-scale projects	Total
Arla	1	3	2	**6**
Carlsberg	2	2	2	**6**
Danish Crown	1	5	1	**7**
HK Scan			1	**1**
TripleNine	1	3	1	**5**
Industry - crosscutting		3		**3**
Total	**5**	**16**	**7**	**28**

Based on the 6R approach, the project portfolio in WP3 was developed with a view to demonstrating water saving and reuse technologies within the following four themes (refer to DRIP Project Plan, revised December 2017, WP3 Task 3.1):

- Water savings with existing and new production technology
- Water reclamation and recycling technologies based on a water-fit-for-purpose approach
- Reduced water usage during CIP cleaning using new and existing CIP strategies and technologies
- Test and documentation of effluent treatment and reuse scenarios also based on a water-fit-for-purpose approach

A fifth theme - water reclamation and recycling for washing and cleaning in open food processing systems (slaughterhouses) – was also part of the revised Project Plan but no projects within this theme were prioritized.

Most of the projects (17 in total), see Table C.6, relate to the theme "Water reclamation and recycling technologies". The projects tested different treatment trains with particular focus on filtration technologies (micro-, ultra- and nanofiltration, reverse osmosis) and UV disinfection technologies, which also were central for the effluent treatment and reuse scenarios. Other separation technologies were tested including flotation and centrifugation, the latter however unsuccessful. One project successfully demonstrated crystallization as a pre-treatment solution.

Three projects related to CIP included sensor-based solutions promoting a "CIP-by-measure" approach. Burst cleaning technologies were tested in one project and was also the focus of two identified projects (Cleaning of fish cookers at Triple Nine and Cleaning of silos at Danish Crown Food) that were abandoned after initial testing due to less promising results and lack of resources with the participating partners.

Table C.6: *Technology testing and development themes in the project portfolio*

End-user	Water savings with existing and new production technology	Water reclamation and recycling technologies	Reduced water usage during CIP cleaning using new and existing CIP strategies and technologies	Test and documentation of effluent treatment and reuse scenarios	Total
Arla	1	3	1	1	**6**
Carlsberg		1	2	3	**6**
Danish Crown	1	6			**7**
HK Scan		1			**1**
TripleNine		3	2		**5**
Industry		3			**3**
Total	**2**	**17**	**5**	**4**	**28**

Only two projects were within the theme "water saving with existing and new technology". However, this theme was addressed through direct implementation by three of the five end-users themselves of a total of 11 "best practices" opportunities or "low-hanging fruits" (Arla: 1; Danish Crown: 6; and HK Scan: 4) identified during the pre-assessments in WP2 or emerging from the increasing awareness on water savings and water efficiency at the end-users created by DRIP participation.

Each project was reported in a standard completion report (including a summary, major deliverables, contribution to overall DRIP success criteria, and next steps) and a number of annexes (including project proposal, technical annexes and project portfolio indicators) - in total more than 1,000 pages of documentation, /Ref. 3.2- 3.30/.

In addition, a 2-page executive summary was prepared for each project and included in Appendix 4 to this report.

Project portfolio water saving potentials

Water savings and increased water efficiency were the main success criteria of DRIP. The water savings at end user level achieved and demonstrated as part of DRIP are summarized in Table 3.7.

In total, water savings of 1.44 Mio. m^3/year or 32 % of the total water consumption at the five end-users have been achieved or demonstrated by DRIP. This corresponds to the annual domestic water consumption of 36,000 persons. Two third of the water savings has been achieved in terms of implemented projects and "low-hanging fruits" or projects under implementation. The remaining one third has been demonstrated through successful pre-studies or pilot projects, most of which are under consideration for implementation by the end-users.

At end-user level, achieved water savings vary considerably from almost 10% at HK Scan and TripleNine to an astonishing 58% at Carlsberg Fredericia achieved through the establishment of a major water recycling plant treating almost all process water in the brewery. Establishment of this plant has been supported by three projects in the DRIP project portfolio (WP3-Carlsberg-3, 4 and 5). For the meat industry, bringing the water catalogue developed in the cross-cutting project (WP3-Industry-2) into a national guideline will pave the road for additional water savings at the same level or higher than the 10-15% implemented or demonstrated in DRIP.

Table C.7: *Summary of water savings achieved and demonstrated in DRIP*

END-USER	Arla	Carlsberg	Danish Crown	HK Scan	TripleNine	Total
Total annual water consumption, m3	**1.600.000**	**750.000**	**1.635.000**	**416.000**	**131.350**	**4.532.350**
DRIP total annual water savings, %	42%	63%	15%	9%	9%	32%
DRIP implemented annual water savings 2015-2021, %	15%	58%	11%	9%	9%	20%
DRIP demonstrated annual water savings beyond 2021, m3	27%	5%	4%		0,2%	12%
DRIP total annual water savings, m3	**673.600**	**475.000**	**240.300**	**39.500**	**12.315**	**1.440.715**
DRIP implemented annual water savings 2015-2021, m3	242.600	435.000	176.300	39.500	12.000	905.400
- Low hanging fruits	*190.000*		*82.500*	*17.000*		*289.500*
- Implemented projects	*22.600*	*435.000*	*15.800*	*22.500*		*495.900*
- Projects under implementation	*30.000*		*78.000*		*12.000*	*120.000*
DRIP demonstrated annual water savings beyond 2021, m3	431.000	40.000	64.000		315	535.315
- Pre-studies	*125.000*	*40.000*	*35.000*			*200.000*
- Pilot projects	*306.000*		*29.000*		*315*	*335.315*

Table C.8 provides an overview of the individual projects in the entire project portfolio with specific information on project type, factory water consumption, process water saving potentials, contribution to factory water saving potential, and type and water savings achieved through implementation of low-hanging fruits at the different locations.

Table C.8: *Water saving potentials in project portfolio including low-hanging fruits*

Project title	Project type	Proces water saving potential (m3/year)	Process water consumption (m3/year)	Proces water saving potential %	Factory water consumption (m3/year) from pre-assessment	Factory water saving potential %	Comment
Arla		**673.600**			**1.600.000**	**42,1%**	
Arla Food Ingredients		**623.600**			**750.000**	**83,1%**	Factory water consumption excludes water in the whey supplied
Low hanging fruits identified/inspired by DRIP - "just-do-it"	Full scale	190.000				25,3%	Seal water management using fixed flow valves on pump seals
WP3-Arla-1: HighQ - Upgrading of treated process wastewater to high quality utility water	Pilot	150.000 - not included					Pilot testing failed to demonstate vviable solutions due to high content of Ca and Cl in wastewater. Project idea was further pursued in WP3-Arla-3 and WP3-Arla-5.
WP3-Arla-2: Reclaiming backwash water from groundwater sand filters	Pilot	21.000	22.000	95%		2,8%	
WP3-Arla-3: Identification, removal and recovery of waste stream substances at Arla DP and Nr. Vium Dairy	Full scale	2.600	7.500	35%		0,3%	
WP3-Arla-4: Evaluation of heat pumps and direct heat exchange in water projects	Pre-study	125.000	125.000	100%		16,7%	
WP3-Arla-5: Applicable treatment of wastewater for reverse osmosis recovery	Pilot	285.000	365.000	78%		38,0%	
Arinco, Videbæk		**50.000**			**850.000**		
WP3-Arla-6: CIP by measures, phase 2	Full scale trials	50.000	595.000	8%		5,9%	20.000 m^3/year already achieved in 2021, another 30.000 m^3/year expected
Carlsberg		**475.000**			**750.000**	**63,3%**	Factory water consumption is 2020 figures excluding 542.000 m3 in the product itself.
WP3-Carlsberg-1: Reduction of water / chemical using burst cleaning technique in fermenters	Full scale trials	33.000 - not included	41.250	80%		4,4%	Tested technology failed to produce the required cleaning of fermenters due to presence of "burned yeast" and tank "calculus".
WP3-Carlsberg-2: Beverage water solution	Pilot	130.000 - not included	130.000	100%		17,3%	Total process consumption is 410.000 m^3/year of which 280.000 m^3/year ends up in the product. The demonstrated savings is not included in the total saving as presently the project has been made redundant by establishment of the Water Recycling Plant
WP3-Carlsberg-3: Identification and overcoming barriers for water reclamation and reuse in Carlsberg Fredericia	Prestudy	See WP3-Carlsberg-5					
WP3-Carlsberg-4:Experimental verification of detailed AOP design for RO permeate polishing	Pilot	See WP3-Carlsberg-5					
WP3-Carlsberg-5: Recycle water quality - Full scale assessment, on/off-line control and QA integration	Full scale	435.000				58,0%	
WP3-Carlsberg-6: CIP by measure	Pre-study	40.000	200.000	20%		5,3%	The estimated saving of 40.000 m^3 is included in the total savings, because it represents a potential expansion of production capacity that will not have an impact on the Water Recycling Plant (WP3-Carlsberg-5)
Danish Crown		**240.300**			**1.635.000**	**14,7%**	
DC Horsens		**91.100**			**925.000**	**9,8%**	
Low hanging fruits identified/inspired by DRIP - "just-do-it"	Full scale	1.100				0,1%	Datt-Schaub, reuse of degreased process water in gut conveyors, 1.100 m^3/year
WP3-Danish Crown-1: Concentration of stick water from fat melting	Pilot	1.000	N.A.			0,1%	Recovery of water from stick water that can substitute use of drinking water in other processes.
WP3-Danish Crown-2: Removal of blood from slaughterhouse process water	Pilot	11.000	17.600	63%		1,2%	
WP3-Danish Crown-3: Treated process water from dehairing process	Pilot	See WP3-DC-8					
WP3-Danish Crown-8: Treated process water from dehairing process	Full scale	78.000				8,4%	

