Int. j. adv. multidisc. res. stud. 2025; 5(1):452-458

Received: 02-12-2024
Accepted: 12-01-2025

International Journal of Advanced Multidisciplinary Research and Studies

ISSN: 2583-049X

Assessment and Identification of Requests for Technology and Innovation Needs within the Danish DK2020 Climate Action Plans

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DOI: https://doi.org/10.62225/2583049X.2025.5.1.3674
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Abstract

This paper identifies requests for technology and innovation needs in the climate adaptation work detailed in the Danish climate action plans, known as the Danish DK2020 Plans, which were conducted by Danish municipalities from the year 2020 and onward, gradually including all municipalities. This paper assesses the evaluation reports conducted, including the evaluation of the first 20 DK2020 municipal pilot climate plans, an evaluation report placing the adaptation work across all 98 Danish municipalities, as well as an evaluation report conducted with emphasis on Region Southern Denmark solely. No studies have so far merged and assessed the findings of the evaluation reports of the climate adaptation work described within the Danish DK2020 municipal climate action plans. This study thus provides valuable insights into the specific requests for technology and innovation needs being expressed by Danish municipalities as future focus areas in climate adaptation work.

It is concluded that the DK2020 municipal climate action plans currently emphasize 'hard' technology and lack integrated planning across sectors and municipalities, hence providing limited multifunctional outputs. Future initiatives should prioritize innovation and multifunctionality, also addressing underemphasized risks such as heat, drought, and near-surface groundwater. Nature Based Solutions (NBS), while promising, are underutilized due to reliance on voluntary participation and land competition; financial incentives are also crucial. Urban NBS implementation should integrate city development and physical planning more effectively through concepts like Sponge City and Blue-Green Infrastructure (BGI), which enhance urban resilience by absorbing and reusing rainwater. Only one-fourth of the DK2020 municipal climate plans request the need for NBS, illustrating a need for broader adoption and strategic integration of such novel approaches. Stronger integration with other sectors, such as the energy sector, could also benefit climate adaptation initiatives, as well as less prioritized climate adaptation activities, and provide multiple benefits. This could, for example, be the utilization of near-surface groundwater for renewable energy production through the supply of district heating and production of PtX through the water-demanding electrolysis process.

Keywords: Danish DK2020, Blue-Green Infrastructure (BGI), Nature Based Solutions (NBS), Denmark

1. Introduction

As the impacts of climate change intensify globally, local municipalities have emerged as pivotal actors in both mitigating and adapting to these changes. Municipalities are not only responsible for the day-to-day management of critical infrastructure and services but also play a central role in implementing long-term climate adaptation strategies. Their proximity to local populations and ecosystems places them at the forefront of addressing climate risks such as flooding, droughts, and extreme weather events. As key stakeholders, municipalities are uniquely positioned to bridge national climate targets with tangible actions that respond directly to local conditions and needs. In Denmark, the DK2020 project provides a structured approach for municipalities to develop climate action plans that align with the Paris Agreement's ambitions of climate neutrality and resilience by 2050. However, the success of these plans depends heavily on municipalities' ability to integrate technological innovations and context-specific solutions into their climate adaptation efforts. Many municipalities, particularly those in smaller or more rural regions, face distinct challenges - such as managing extensive agricultural lands or dealing with

region-specific climate impacts - that require tailored approaches beyond what global frameworks offer.

This study focuses on two Danish regions, Region Zealand and Region South, and explores how municipalities within these regions are addressing their climate adaptation needs under the DK2020 framework. Through an analysis of municipal reports and climate action plans, the research seeks to identify the specific technology requests and innovation needs that these municipalities have articulated. By doing so, the study aims to highlight the critical role municipalities play as drivers of climate adaptation innovation and as coordinators of local, national, and international efforts. Municipalities are not only implementers but also facilitators of broader stakeholder engagement in climate action. Their ability to collaborate with regional governments, knowledge institutions, and private sector actors will be essential in ensuring that technological solutions are both effective and widely adopted. This study contributes to a growing understanding of how local governments, through their unique positioning, can catalyze innovation in climate adaptation, offering valuable lessons for other regions and countries facing similar challenges.