Table C.8 cont'd: *Water saving potentials in project portfolio including low-hanging fruits*

Project title	**Project type**	**Proces water saving potential (m^3/year)**	**Process water consumption (m^3/year)**	**Proces water saving potential %**	**Factory water consumption (m^3/year) from pre-assessment**	**Factory water saving potential %**	**Comment**
DC Beef Holsted		**15.800**			**220.000**	**7,2%**	
WP3-Danish Crown-4: Reuse of tripe cooling water for cleaning of stomachs	Full scale	6.000	14.000			2,7%	
WP3-Danish Crown-5: Recycling of rinse water from gut conveyor	Full scale	9.800	20.000	49%		4,5%	
DC Food, Vejle		**77.800**			**300.000**	**25,9%**	
Low hanging fruits identified/inspired by DRIP -"just-do-it"	Full scale	42.800				**14,3%**	Improved cocktail sausage production and cleaning process, 23.000 m^3/year. Adjustment of can washing machines, 19.800 m^3/year
WP3-Danish Crown-7: Reuse of cooking water from autoclaves	Pre-study	35.000	48.000	73%		**11,7%**	Water saving potential reflects 80-90% of water use for autoclaves (35.000 m^3/year) and 40-50% of make-up water use for cooling towers (13.000 m^3/year)
DC Food, Svenstrup		**35.600**			**100.000**	**35,6%**	
Low hanging fruits identified/inspired by DRIP - "just-do-it"	Full scale	18.600				18,6%	Reuse of cooling water in deep-drawing machines, 5.600 m^3/year. Replacing nozzles in cooling, 13.000 m^3/year
WP3-Industry-1: Recycled water for evaporative cooling towers	Pilot	17.000	17.000	100%		17,0%	
DC Food, Esbjerg		**20.000**			**90.000**	**22,2%**	
Low hanging fruits identified/inspired by DRIP - "just-do-it"	Full scale	20.000				22,2%	Recirculation of water for soup cooling for cleaning purposes, 20.000 m^3/year
HK Scan		**39.500**			**416.000**	**9,5%**	
Low hanging fruits identified/inspired by DRIP - "just-do-it"	Full scale	17.000				4,1%	Recirculation of cooling water for topseal packaging machines (7-9.000 m^3/year). Replacing high pressure valves in drum sieves in the garbage room (2-4.000 m^3/year). Adjusting valve diameter in various machines (2-4.000 m^3/year). Better management of water flow and pressure in various machines (2-4.000 m^3/year)
WP3-HK Scan-1: Reuse of water in the chicken feet processing line	Full scale	22.500	50.000	45%		5,4%	Completion report states water savings of 20-25.000 m^3/year. Water consumption in chicken feet processing line is 200 m^3/day
Triple Nine		**12.315**			**131.350**	**9,4%**	Factory water consumption excludes 236.340 m^3/year in the incoming fish
WP3-TripleNine-1: Avoiding overfoaming during CIP of evaporators	Pre-study	0					Project was closed down. Further activities conducted in WP3-TripleNine-6: CIP optimization
WP3-TripleNine-3: Removal of TVN from stick water and controlled struvite precipitation	Pilot	0					Treatment test unsuccesful due to a combination of damage of treatment unit and proces alterations creating inhomgeneous process water
WP3-TripleNine-4:Concentration of products from floor water and landing water	Pilot	See WP3-TripleNine-5					Completion report estimates water saving in the process to be 50-70%, Appendix and presentation at 2019 workshop says 12.000 m^3 eller 75 %.
WP3-TripleNine-5: Regulatory challenges in use of reclaimed water and foam from landing water	Full scale support	12.000	16.000	75%		9,1%	
WP3-TripleNine-6: CIP optimization	Pilot	315	4.500			0,2%	
Industry crosscutting projects							
WP3-Industry-2: Water catalogue for use of treated process water in the meat industry	Pilot	N.A.					
WP3-Industry-3: Characterization and removal of low-level bio-effluent organic matter and growth potential	Pilot	N.A.					Development and improvement of methodologies to characterize and remove low level organic matter as well as specific compounds in pure and ultrapure water like e.g. NF/RO permeates and condensates to enable quantification of the risks and define criteria for safe storage and use/reuse hereof.
Total		**1.440.715**			**4.532.350**	**31,8%**	

Project portfolio energy and resource saving potentials

While water was the overarching focus of DRIP, the business rationale for the participating food industries and technology providers is justified not only by water savings and water reuse but also by associated energy savings as well as possible savings or recovery of resources (e.g. chemicals and food products) in the process and wastewater. Thus, the true-cost-of-water and the value of water saved or reused is not reflected in the water price alone but also in the value of energy (in terms of heat) and resources bound in the process and wastewater. Several projects clearly demonstrated this in the DRIP project portfolio.

- The water recycling plant at Carlsberg Fredericia, supported by three DRIP projects (WP3-Carlsberg -3,4 and 5) contributes to a 10% savings in energy consumption at the brewery due to production of biogas and pre-heated water
- In the two CIP by measure projects (WP3-Arla-6 and WP3-Carlsberg-6), energy and resource savings contribute positively to the business cases.
- While water savings have been marginal, resource saving and recovery from process water streams contribute positively to business cases in four projects – WP3-Arla-3, WP3-Carlsberg-1, WP3-Danish Crown-1 and WP3-Danish Crown-2
- The project WP3-Arla-4 demonstrated that introducing direct heat exchange and large-scale heat pumps offer opportunities for recovering heat from cooling towers and evaporative coolers to the tune of 2.6 MW and 9.9 MW respectively equivalent to the consumption and thus potential water saving of 125.000 m3/year. However, 97% of the associated savings in operating cost were associated with energy savings and only 2-3% results from water savings.
- The flotation plant for concentration of landing water at TripleNine Thyborøn, the ongoing establishment of which has been supported by two DRIP projects (WP3-TripleNine-4 and 5), has an estimated energy savings of 304 tons coal/year and 174.935 Nm^3 gas/year corresponding to a reduced CO_2 emission of 955 tons/year.

As part of DRIP, IN-Water has initiated development of a MS Excel based tool to quantify the true costs of water use in different unit operations across a manufacturing facility. The purpose of the tool is that following a through water audit, it will be possible to pin-point the "hot-spots" of financial costs related to water use in a facility. This may not be the processes with the highest water consumption - but more likely processes where materials such as raw materials and products are lost with wastewater - and downstream costs for wastewater treatment and disposal adds to the financial water cost allocated to this specific process. IN-Water will beyond DRIP continue to develop the tool and seek further funding to solve the inherent challenge on how to distribute costs when water is used more than once. In this way the tool can be used for scenario analysis and optimization to identify scenarios with lower total true costs of water - and not only a baseline tool to evaluate the current state of the facility.

Project portfolio indicators

A series of eight indicators was developed to provide a snapshot of the proposed technological solutions in the WP3 project portfolio. This included water saving potentials, technical complexity, risk profile, business case (in terms of investment and payback period) and market attractiveness (in terms of readiness and scalability) - each of them graduated in three score levels, see Table C.9 below.

Table C.9: *Terminology for project portfolio indicators*

Annual water saving potential				CAPEX		Payback period	
Process level		**Factory level**					
	<20%		<10%		<750.000 DKK		<1 year
	20-50%		10-20%		750-2.500.000 DKK		1-2 years
	>50%		>20%		>2.500.000 DKK		>2 years
Technical complexity		**Food safety and quality risks**		**Market readiness**		**Scalability**	
	Can be implemented by in-house staff		No food safety and quality risks identified due to the process or specific application		Substantial development in technology is required before introduction in the market		Applicable in industries with similar production (e.g. cheese production)
	External assistance required- smaller retrofit or simple new solution		Minor food safety and quality risks requiring alterations in e.g. pipe systems and/or documentation		Minor adaptations of the technology and new documentation is required		Broadly applicable in the specific food industry (e.g. dairies)
	External assistance required – larger retrofit or complex new solution		Major food safety and quality risks requiring regulatory approval/dispensa tion based on documentation/ research		The technology is fully developed/ adapted, supported by solid documentation and thus ready for market dissemination		Broadly applicable in the food and beverage industry – and eventually also in other industry segments

An overview of WP3 project portfolio indicators appears in Table C.10. The project portfolio characteristics can be summarized as follows:

- Process water saving potential in two third of the projects exceeded 50% while their individual contribution to factory water savings also for two third of the projects was less than 10%
- The technical complexity of the projects was fairly evenly distributed on the three levels
- Food safety and quality risk were only minor issues in two third of the projects and only a major issue in two projects requiring regulatory approval/dispensation based on documentation/research
- More than half of the projects required investment higher than 2.5 Mio. DKK and had a payback period exceeding two years. However, payback period exceeded five years only for three projects
- Almost half of the technological solutions tested were ready for market dissemination while another half of the project portfolio requires minor adaptation of the technology and new documentation
- Almost all technological solutions in the project portfolio were broadly applicable in the food and beverage industry and eventually also in other industry segments

Table C.10: *Project portfolio indicators. *) for a single CIP line*

Project title	Water saving potential		Technical complexity	Food safety and quality risk	CAPEX invest-ment	Payback period	Market readiness	Scalability
Arla	**Process**	**Factory**						
WP3-Arla-1: HighQ – Upgrading of treated process wastewater to utility water	N.A.	💧💧	⚙⚙⚙	✚✚	$$$	⌛⌛⌛	👍👍	🏭🏭🏭
WP3-Arla-2: Backwash water from groundwater sand filters	💧💧💧	💧	⚙⚙	✚✚	$$	⌛⌛⌛	👍👍	🏭🏭🏭
WP3-Arla-3: Identification, removal and recovery of waste stream substances at Arla DP and Nr.Vium dairy	💧💧	💧	⚙	✚	$	⌛	👍👍👍	🏭🏭🏭
WP3-Arla-4: Evaluation of heat pumps and direct heat exchange in water projects	💧💧💧	💧💧	⚙⚙⚙	✚	$$$	⌛⌛⌛	👍👍	🏭🏭🏭
WP3-Arla-5: Applicable pretreatment of waste water for reverse osmosis	💧💧💧	💧💧💧	⚙⚙⚙	✚✚	$$$	⌛⌛⌛	👍👍👍	🏭🏭🏭
WP3-Arla-6: CIP by measures, phase 2	💧	💧	⚙	✚✚	$ *)	⌛	👍👍👍	🏭🏭🏭
Carlsberg								
WP3-Carlsberg-1: Reduction of water/ chemicals using burst cleaning techniques	💧💧💧	💧	⚙	✚	$$	⌛	👍👍👍	🏭🏭
WP3-Carlsberg-2: Beverage water solutions	💧💧💧	💧	⚙⚙⚙	✚	$$$	⌛⌛⌛	👍👍	🏭🏭🏭
WP3-Carlsberg-3: Identification and overcoming barriers for water reclamation and reuse	N.A.	💧💧💧	⚙⚙⚙	✚✚✚	$$$	⌛⌛⌛	👍👍	🏭🏭🏭
WP3-Carlsberg-4: Experimental verification of detailed AOP design for RO permeate polishing	💧💧💧	💧💧💧	⚙⚙	✚✚	$$$	⌛⌛⌛	👍👍	🏭🏭🏭
WP3-Carlsberg-5: Recycling water quality – full scale assessment, on/off-line control and QA integration	N.A.	💧💧💧	⚙⚙⚙	✚✚	$$$	⌛⌛⌛	👍👍👍	🏭🏭🏭
WP3-Carlsberg-6: CIP by measure	💧💧	💧	⚙⚙	✚✚	$ *)	⌛⌛	👍👍	🏭🏭🏭
Danish Crown								
WP3-Danish Crown-1: Concentration of stick water from fat melting	💧	💧	⚙⚙	✚✚	$$$	⌛	👍👍	🏭🏭
WP3-Danish Crown-2: Removal of blood from slaughterhouse process water	💧💧💧	💧	⚙⚙	✚✚	$$$	⌛⌛	👍👍	🏭🏭🏭
WP3-Danish Crown-3: Treated process water for the dehairing process	💧💧💧	💧💧	⚙⚙⚙	✚✚✚	$$$	⌛⌛⌛	👍👍	🏭🏭🏭
WP3-Danish Crown-4: Reuse of tripe cooling water for cleaning of stomachs	💧💧	💧	⚙	✚	$	⌛	👍👍👍	🏭🏭🏭
WP3-Danish Crown-5: Recycling of rinse water from gut conveyor	💧💧	💧	⚙	✚	$	⌛	👍👍👍	🏭
WP3-Danish Crown-7: Reuse of cooking water from autoclaves	💧💧💧	💧💧	⚙⚙	✚✚	$$$	⌛⌛	👍👍	🏭🏭🏭

WP3-Danish Crown-8: Treated process water for dehairing process – full scale	💧💧💧	💧	⚙⚙⚙	👤👤👤	$$$	⌛⌛⌛	👍👍👍	🏭🏭🏭
HK Scan								
WP3-HK Scan-1: Upcycling of water in the chicken feet processing line	💧💧💧	💧	⚙	👤👤	$$	⌛⌛	👍👍	🏭🏭
TripleNine								
WP3-TripleNine-1: Avoiding overfoaming during CIP of evaporators	💧💧💧	💧	⚙⚙	👤	$$	⌛⌛⌛	👍👍	🏭🏭
WP3-TripleNine-3: Removal of TVN from stick water and controlled struvite precipitation	💧💧💧	💧	⚙⚙⚙	👤👤	$$$	⌛⌛⌛	👍	🏭🏭🏭
WP3-TripleNine-4: Concentration of products from floor water and landing water	💧💧💧	💧	⚙⚙	👤👤	$$$	⌛⌛⌛	👍	🏭🏭🏭
WP3-TripleNine-5: Regulatory challenges in use of reclaimed water and foam from landing water	💧💧💧	💧	⚙⚙	👤👤	$$$	⌛⌛⌛	👍👍	🏭🏭🏭
WP3-TripleNine-6: CIP optimization	💧	💧	⚙⚙	👤👤	$$	⌛⌛	👍👍	🏭🏭🏭
Industry crosscutting								
WP3-Industry-1: Recycled water for evaporative cooling towers	💧💧💧	💧💧	⚙⚙⚙	👤	$$	⌛⌛⌛	👍	🏭🏭
WP3-industry-2: Water catalogue for use of treated process water in the meat industry	💧💧💧	💧💧💧	⚙⚙⚙	👤👤👤	$$$	⌛⌛⌛	👍👍	🏭🏭🏭
WP3-Industry-3: Characterization and removal of low-level bio-effluent organic matter and growth potential	N.A	N.A	⚙⚙	👤👤	$$$	⌛⌛⌛	👍👍	🏭🏭🏭

Task 3.2 System analysis, scenario development, prioritization and evaluation

The evaluation and prioritization of project ideas maturing the project portfolio was carried out in as part of this task but described under **Task 3.1**.

The intended system analysis and scenario development in terms of additional mapping activities on a higher level of detail or of not yet mapped production activities with end-users (on top of pre-assessments done in WP2) was not initiated. Priority was given to bring the projects in the project portfolio to pilot stage at least instead of ending up with a project portfolio comprising more but less developed projects.

Task 3.3 Supporting projects through preparation of investment business cases

This task was never initiated, se Section C.2, task 2.10.

C.4 Work package 4 – Project foundation[7]

C.4.1 Background and objectives

The background for this Work Package 4 (WP4) was to bring the scientific knowledge and approaches at the knowledge partners (particularly the universities) into play to provide a foundation and support for the technology development and implementation in the WP3 project portfolio. This was achieved by establishing a range of theme-based university driven research tasks, characterized by a relevance across projects in WP3 and subsequently by generic approaches. The tasks were based on demands from at least one end-user and/or one technology provider, and this connection was linking the research activities with the technology development and demonstration in the specific projects in WP3.

The overall objectives of this work package WP4 were to fill in the gaps between current knowledge/available best practices and needs identified from the projects and partners through longer forward-looking activities.

C.4.2 Summary of work package deliverables

To fulfill the objectives WP4 included a number of tasks, and the activities and outcomes are presented below.

Task 4.1 - Identification of the optimal water quality for a given purpose (water for given processes, CIP rinsing, cooling towers etc.)

It is essential that water used for a certain purpose meets the water quality required for this use. Therefore, the highest water quality may not be required for all purposes, so identifying and achieving the right quality for a given use is the key to be more water efficient. This requires monitoring of the water quality and assessment of the risk for using a given water quality for a given purpose.

Monitoring programs. A main requirement for obtaining an optimal water quality is establishing a proper monitoring program for the water quality, and a subsequent evaluation of the measured water quality. Contributions were delivered to and reported as part of the following projects

- WP3-Arla-1: HighQ – Upgrading of treated process wastewater to high quality utility water
- WP3-Arla-2: Reclaiming backwash water from groundwater sand filters
- WP3-Carlsberg-5: Recycle water quality – Full scale assessment, on/off line control and QA integration

Chemical risk assessment & treatments. The main activities were related to the planning, development and implementation of the Water Recycling Plant at Carlsberg (WP3-Carlsberg-5). Initially, as a part of the feasibility study (WP3-Carlsberg-3), a chemical risk assessment (Fig. 3.7) was conducted, where all chemicals handled at the site were evaluated. In total, 250 compounds were identified and evaluated, mainly whether the compounds can be removed by the planned treatment processes. The mass flow and concentration of the compounds were estimated as well as the dilution. Based on the chemical characteristics of the compounds, their treatability with biological treatment was modelled, as well as the treatability with reverse osmosis. The overall purpose was to estimate the concentration of the compounds in the treated water to evaluate whether any compounds that may pass the treatment barriers could

[7] References in this section refer to Appendix 5 if not otherwise written

induce a potential risk associated with its exposure and/or effects (Hedegaard et al., 2017, 2018). These evaluations were used when it was considered at Carlsberg whether a final polishing step based on advanced oxidation processes (AOP) should be included.