1.1 Background of the DK2020 project

The DK2020 project showcases Denmark's efforts in tackling climate change and initially started with 20 municipalities in 2019, committed to creating climate action plans that match the goals of the Paris Agreement (UN, 2015) [5]. The aim of the DK2020 climate plans is hence for the municipalities to be climate neutral and resilient by 2050, with clear targets along a pathway that cover all areas of municipal activities related to climate mitigation and adaptation. By using the Climate Action Planning Framework (CAPF) being developed by C40 - following best practices, tools and steps of megacities - the DK2020 project hence meets international standards in addressing climate mitigation and adaptation. Thus, the CAPF is a tool for creating plans to fight climate change and make communities stronger against extreme weather etc. and helps cities in making strategies that match the goals of the Paris Agreement (UN, 2015) [5]. The tool was developed with help from cities in the C40 Climate Action Planning Pilot Program through collaborative efforts from 2017 to 2018 making improvements to the tool as they updated their own climate action plans. The CAPF was updated again in March 2020 after cities have used it for a period and shared what worked best (C40 Cities, 2020) [6].

The Danish DK2020 plans however goes beyond the CAPF by adapting also more locally developed climate solutions. Thus, many smaller Danish municipalities have e.g., large agricultural and industry sectors making the experiences from megacities (the C40 Cities) challenging and hence the need for looking to more context specific solutions. This approach has benefitted many Danish municipalities, providing valuable examples of climate actions, and being useful not just in Denmark, but also in other places including cities and rural areas in the Nordic countries and around the world (CONCITO, 2021a; CONCITO, 2021b) [7, 8]. The philanthropic Danish organization Realdania - a former mortgage institution - led the DK2020 project and made the call for municipalities to join it (Realdania, 2024a) [10], working together with C40 Cities and CONCITO, a Danish Green Think Tank (CONCITO, 2024a) [9]. Starting with 20 Danish pilot municipalities participating in 2019, it has now grown (2024) to include almost all the 98 Danish municipalities, the association of Danish municipalities, named Local Government Denmark, KL (KL, 2024) [11], as well as all 5 Danish Regions (Danske Regioner, 2024) [13], with continued support from CONCITO and C40. The evaluation reports assessed in this document were all conducted within this first phase where Danish municipalities have implemented and finalized their DK2020 plans (2023).

The current phase (ultimo 2024) has been the creation of the 'Climate Alliance' initiated by the 5 Regions, KL and Realdania, with CONCITO and C40 being knowledge partners, which will run for 5 years. The purpose of the Climate Alliance is to create a framework for a shared development space for the comprehensive transition work that awaits municipalities and regions on the path to climate neutrality by 2050. A central task is to develop a common professional toolkit in the form of an implementation framework that will provide knowledge-based decision support and guidance to municipalities, regions, and the partnership behind the alliance. This includes, for example, implementation support, the establishment of a monitoring system, and an annual status report that follows up on completed initiatives and progress in the transition (Realdania, 2024b) [12].

1.2 Study focus

In this study, we focus on two out of five case Regions within Denmark, being Region Zealand and Region South, and seek to identify the request for technology and innovation needs within the two regions' municipal climate adaptation work. The aim is to reveal if future pathways of the municipal climate adaptation work can be identified, by pointing to which focus areas it addresses and whether some overall themes for future adaptation solutions requested can be extracted. Thus, the purpose of the study is hence to identify requests for technology and innovation needs (adaptation solutions) within the two targeted regions by assessing the DK2020 municipal reporting among others.

2. Methodology

2.1 Choice of case Regions within Denmark

The case study within Region Zealand and Region South has been selected as a part of the EU Interreg research project named 'POSEIDION', currently running from 2024-2028, which is a collaboration between the two Danish Regions addressed *and* the Northern part of Germany. A part of the project is to identify technology requests and innovation needs and provide pilot sites for testing new adaptation solutions and in general facilitate knowledge exchange between Denmark and Germany emphasizing climate adaptation technologies and tools (digital tools) (SCC, 2024) [2].

2.2 Municipal reporting

The assessment of the DK2020 municipal reporting entails in total three municipal reports for each of the 17 and 22 municipalities being a part of Region Zealand and Region South respectively. The reports assessed for each municipality are the municipal: 1) DK2020 Plan, 2) Climate Adaptation Plan, and the 3) Wastewater Plan. First the DK2020 plans were assessed to get a more holistic picture of the climate actions (mitigation *and* adaptation) taken by the specific municipality, followed by the Climate

Adaptation Plans with specific emphasis on climate adaptation initiatives within the municipality. Following that, attention was given to the municipal Wastewater Plans, as activities by municipal utilities to a great extend impact climate adaptation within local communities.

2.3 Identifying technology requests and innovation needs

The concrete methodology applied when going through the three municipal reporting, can be described as a 'thematic snowballing' method (Patton, 2002; Saldana, 2016) [3, 4], identifying existing requested future focus areas for climate adaptation solutions, as they gradually reveled when assessing the reports. Thus, constantly adding new focus areas to the table matrix, as they were addressed in the DK2020 reports, etc. Three main headings were consequently developed, being '*Rain & cloud burst'*, '*Seawater & storm surge', 'Heat, heatwaves, and drought',* and a minor thematic area titled '*Others'* (see Table 1 and 2 in the following section).

Thus, the DK2020 plans have been assessed for i) existing climate adaptation solutions deployed, marked 'v', and ii) future focus areas of climate adaptation solutions, market 'x'. There is no distinction between whether the solution is widely deployed or not, when marked 'v', nor whether future solutions marked 'x', is requested to be widely deployed in the future or not, or just simply identified as important future areas of the climate adaptation work.

2.4 Limitations

Even though three municipal reports have been studied for each municipality within the two regions the findings do not necessarily reflect the full climate adaptation work applied by the municipalities, as some initiatives might not be explicitly mentioned within the plans studied. An example is the use of water tubes/sandbags, which rarely is mentioned as a technology applied within the municipalities. Additional search on municipal websites however reveled, that the technology *is* widely deployed within most of the DK2020 municipalities. Another example is the use of rainwater basins for water storage/retention combined with recreational purpose; such technology *is* deployed in Roskilde Municipality even though the studied plans do not indicate this. Many other examples could be mentioned.

Thus, a complete overview of existing climate adaptation solutions deployed has been challenging, as not fully being addressed in the three municipal plans studied. Having pointed out this limitation in identifying *existing* climate adaptation initiatives, this present paper complies with the target of identifying future technology requests and innovation needs of Danish municipalities located within the two regions studied to reveal future pathways in climate adaptation solutions. In the following, we present the findings of the assessment, composed by two tables - one for each region - in which the existing and requested climate adaptation solutions are outlined.

3. Findings

Below, we present the findings from the assessment of the DK2020 reporting, entailing three municipal reports as outlined above, which are condensed in two tables; one for each region analyzed. Following that, we summarize the findings, which are further elaborated in section 4 'Discussion', and finally, a conclusion is provided in section 5.

3.1 Assessment results DK2020 reporting

In the following the results of the extensive assessment is presented for Region Zealand in Table 1, and Region South in Table 2.