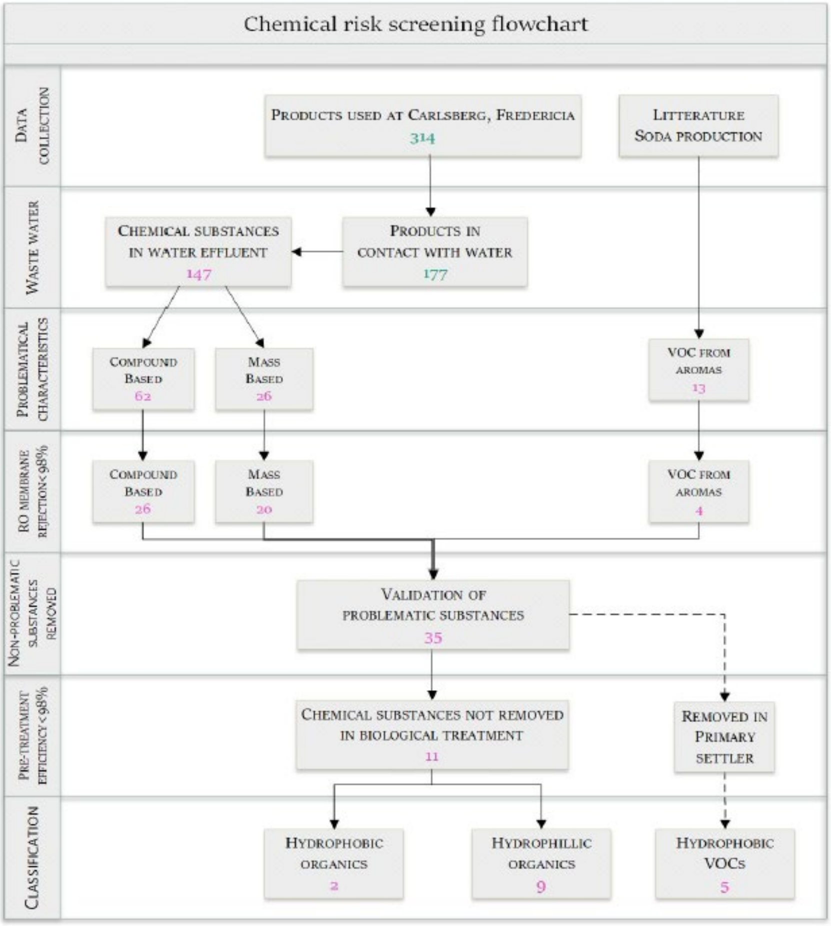

Figure C.7. *Conceptual flow chart of the screening processes of potential compounds in the recovered water at Carlsberg (related to projects Nos. WP3-Carlsberg-3 and WP3-Carlsberg-5).*

The study also included evaluation and effects of various water sources e.g. rainwater run-off and how that would affect the resulting water quality as well as evaluation of the required water quality of the treated water to prevent corrosion in the distribution system (Schliemann-Haug & Albrechtsen, 2020b).

Based on the chemical risk assessment, a monitoring program was established to evaluate the performance of the Water Recycling Plant, which was a substantial part of the foundation for the acceptance of the treatment train by the authorities. During the upstart of the Water Recycling Plant the resulting water quality was continuously evaluated whether it was fit-for-purpose.

A potential new technology (Vacuum-UV) was evaluated to polish the treated water to remove residuals of specific organic compounds of concern or general organic matter which could give rise to microbial aftergrowth (Schliemann-Haug & Albrechtsen, 2019a, 2020a; Goonesekera, et al., 2021). This was addressed in WP3-Carlsberg-4, and WP3-Industry-3.

In relation to using recycled water in cooling towers (WP3-Industry-1) water quality is also an issue, particularly the microbial water quality, and we provided a review of the microbial growth, potentials for monitoring and how to prevent and remove biofilm in these systems as a foundation for the re-design and management of cooling towers (Schliemann-Haug & Albrechtsen, 2019b).

Task 4.2 - Further development of the eco-efficiency concept, including an eco-efficiency light tool

Eco-efficiency is an assessment of the environmental impact relative to the creation of a value, i.e. creating a product or a service. Eco-efficiency is a combination of environmental life-cycle assessment and economic valuation. Basically, it focuses on supporting an increase in productivity or value creation, monetary or otherwise, while using fewer resources and/or lowering the environmental impact. An eco-efficiency study evaluates options for technology development or replacement, in comparison with a "business as usual" case. As such, eco-efficiency most often compares two or more systems, establishing which system is more eco-efficient, rather than whether a product is eco-efficient on its own.

A full eco-efficiency evaluation was carried out for the following three specific projects in WP3 where particular relevant insights into the sustainability of the systems were wanted:

WP3-HKScan-1: Upcycling of water in the chicken feet processing line (Zhang et al., 2017). A couple of scenarios were analysed and compared with the base line scenario (the present situation). The basic principle was to reuse the water from one rinsing step in a step earlier (upstream) in the process where the chicken feet were dirtier (Fig. 3.8). This analysis showed

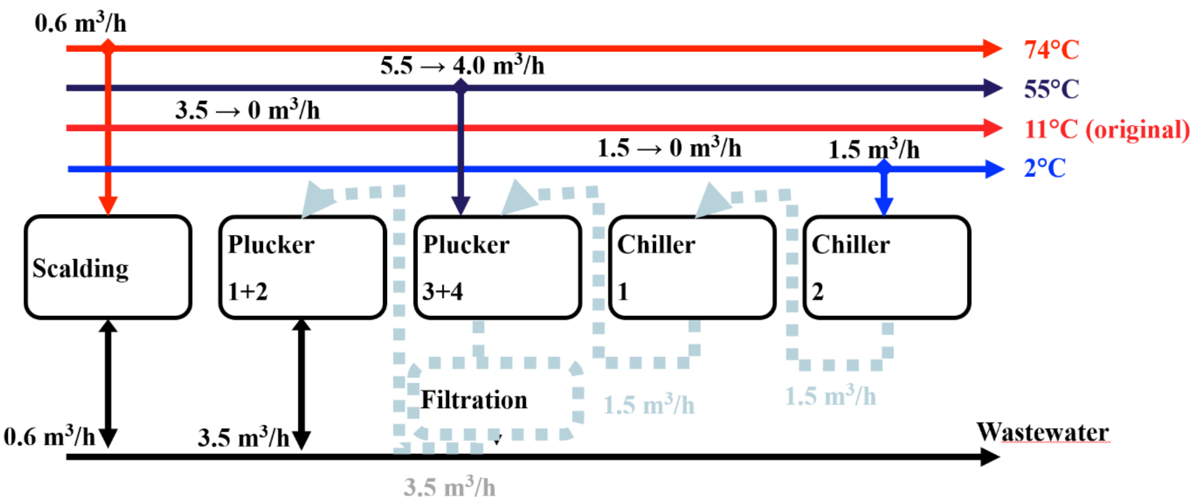

Figure 3.8. *Chicken feet processing line with water reuse. Upcycling of water from downstream process to upstream dirtier process.*

that the economic burden of reuse practice would be negligible. Beside the substantial water saving, heating was also saved and this was the most influencing cost item and therefore the established reuse practice was a more eco-efficient solution.

WP3-Danish Crown-1: Concentration of stick water from fat melting (Guberman et al., 2017). The fat melting process in the slaughtering process generates large volumes of stick water. The stick water is wastewater with high quality protein in the dry matter content of the wastewater, and because of the high protein content the stick water is difficult to treat. Part of the stick water is treated at a biogas plant, however, a large part is continuously being treated at a municipal wastewater treatment plant (together this was considered as the business-as-usual option). The new option was to install an on-site wastewater treatment facility with reverse osmosis treatment technology to recover some water and the protein for use as a product. Compared to the old option, the new option had a smaller environmental impact for 10 out of 12 non-toxicity categories, including climate change. Main uncertainties were related to the emissions of some toxic substances, which was recommended for further investigation to confirm the results.

WP3-Carlsberg-5: Water Recycling Plant at Carlsberg (Wörlen et al., 2021). Two options were compared: a) The business-as-usual option, using drinking water for all processes and delivering wastewater to a municipal waste water treatment plant. b) The new option, where on-site advanced water treatment recovered most of the water to be used for process water. Sludge removed in the treatment of the water was treated locally in a biogas facility. The new option showed large reductions in fresh water and marine eutrophication impact categories but improved the climate change impact categories slightly. It was an important learning that despite the production of biogas, avoided heat loss and use of certified wind energy on-site, there was virtually no improvement in the climate change performance from the installation of the decentralized water treatment (new option) because of intensified treatment compared to conventional wastewater treatment. It will be important in the future to spend more effort to establish the certainty of these results, as well as make actual further improvements to the climate change performance of the installation by the reduction of chemical use, and establishing and to the largest extent possible avoiding biogas leakage.

Eco-efficiency light. A simple eco-efficiency analysis was carried out for project *WP3-Arla-2: Backwash water from groundwater sand filters* (DTU Environment, 2019) and an eco-efficiency screening study was carried out for *WP3-Carlsberg-3: Identification and overcoming barriers for water reclamation and reuse in* Carlsberg Fredericia (Godskesen et al., 2019). The latter project was a pre-study for *WP3-Carlsberg-5* mentioned above. The project group intended to develop an 'Eco-efficiency-light'-tool, which would allow a fast eco-efficiency screening of proposed technological developments. The idea was to identify a sub-set of information and selected parameters relevant for a quick yet reliable evaluation of new technical solutions. Unfortunately, the limited access to cases and their data prevented the development of such a generic framework. A dedicated effort to collect and evaluate a larger number of case studies still has the potential to develop a screening tool, but will require future investment from project partners and further transparency in cost and material use of proposed technology developments.