Table 1: Climate adaptation solutions in Region Zealand

Existing climate adaptation solutions implemented (v) & Requested/future focus areas identified (x) by 17 DK2020 municipalities within Region Zealand NBS: Nature Based Systems WW: Wastewater GHG: Green House Gas BD: Biodiversity GW: Ground water BGI: Blue Green Infrastructure LAR: Lokal Afledning af Regnvand (Sustainable Urban Drainage Systems) WB: Wave Braker Green letter: Solution only present in this specific region	Solrød	Faxe	Greve	Guldborgsund	Holbæk	Køge	Lejre	Lolland	Næstved	Odsherred	Roskilde	Slagelse	Stevns	Vordingborg	Ringsted	Kalundborg
- *Rain & cloud burst*																
Rainwater basin or lake for water storage/retention	v	v	v	v	v	v	v	v	x	v	x	v	v	v	x	v
Rainwater basin or lake also with recreational area	v		v		x	v	v	v	v	v	x		x	x	v	
Coast or open land water-nature projects (NBS)	v	v	v		x		v		v	x	x	x	v	x	x	v
Parrael water course stretch supports existing stretch	v															
Roof & fortified areas with retention/permeable surface		v	x		x	v	x			x	x		x	v	x	v
Crop, tree, and bushes being climate resilient (wet)		v				x							x			
Increase/apply separate sewerage systems (water/WW)	v	v	v	v	v	v	v	v	x	v	x	x	v	x	x	v
Lowering city spaces (e.g., squares) to store rainwater		x														
Store/use water on farmland (multifunctionality, agri)		x	x	x						x					x	
Flood low-lying farmland (multifunctionality, GHG/BD)				x	x			v	v				v	x	x	
Diverting cloudburst water e.g., elevated curbstone/ditch		x	x						x		x		x	x	x	
Measures to avoid flooding from water courses		x	x	x			x	x	x	x			v	v		v
Tree planting for e.g., water protection & BD & GHG	x	x				x				v	x		v		x	v
Wild nature & biodiversity in urban environment	x	x	x						x		x			x	x	x
Measures to handle high GW & near-surface GW	x	x	v	x	x		x		x	x	x	x	x			x
Water management via drainage and pump systems	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
Measures for surface water penetrating to groundwater			x				x		x							
Cloudburst storage/routes; cycle path/trough shape road			x						x	x					x	
Measures to adapt to seasonal high/low groundwater						x		x					x			x
Manage water local e.g., fascine/ditch/plants/BGI (LAR)			x	x	x	x	x	x	x	v	x		v	x	x	x
Rainwater for process, cooling, or toilet flush water																x
Enhance water drainage and/or waterpipe capacities				x	x				x	x				x		
Measures to protect erosion caused by water courses													v			
Mobile water barriers solutions on e.g., roads						x										
Rural WW managed by willow, infiltration systems etc.		v			v		v	v	v	v		v	v		v	
- *Seawater & storm surge*																
Transverse dykes on beach	v															
Sea dike/land soil berm (jordvold) incl. future elevations	v	v	v	v	v	v	v	v	v	v	v	v		v	v	
Re-store and establish sand dunes (sand feeding)	v	v	v	v	x	v								v		x
Use of locks	v			v	v	x			v		v			v		x
Highwater walls prevent sea floods/saltwater intrusion	v	v				x	v					v			x	x
Terrain elevation to enhance runoffs	v				v									x		
Counter flap to avoid saltwater intrusion to sewerage		x			x											
Erosion protection of beach/roads (e.g., foreshore)		v		x		v		x		x		x		v		x
Mobile highwater walls, e.g., stoplogs	x			x		x										
Mobile water barriers, e.g., water tube, sandbags	v	v	v	v	v	v	v	v		v	v	v		v	v	v
Elevation of harbor with bulwarks & harbor wall				v	x				v							v
Coastal protection via e.g., groins (WB) and rock reefs			v		x		v			x					x	v
- *Heat, heatwaves, and drought*																
Crop, tree and bushes being climate resilient (dry)		x				x							x			
Measures to deal with heat in general needed			x	x			x							x	x	x
Optimize/renovate buildings for better indoor climate	x				x	x							x			
Heat resilient and durable road pavement (asphalt)	x															
Reduce urban-heat-island effect by NBS/sponge city/BGI	x	x	x		x	v			x				x	x	x	x
Protect water sources from drying out (courses/lakes)							x		x	x				x		
- *Others*																
Climate resilient buildings / codes (dry/wet/heat)			x											x	x	x
Hydraulic knowledge & assessment needed in general					x		x			x						
Measure capacity of drainage & sewerage systems					v									x		
Local water measuring for enhanced warning systems								x							x	