Task 4.3 - Development of strategies for more efficient CIP cleaning

This task focused on reducing water consumption in food industries by improving Cleaning-in-Place (CIP) operations, considering that the execution of CIP is critical for food safety and public health. The task was partly fulfilled as a part of a PhD-study 'Novel Strategies for Cleaning-in-Place Operations', Appendix 6 (Yang, 2018).

In an initial mapping study at Carlsberg Danmark A/S (Fredericia), the most time- and resource-consuming CIP operations were identified. The suggestions for improving the existing CIP systems in the brewery were representative for the processes where similar CIP systems are utilized in other fields. Based on this mapping a range of studies were conducted.

Firstly, a study based on the cleaning of an industrial brewery fermenter demonstrated how to analyse historical cleaning data to improve cleaning operations in the future. The proposed analysis approach detected anomalies in a CIP system online and offline. A trouble-shooting process was advised to guide the operators to diagnose the likely anomaly or fault, Appendix 6 (Yang et al., 2018b).

Secondly, Computational Fluid Dynamics (CFD) was used to simulate the displacement of a cleaning agent (Fig. C.9) by water during the intermediate and final rinses of pipe systems. This identified dead zones and calculated rinsing time, minimum water consumption, minimum generation of waste water, and pressure drop, etc. The cross-comparison of different pipe geometries indicated key factors that determine the cleanability of various pipe elements. CFD modelling proved to be an effective tool for the hygienic design of pipe systems and the optimization of pipe rinsing, Appendix 6 (Yang et al., 2018a).

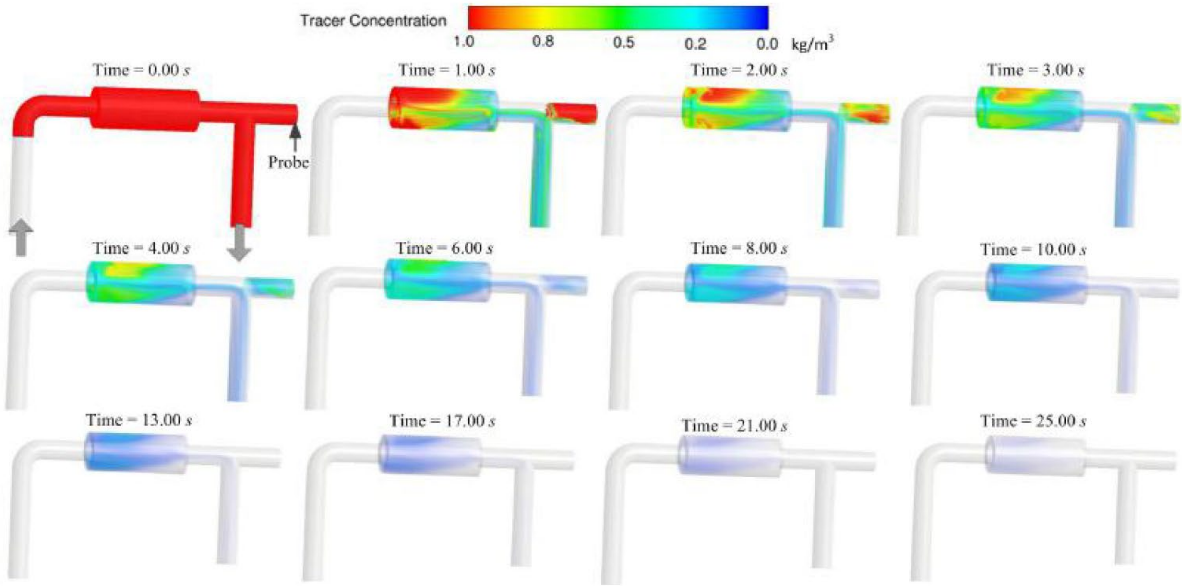

Figure C.9: *Example of Computational Fluid Dynamics (CFD) modelling of displacement profiles of liquids during CIP over time in an example of a technical installation (Yang et al., 2018a).*

Thirdly, burst cleaning technique to clean the tank surfaces soiled by egg yolk (added as a model food soil) was studied. The experimental observations were compared with the conventional cleaning method using continuous flows. Different cleaning parameters were investigated and optimized for removing the soil material at the lowest cleaning costs. The primary findings from pilot-scale studies were then examined in scale-up tests, Appendix 6 (Yang et al., 2019b).

Fourthly, a three-stage measurement-based partial recovery CIP system was designed. The purpose of the design was to prolong the lifetime of cleaning liquid by only recycling the clear liquid from the CIP outlet. The proposed approach was compared with other cleaning scenarios for economic analysis. Lastly, the cleaning of toothpaste soil from vessel surfaces by impinging liquid jet and falling film was studied. The properties of the soil material and the removal force were investigated. The adhesive removal model presented by other researchers was applied to describe the experimental results. This study is the first work to integrate the effect of soil soaking and the cleaning by falling film into the existing model, Appendix 6 (Yang et al., 2019a).

Three projects (WP3-Carlsberg-6, WP3-Arla-6, and WP3-TripleNine-6) have focused on reducing the use of water, energy and chemicals in CIP operations by introducing a “CIP-by-measure” approach as alternative to existing and more traditional “CIP-by-recipe” approaches.

Results have been promising in the Carlsberg and Arla cases and are reported as part of WP3 reporting.

Task 4.4 - Process Analytical Chemistry for new water streams

For reuse of reverse osmosis (RO) membrane permeate instead of potable water in the dairy industry the quality of reclaimed water (i.e. qualitative and quantitative information on which compounds permeate the membranes) was established. Ultrafiltration, RO, and RO polisher (ROP) permeate was characterized with regard to organic and inorganic compounds. Results indicate that smaller molecules and elements (such as phosphate, but mainly urea and boron) pass the membrane, and a small set of larger molecules (long-chain fatty acids, glycerol-phosphate, and glutamic acid) are found as well, though in minute concentrations (<0.2 μM). Growth experiments with two urease-positive microorganisms, isolated from RO permeate, showed that the nutrient content in the ROP permeate supports limited growth of one of the two isolates, indicating that the ROP permeate may not be guaranteed to be stable during protracted storage, Appendix 6 (Skou et al., 2018).

Task 4.5 – Microbial safety and quality of process water streams

In process water streams subsequently treated for water reuse, the risk of deterioration of the microbial water quality was considered regarding growth potential during storage and distribution and how to prevent the deterioration.

Reverse Osmosis (RO) membranes, used for filtration in the food industry, are highly susceptible to biofilm formation, which may decrease performance and increase industrial costs. In order to identify and characterize the biofilm forming communities, industrial RO membranes from whey water recovery lines in a dairy industry were investigated before and after Cleaning-In-Place (CIP) treatments. Phase contrast and Confocal Laser Scanning Microscopy (CLSM) were used to visualize the biofilms. The Heterotrophic Plate Count (HPC) and yeast population were enumerated, and 16S, 26S, and ITS rRNA sequencing were employed to identify the dominant isolates. A dense biofilm of the filamentous yeast species *Saprochaete clavata* and *Magnusiomyces spicifer* was observed together with budding yeasts and Gram-negative bacteria. The filamentous yeasts had long hyphae, which spatially dominated the biofilm on the retentate and permeate surface and they were not inactivated by the standard CIP treatment. Since neither plate counts nor DNA-based methods reflect the wide membrane coverage of the filamentous yeasts, their role in biofouling may easily be underestimated, Appendix 6 (Vitzilaiou et al., 2019).

Representative strains from the two filamentous yeast species were further characterized and displayed similar physiological and biochemical characteristics. Both strains tested were able to grow in twice RO-filtrated permeate water and metabolize the urea present. Little is known about the survival characteristics of these strains. According to the heat tolerance experiments, the D60°C of *S. clavata* and *M. spicifer* is 16.37 min and 7.24 min, respectively, while a reduction of 3.5 to >4.5 log (CFU/mL) was ensured within 5 min at 70°C. UV-C light at a dose level 10 mJ/cm2 had little effect, while doses of 40 mJ/cm2 and upward ensured a ≥4log reduction in a static laboratory scale set-up. The biofilm forming potential of one filamentous yeast and one budding yeast, *Sporopachydermia lactativora*, was compared in assays employing both nutrient rich as well as nutrient poor media, and only the filamentous yeast was able to create biofilm. However, on RO membrane coupons in static systems, both the budding yeast and a filamentous yeast were capable of forming single strain biofilms and when these coupons were exposed to different simulations of CIP treatments both the filamentous and budding yeast survived these. The dominance of these yeasts in some filter systems tested, their capacity to adhere and their tolerance toward relevant stresses as demonstrated here, suggest that these slow growing yeasts are well suited to initiate microbial biofouling on surfaces in low nutrient environments, Appendix 6 (Vitzilaiou et al., 2020).

A way to handle and prevent microbial aftergrowth is UV inactivation. The UV inactivation kinetics of microorganisms and their potential tolerance towards UV were assessed. A range of bacteria and yeasts isolated from slaughterhouse and dairy associated process water streams were investigated together with a naturally aggregating and a non-aggregating *S. aureus* strain. Also, bacteriophages from dairy associated cultures were investigated at different wave lengths and in different matrices. UV doses up to 360 mJ/cm^2 were employed. The UV tolerance varied significantly among different microorganisms and phages. Aggregating bacterial strains were more robust than non-aggregating both between and within species. Biofilm forming filamentous yeast strains from membrane operations exhibited particularly high tolerance towards UV. Interestingly, log-linear relationships between inactivation and doses applied were never observed at the levels and doses applied since all microorganisms and phages displayed some degree of tailing effect in this system, Appendix 6 (Vitzilaiou et al., 2021).

Task 4.6 – Selection and implementation of new and relevant sensors for documentation of safe reclamation and reuse of water in food manufacturing industries

To reduce water consumption by treatment and reuse requires water quality monitoring to ensure that the water quality is adequate and safe to use in the production. Therefore, we reviewed the technologies suitable for real-time monitoring of physical, chemical and microbial water quality parameters in water types relevant to the food and beverage industry. Furthermore, aspects were discussed when considering designing water quality monitoring in the food and beverage industry (Tang & Albrechtsen, 2020). The review showed that while technologies for real-time monitoring are rapidly developing, it is nonetheless still technologies for quantifying physiochemical parameters such as pH, turbidity and conductivity that are the most commonly used due to their applicability in different water types and ability to provide a real-time signal. Parameters such as conductivity, TOC and pH can act as indicators of specific water quality issues caused by e.g. process failure, unwanted mixing of water types and microbial growth. It may be more feasible to monitor indicator parameters than multiple specific parameters in cases where it e.g. may not be possible to monitor the specific parameter in real-time or the risk is caused by several contaminants making monitoring complex and expensive.

Technologies for monitoring inorganic and microbial water quality are often automated versions of laboratory methods. Often these technologies are installed online, withdrawing a sample from the water stream with a fixed time interval. The analysis often requires reagents and sample preparation time. The microbial methods may require incubation time of several hours. Consequently, the results are not real-time and it may be more feasible to do regular manual sampling. Real-time methods based on UV-Vis and NIR spectroscopy are available for aggregated organic parameters such as TOC and COD. New technologies are emerging that e.g. are based on new measuring principles such as biosensors. Others, such as the electronic tongue, is based on well-known sensor technologies, but apply advanced computer algorithms to process the data and gain more specific data. The possibility for monitoring more water quality parameters in real-time can lead to better monitoring in the food and beverage industry, thereby enabling reuse of water streams while ensuring that the water quality is adequate and that food safety is not compromised.

From the original planning of the project the on-line sensor developed by Grundfos (BACMON) was seen as a major asset and a core in this task. Unfortunately, Grundfos took BACMON off the market and reduced their engagement in the project which reduced the activities in this task substantially.

Tasks not conducted

Finally, a total of four tasks (Task nos. 4.8-4.11) related to treatment of stick water and brine, to scalability of good practices solutions and new business cases and business models to be initiated on demand according to the DRIP Project Plan were not prioritized by DRIP partners and thus not conducted.

C.4.3 Conclusions and future directions

- Use of proper chemical risk assessments and solid monitoring programs can pave the road for successful implementation of new technologies with reuse of water. This facilitates the approval from the authorities of the new approaches
- Evaluation of environmental sustainability can be a useful tool in the choice between different technologies. However, the economy has a strong influence on decisions and therefore eco-efficiency provides an even better decision support although data acquisition and handling are time consuming
- CIP-cleaning can be optimized e.g. by CFD-modelling as well as by monitoring the efficiency of the CIP process to obtain 'CIP-by-measure' instead of 'CIP-by-recipe'
- Deep and advanced chemical analysis of selected chemical species can be a way to monitor the efficiency of a process
- Although well implemented, advanced treatment processes such as e.g. membrane filtration may still have some caveats, e.g. growth of microorganisms on the backside of the membrane or passage of small molecules, which may support microbial growth. After polishing may be required by oxidation of the compounds (e.g. AOP) or disinfection (e.g. UV) to prevent the microbial after growth
- On-line sensors still have a huge potential but it remains a challenge to get the more advanced sensors implemented

D. Management and collaboration

The extent of the partnership with initially 18 partners, of which a large part had not collaborated with each other beforehand, caused a long period for establishment of project platforms and idea development. Once collaboration and constellations were established, the partnership gave basis for innovative projects that could not have been defined beforehand.

Openness between partners, especially within the same group of partners (knowledge providers, technology providers, end users) could be challenging at times, as there were overlaps and competition between the partners regarding business and knowledge areas. This came up as an issue though it was an important consideration when creating the DRIP partnership to have partners with complementary expertise and competencies. However, the partners were building trust over time, which eliminated the largest part of such challenges. In some cases, though projects were delayed due to need of clarification of responsibilities and degree of knowledge and data sharing within projects, mostly in the early phase of projects, where a trustful cooperation was not yet established.

The governance structure allowed partners to investigate ideas, but also showed the dependencies of motivated and engaged project participants from the partners involved. The change in the partnership structure, with fewer work packages, and a stronger technical project management was very beneficial for the progress of the projects within the partnership. A clearer and earlier definition of common working processes and standardization of templates could have facilitated a broader cooperation and knowledge sharing between partners. Further, this demonstrates, that in large and complex partnership, there is a need for continuous evaluation, to ensure the optimal and most progressive partnership performance.

As part of the interview, the partners were asked for an advice for companies considering participating in a partnership as DRIP. A collection of the replies was:

On partner commitment and outcome:

- Prioritize time for participation in the partnership, believing that it provides value, especially in the beginning
- Communicate clearly about the company's competencies and what you can contribute to the collaboration
- Be selective, go for a few good projects that have high value - with strategic significance and generic - "kill your darlings"
- Go for it and contribute, set aside time and be open about your business
- Ensure continuity in resources and responsibilities in relation to the work with the partnership

On partnership structure and governance:

- Make sure to ensure structure from the start - which documents to work on, make sure that mappings are made quickly so that projects can be started.
- Make sure that there is a project manager as a dedicated function in the partnership

E. Other results and assessments

E.1 Dissemination

Appendix 6 provides an overview of dissemination activities in DRIP including international peer reviewed scientific papers (14 in total), Book chapters (1), Danish and international conference presentations (29 in total), PhDs partly funded by DRIP (4 in total), and B.Sc. and M.Sc. student projects that have been attached to DRIP (12 in total).

Appendix 7 provides an overview over non-scientific articles published online, in technical magazines and newspapers, as well as radio coverage. More than 30 articles arise from the communication of the lighthouse projects at the participating end-users lighthouse projects. The list in Appendix 7 is not exhaustive but serves to demonstrate the outreach of the light house ambitions and results.

E.2 Internal partnership evaluation

Individual interviews with all partners were performed in 2020, to collect and organize the experiences of the partners gained through the DRIP partnership period.

Generally, there was a high degree of satisfaction from participating in DRIP. The partners highlighted the acquirement of new knowledge, the developed solutions and applications, the general raised awareness of water saving potentials, the networking abilities, and the triple-helix structure.

The partners emphasized the allocation of resources within the partnering companies, e.g., the prioritization of resources, the continuity of staffing, and the sense of ownership of the individuals, as one of the largest determinants of success of the individual company. It was emphasized, that the level of competencies and knowledge available within the DRIP participants was enormous, and the level of engagement when partners were reaching out was very high. Further, some of the technology providers emphasized that solutions and developmental activities that could be beneficial for one end user in DRIP would not necessarily be prioritized by a technology provider possessing the relevant competencies. This is due to internal structures, where larger companies will consider new activities and potential business areas contribution to value creation into account, also large technology companies have development plans as driver for prioritizations in the short to medium term. Smaller technology companies are more agile in responding to new opportunities. However, the partnership has demonstrated examples of both larger and smaller technology companies choosing to focus on new business areas.

On a concluding note, many partners expressed a clear interest in participating in future partnerships or similar activities after the finalization of DRIP. There was a wide agreement that the obtained benefits from the established network and cooperation will span beyond the lifetime of DRIP.

Appendix 6: Scientific publication and conference proceedings/presentations

International scientific papers

Damkjær, K.B., K.M. Sørensen and S.B. Engelsen (2019). Investigating the feasibility of using near-infrared spectroscopy for inline monitoring of the salt content in industrial process water, in *Proc. 18th Int. Conf. Near Infrared Spectrosc.*, Ed by S.B. Engelsen, K.M. Sørensen and F. van den Berg. IM Publications Open, Chichester, pp. 23–30.

Pedersen, E.R.G. et al (2017): What is in a Business Case? Business Cases as a Tool-in-Use for Promoting Water Management Practices in the Food Sector*, Journal of Cleaner Production,* 62:1048-1060

Skou, P.B., T.H.A. Berg, S.D. Aunsbjerg, D. Thaysen, M.A. Rasmussen, F.W.J. van den Berg (2017). Monitoring Process-Water Quality Using Near Infrared Spectroscopy and Partial Least Squares Regression with Prediction Uncertainty Estimation, *Applied Spectroscopy*, 71:410-421

Skou, P.B., S.E. Holroyd, F.W.J. van den Berg (2017). Tutorial – applying extreme value theory to characterize food processing systems, *Journal of Chemometrics*, e2896:1-12

Skou, P.B., B. Khakimov, T. Hansen, S. Aunsbjerg, S. Knøchel, D. Thaysen, F.W.J. van den Berg (2018). Chemical characterization by GC-MS and ICP-OES of membrane permeates from an industrial dairy ingredient production used as process water, *Journal of Dairy Science*, 101:135–146

Stoica, I.M., H. Babamoradi, F.W.J. van den Berg (2017). A statistical strategy to assess cleaning level of surfaces using fluorescence spectroscopy and Wilks' ratio, *Chemometrics and Intelligent Laboratory Systems*, 165:11-21

Stoica, I.M., E. Vitzilaiou, H. Lyng Røder, M. Burmølle, D. Thaysen, S. Knøchel, F.W.J. van den Berg (2018). Biofouling on RO-membranes used for water recovery in the dairy industry, *Journal of Water Process Engineering*, 24:1-10

Vitzilaiou, E., Aunsbjerg, S. D., Mahyudin, N. A., and Knøchel, S. (2020). Stress Tolerance of Yeasts Dominating Reverse Osmosis Membranes for Whey Water Treatment. *Front. Microbiol*. 11, 816. doi: 10.3389/fmicb.2020.00816. (Journal IF 4.235)

Vitzilaiou, E., Kuria, A.M., Siegumfeldt, H., Rasmussen, M.A., Susanne Knøchel, S. (2021). The impact of bacterial cell aggregation on UV inactivation kinetics. Water Research, Volume 204, 1 October 2021, 117593

Vitzilaiou, E., Stoica, I. M., and Knøchel, S. (2019). Microbial biofilm communities on Reverse Osmosis membranes in whey water processing before and after cleaning. J. Memb. Sci. 587. doi: 10.1016/j.memsci.2019.117174. (Journal IF 7.183)

Yang, J., Jensen, B. B. B., Nordkvist, M., Rasmussen, P., Gernaey, K. V. & Krühne, U., (2018a). CFD modelling of axial mixing in the intermediate and final rinses of cleaning-in-place procedures of straight pipes, *Journal of Food Engineering*. 221, p. 95-105. DOI: 10.1016/j.jfoodeng.2017.09.017

Yang, J., Jensen, B. B. B., Nordkvist, M., Rasmussen, P., Pedersen, B., Kokholm, A., Jensen, L., Gernaey, K. V. & Krühne, U., (2018b). Anomaly Analysis in Cleaning-in-Place Operations of an Industrial Brewery Fermenter, *Industrial & Engineering Chemistry Research*. 57, 38, p. 12871-12883 13 p. DOI: 10.1021/acs.iecr.8b02417

Yang. J., Bhagat, R.K., Fernandes, R.R. , Nordkvist, M., Gernaey, K.V. , Krühne, U. , Wilson, D.I., (2019a). Cleaning of toothpaste from vessel walls by impinging liquid jets and their falling films: Quantitative modelling of soaking effects. *Chemical Engineering Science*, Volume 208, 23 November 2019, 115148. doi.org/10.1016/j.ces.2019.08.006

Yang, J., Kjellberg, K., Jensen, B. B. B., Nordkvist, M., Gernaey, K. V., Krühne, U. (2019b). Investigation of the cleaning of egg yolk deposits from tank surfaces using continuous and pulsed flows. *Food and Bioproducts Processing, Food and Bioproducts Processing*, Volume 113, January 2019, Pages 154-167 DOI: 10.1016/j.fbp.2018.10.007

Book chapters

Knøchel, S.: Fit-for-purpose water reuse in the food in Sustainable Use of Water by Industry: Perspectives, Incentives, and Goals 2021 Eds. Davis & Rosenblum. IWA Publishing

Conference contributions.

Biofilms 8 (Århus, May 2018): Poster: Heat and CIP tolerant filamentous yeasts dominating Reverse Osmosis membrane biofilms. E. Vitzilaiou, I. Stoica, H. L. Røder, M. Burmølle, S. D. Aunsbjerg, Dorrit Thaysen, S. Knøchel.

Danish Water Forum - Annual Conference (Copenhagen, January 2020): Oral presentation:Triple-helix partnership as a tool for increased water efficiency in the food and beverage industry. Bengaard, H., Albrechtsen, H-J., Rasmussen, J. & Christiansen, A.

Danish Water Forum - Annual Conference (Copenhagen, 31st January 2019): Oral presentation: UV-C tolerance of microorganisms from food processing water streams. E. Vitzilaiou and S. Knøchel.

Danish Water Forum - Annual Conference (Copenhagen, January 2018): Oral presentation: Introduction to the DRIP project; Chair; J. Rasmussen.

Danish Water Forum - Annual Conference (Copenhagen, January 2018): Oral presentation: Opportunities for increased water efficiency in Danish food processing industry. M. Andersen, G.H. Kristensen.

Danish Water Forum - Annual Conference (Copenhagen, January 2018): Oral presentation: Industrial cleaning-in-place processes in brewery – a systematic mapping study. J. Yang, K.V. Gernaey, U. Krühne, P. Rasmussen, A. Kokholm, M. Nordkvist.

Danish Water Forum - Annual Conference (Copenhagen, January 2018): Oral presentation: Reuse of water in Danish pork slaughterhouses. K. Sørensen, A. G. Koch, T.F. Chemnitz, L. Niss.

Danish Water Forum - Annual Conference (Copenhagen, January 2018): Oral presentation: Eco-efficiency of introducing water efficiency at the chicken feet processing line at the chicken slaughtering house HK Scan in Vinderup Denmark. Godskesen, B., Zhan, X. & Rygaard, M.

Danish Water Forum – Annual Conference (Copenhagen, January 2019): Poster presentation: Water efficient process optimization by applying flotation technology for further reuse of landing water. Rebsdorff, M.L.

Danish Water Forum – Annual Conference (Copenhagen, January 2019): Poster presentation: Aiming for reduced chloride discharge at Arla DP – simple means with significant effects. Andreasen, R.R.

Danish Microbiology Society Annual Congress (Copenhagen, November 2018): Poster: Microbiology of whey water after UF- and RO- filtration. E. Vitzilaiou and S. Knøchel.

EHEDG World Congress on Hygienic Engineering and Design (2 - 3 Nov 2016, Herning, Denmark). Poster presentation and proceeding publication. Simulation of Axial Mixing by CFD during the Rinse of CIP procedures. Yang, J., Gernaey, K. V., Krühne, U.

Food Micro Conference (Berlin, September 2018): Oral presentation: Stress tolerant biofouling communities on RO membranes used for treatment of whey water in a dairy industry. E. Vitzilaiou, I. Stoica, S. Knøchel.

Fouling and Cleaning in Food Processing Conference (Lund, Sweden, 17 – 20 April 2018): Oral presentation and proceeding publication. Cleaning of tank surfaces fouled by egg yolk. Yang, J., Kjellberg, K., Jensen, B.B.B., Nordkvist, M., Gernaey, K.V., Krühne U.

IAFP International Association of Food Protection (on-line April 2021): Oral presentation. Fit for Purpose Water Reuse in the Food Processing Industry. Microbiological challenges. S. Knøchel

IFC Water Congress (Process water and wastewater – Water management and sustainability). MCH Messecenter Herning (14-15.11.2018). Oral presentation. Water Reuse in the industry – legal, safety and quality challenges. Hansen, L.T.

IFC Water Congress (Water in the Food Industry - Water efficiency - Reduce, Reuse and Recycle). MCH Messecenter Herning (6.-7.10.2021). Oral presentation. Water reuse in operation - is drinking water the ultimate quality criteria for water (Keynote). Albrechtsen, H.-J.

IFC Water Congress (Water in the Food Industry - Water efficiency - Reduce, Reuse and Recycle). MCH Messecenter Herning (6.-7.10.2021). Oral presentation. Together Towards Zero' in practise – Implementation of large scale water recycling at Carlsberg, Denmark. Kokholm, A., Bak, S.N.

IFC Water Congress (Water in the Food Industry - Water efficiency - Reduce, Reuse and Recycle). MCH Messecenter Herning (6.-7.10.2021). Oral presentation. Risk assessment of the use of treated process water for cleaning purposes in the food industry: a case study. Truelstrup Hansen, L.

IFC Water Congress (Water in the Food Industry - Water efficiency - Reduce, Reuse and Recycle). MCH Messecenter Herning, (6.-7.10.2021). Oral presentation. Case study – from tap to treated process water in the meat industry. Sørensen, K.

IChemE Advances in Process Automation and Control 2017 (Birmingham, UK. 12– 14 June 2017): Oral presentation. Anomaly Detection and Diagnosis Using Multivariate Analysis Tools in Industrial Cleaning-in-Place Operations. Yang, J., Nordkvist, M., Gernaey, K. V., Krühne, U. (2017).

IUVA World Congress Sydney (February 2019): Oral presentation: UV-C tolerance of microorganisms from food processing water streams. E. Vitzilaiou., K. Nielsen and S. Knøchel.

IUVA Americas Conference Florida (February 2020): Oral presentation: UV treatment efficacy and bacterial cell aggregation. E. Vitzilaiou, A. M. Kuria, L. Obari and S. Knøchel.

IWA, Rambøll workshop (On-line June 2021): Oral presentation Fit for PurposeWater Reuse in the Food & Beverage Industry S. Knøchel

12th IWA International Conference on Water Reclamation and Reuse (Berlin, Germany, 2019): Oral presentation: Eco-efficiency of on-site water reclamation at a large brewery. Godskesen, B., Sundaram, D. D., Albrechtsen, H-J. & Rygaard, M.

12th IWA International Conference on Water Reclamation and Reuse (Berlin, Germany, 2019): Oral presentation: Water efficiency in food industry - ways to improvements. Hans-Jørgen Albrechtsen, H. Bengaard, J. Rasmussen

IWA World Water Congress and Exhibition (On line Copenhagen, May 2021): Poster presentation w. oral pitch. UV treatment of food processing water: efficacy towards aggregating and non-aggregating food associated microorganisms. E. Vitzilaiou, S. Knøchel.

IWA World Water Congress and Exhibition (Japan, September 2018): Poster: Microbiology of whey water after UF- and RO- filtration. Vitzilaiou, E. and Knøchel, S.

IWA World Water Congress (Tokyo, Sept 2018): Workshop on water reuse + Danish Pavillon pitch talk, S. Knøchel

Water conference, Durban (South Africa, May 2016): Theme: "Show casing the Danish Water Sector", Oral presentation S. Knøchel.

Water Reuse Association (On-line, June 2021): Oral presentation Fit for Purpose Water Reuse in the Food Processing Industry. S. Knøchel

PhDs (partly funded by DRIP)

P.B. Skou, (2017). Process-water characterization and quality monitoring in the dairy industry – moving towards replacing potable water, PhD thesis, University of Copenhagen, December 15, 2017. Currently at ARLA Food Ingredients,

I.M. Stoica, (2018). Characterization of surface fouling and biofilm formation under water reuse scenarios in dairy and meat industry, PhD thesis, University of Copenhagen, September 25, 2018. Currently at Carlsberg.

Jifeng Yang, (2018). Novel Strategies for Cleaning-in-Place Operations. DTU Department of Chemical and Biochemical Engineering. Supervisors: Krühne, U., Gernaey, K. V., Friis, A., Hansen, P. H., Mauermann, M. & Nordkvist, M.

E. Vitzilaiou (2021). Microbiological quality and safety issues associated with water reuse in the food processing industry - with focus on membrane and UV treatment. PhD thesis, University of Copenhagen Expected to hand in late 2021.

B.Sc. and M.Sc. Student projects

Yuxin Liang, 2021. UV tolerance of Lactococcus lactis phages relevant to cheese production. M.Sc. University of Copenhagen, Department of Food Science, Section of Food Microbiology. Supervisor S. Knøchel.

Sofie Halkier, 2020. CO_2 footprint and eco-efficiency evaluation of water technology at Carlsberg Brewery. B.Sc. DTU Environment. Supervisor Hans-Jørgen Albrechtsen, Martin Rygaard.

Rony Antony, 2018. Re-use and Recovery of Process Water Streams in the Food and Beverage Industry: a Comparison of Guidelines and Regulations in Different Countries. University of Copenhagen. Supervisor S. Knøchel.

Suvasini Balasubramanian, 2018. UV inactivation of bacteria from processed water in the food industry, M.Sc, University of Copenhagen. Supervisor S. Knøchel.

Kajsa Karin Marie Enhörning, 2018. Risk evaluation of reuse of water at breweries, Carlsberg. M.Sc. Eng., DTU Environment. Supervisors Hans-Jørgen Albrechtsen, Mathilde Jørgensen Hedegaard. Collaboration with Carlsberg.

Hanne Aarslev Jensen, 2018. Development of a quantitative PCR method with propidium monoazide for detection of surviving bacteria following water disinfection treatments. M.Sc. Eng. Food Technology, DTU. Supervisor Lisbeth Truelstrup Hansen.

Shwetha Meena Sakthi Nallasivam, 2018. Experimental investigation of dairy fouled membrane cleaning with help of ultrasound. DTU Department of Chemical and Biochemical Engineering. Supervisors: Ulrich Krühne, Ines Pereira Rosinha Grundtvig, Manuel Pinelo. Danish Innovation Scholarship.

Deepa Durga Sundaram, 2018. Ecoeffeciency of water reclamation at breweries, Carlsberg. M.Sc. Eng., DTU Environment. Supervisors Hans-Jørgen Albrechtsen, Berit Godskesen. Collaboration with Carlsberg. Danish Innovation Scholarship.

Niranchana Venkatesh, 2018. Techno-economic assessment of methods for calcium precipitation from dairy ultrafiltration permeates. DTU Department of Chemical and Biochemical Engineering. Supervisors: Krist V. Gernaey, Ines Pereira Rosinha Grundtvig, Pedram Ramin. Danish Innovation Scholarship.

Boyan Chen, 2017. Application of sensors in food manufactoring industry. M.Sc. Eng., DTU Environment. Supervisor Hans-Jørgen Albrechtsen. Danish Innovation Scholarship.

Sebrina Thyssen, 2017. UV treatment and inactivation of bacteria in recycled water in the food industry. M.Sc. Eng., Food Technology, DTU. Supervisor Lisbeth Truelstrup Hansen.
Xueqian Zhang, 2017. Life-cycle assessment of rinsing water management of resource recovery in food production. M.Sc. Eng., DTU Environment. Supervisors Martin Rygaard, Berit Godskesen. Hans-Jørgen Albrechtsen. Collaboration with UltraAqua, DHI, HK Scan. Danish Innovation Scholarship.

Appendix 7: Articles published in other than scientific magazines

Food-Supply: Nyt Carlsberg-anlæg kan halvere vandforbruget på øl - Food Supply DK (food-supply.dk) Publication date: June 25th, 2020

Food Marketing and Technology, Indian edition Carlsberg has inaugurated a new water recycling plant at its brewery. (fmtmagazine.in) Publication date: July 2nd, 2020

Ritzau: Rejsegilde på Carlsbergs nye vandgenindvindingsanlæg i Fredericia | Landbrug & Fødevarer (ritzau.dk) Publication date: June 29th, 2020

AquaTech: Carlsberg Fredericia brewery to cut water waste | Aquatech (aquatechtrade.com) Publication date: June 18th, 2020

Water Tech Online: Danish brewer opens water recycling plant that reuses 90% of process water | Water Technology (watertechonline.com) Publication date: May 10th, 2021

Dagligvarehandlen: Nyt anlæg vil halvere Carlsbergs vandforbrug i Fredericia | Dagligvarehandlen Publication date: June 29th, 2020

ClimateAction: Carlsberg promises to halve water consumption in sustainability pledge - Climate Action Publication date: October 1st, 2019

Fredericia Dagblad: Nyt anlæg på Carlsberg imponerede minister: - Vi kan ikke gøre det alene | frdb.dk Publication date: June 29th, 2020

Fredericia Dagblad: Carlsberg i samarbejde med Fredericia Spildevand: Nyt anlæg skal sikre mindre vandforbrug på bryggerier verden over | frdb.dk Publication date: February 9th, 2020

Food Nation Denmark: Partnering for Sustainable Water Technologies (foodnationdenmark.com) Publication date: Unknown

Landbrugsavisen: Landmænd er med til halvere spild i ølproduktionen | LandbrugsAvisen Publication date: June 30th, 2020

Clean Tech Watch: Carlsberg investerer millioner i genbrug af vand (ctwatch.dk) Publication date: September 25th, 2019

The Chemical Engineer: Carlsberg to halve water usage at Danish brewery - News - The Chemical Engineer Publication date: October 28th, 2019

Operations Engineer: Article Details Articleid=230165 | Operations Engineer Publication date: September 10th, 2020

Sustain Report: Carlsberg optrapper indsatsen for at reducere vandspild (sustainreport.dk) Publication date: February 13th, 2020

Water Online: Carlsberg Group Investment Halves Water Usage At Its Brewery In Fredericia, Denmark (wateronline.com) Publication date: September 25th, 2019

European Supermarket Magazine: Carlsberg Unveils New Water Recycling Plant | ESM Magazine Publication date: July 1st, 2020

Spotlight Mining: The World's Most Water Efficient Brewery – Spotlight Mining Publication date: July 25th, 2021

Water and Wasted Digest: Denmark Brewery Selected as Test Site for Water Recycling Plant | WWD (wwdmag.com) Publication date: June 30th, 2020

Environmental Leader: Beer Maker Carlsberg Halves Water Usage at its Brewery (environmentalleader.com) Publication date: October 30th, 2019

Horsens Folkeblad: Ny rekord-investering i Horsens: Slagteri opgraderes for trecifret millionbeløb | hsfo.dk Publication date: November 30th, 2020

Effektivt Landbrug: DC reducerer vandforbruget med ni procent på slagteri (landbrugnet.dk) Publication date: November 30th, 2020

Klimafokus: Slagteri renser og genbruger procesvandet (klimafokus.dk) Publikation date: December 1st, 2020

CSR: Clean Chicken Feet with Half the Water | CSR.dk Publication date: May 25th, 2021

DR P4 Radio: https://www.dr.dk/radio/p4vest/p4-weekend-midt-vest/p4-weekend-2018-11-03-06-03#!00:00:00 Publication date: September 3rd, 2018

Food Nation Denmark: New technology can reduce the food industry's water consumption (foodnationdenmark.com) Publication date: Unknown

Ritzau: Ny miljøteknologi kan mindske fødevarebranchens vandforbrug | Teknologisk Institut (ritzau.dk) Publication date: February 18th, 2020

Fiskeritidende: Ny teknologi kan halvere TripleNines vandforbrug- Fiskeri Tidende | Fiskeritidende.dk Publication date: February 18th, 2020

Dansk Industri: TripleNine Denmark A/S halverer vandforbruget - læs mere på DI - DI (danskindustri.dk) Publication date:

Clean Tech Watch: Ny avanceret renseteknologi vil reducere vandforbruget i fødevarebranchen (ctwatch.dk) Publication date: February 18th, 2020

Appendices - not included in the public version

Appendix 1: List of references, WP1 – Risk prevention and regulatory issues

Appendix 2: List of references, WP2 – Industry analysis

Appendix 3: List of references, WP3 – Project execution

Appendix 4: Executive summaries, WP3 Project portfolio

Appendix 5: List of references, WP4 – Project foundation