Existing climate adaptation solutions implemented (v) & Requested/future focus areas identified (x) by 22 DK2020 municipalities within Region South NBS: Nature Based Systems WW: Wastewater GHG: Green House Gas BD: Biodiversity GW: Ground water BGI: Blue Green Infrastructure LAR: Lokal Afledning af Regnvand (Sustainable Urban Drainage Systems) WB: Wave Braker Green letter: Solution only present in this specific region	Fanø	Varde	Esbjerg	Tønder	Billund	Vejen	Ærø	Haderslev	Vejle	Kolding	Fredericia	Sønderborg	Middelfart	Assens	Nordfyn	Odense	Faaborg	Svendborg	Nyborg	Kerteminde	Ærø	Langeland
- *Rain & cloud burst*																						
Rainwater basin or lake for water storage/retention			x	x		x	x	v	v	x	v	x		v		v	x	v	v	x		
Rainwater basin or lake also with recreational area			x	v			x	v	v		x	v	v	v	v	v		x	v	x	x	x
Coast or open land water-nature projects (NBS)		x		x			x	x	x	x	v	x	x	x	x	x		x	x		v	
Roof & fortified areas with retention/permeable surface		x	x	x	x	x		x	v	x	x	x	v	v	x	v	x	v	x	x	v	v
Crop, tree, and bushes being climate resilient (wet)									x										x			
Increase/apply separate sewerage systems (water/WW)	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
Lowering city spaces (e.g., squares) to store rainwater											x					x						
Store/reuse water on farmland (multifunctionality, agri)									x	x		x		x		x		x				x
Flood low-lying farmland (multifunctionality, GHG/BD)	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x			x	x	
Diverting cloudburst water e.g., elevated curbstone/ditch								v	v	x	x	v		x	v		v		x			
Measures to avoid flooding from water courses	x	x		x	x		x	x	x	x	x	v		x	v	x	v	x		x	x	
Opening of previous hidden/piped water courses (BGI)								x								x						
Tree planting for e.g., water protection & BD & GHG	x	x	v	x	x	x	x	x	x	x	x	v	v	x	x	x	v	x	x	x	x	
Wild nature & biodiversity in urban environment		v	x				x		x	x	x	v	v	x	v	v	x	x				
Measures to handle high GW & near-surface GW	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x				x
Water management via drainage and pump systems	v	v	v				v			x	v	v	v	v	v	v	v	v	v	v	v	
Measures for surface water penetrating to groundwater			x					x									x	x	x	v		
Cloudburst storage/routes; cycle path/trough shape road									v		x		v		x		v		x			
Manage water local e.g., fascine/ditch/plants/BGI (LAR)	x	x	x	x	x	x	x	x	x	v	x	v	x	v	x	v	x	v	v	x	v	v
Rainwater for process, cooling, or toilet flush water							x															
Enhance water drainage and/or waterpipe capacities	x	x	x		x			x		x	x	x		v	x	v	x	x	x			x
Measures to protect erosion caused by water courses									x					x			v					

Rural WW managed by willow, infiltration systems etc.			v	v								v	v						v	v		v
Measures to prevent water flooding/undermine roads					x			x		x	x							x			x		
Establish back-land dikes for course flood protection								x															
- *Seawater & storm surge*																							
Sea dike/land soil berm (jordvold) incl. future elevations	v	x	v	v			v	v	v	v	v	v	v	v	v	x	v	v	v	v	v	v	v
Retreat dikes further in land														v					x				
Re-store and establish sand dunes (sand feeding)	v	v	v				v	v			v				v	v	v	x					v
Establish slope protection by e.g., stone ral (ral feeding)										x	v					v		x					
Use of locks		v	v				v	v	v	v					v		x		x				
Highwater walls prevent sea floods/saltwater intrusion			v				v	v	v		x	v	v		v	v	x	x	x				
Terrain elevation to enhance runoffs								v			v		x										
Counter flap to avoid saltwater intrusion to sewerage											v			x									
Erosion protection of beach/roads (e.g., foreshore)			v					v	x	x		x		x		x		x		x		x	
Mobile highwater walls, e.g., stoplogs												x	x							v			
Mobile water barriers, e.g., water tube, sandbags	v	v	v	v			v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
Elevation of harbor with bulwarks & harbor wall	v									x				v	x	x					x		
Coastal protection via e.g., groins (WB) and rock reefs	v	v	v				v	v	v		v	v				v	v	v	v	v	v	v	v
Floating bridges for sea rice and wave breaker (WB)																					v		
- *Heat, heatwaves, and drought*																							
Crop, tree and bushes being climate resilient (dry)									x						x		x	x			x		
Measures to deal with heat in general needed	x			x	x										x	x	x	x			x		
Optimize/renovate buildings for better indoor climate			x	x					x	x							x	x			x		
Reduce urban-heat-island effect by NBS/sponge city/BGI									x	x					x		x	x					
Protect water sources from drying out (courses/lakes)															x			x			x		
Measure temperature changes in water courses						x																	
- *Others*																							
Climate resilient buildings / codes (dry/wet/heat)	x						x								x		x	x			x		
Hydraulic knowledge & assessment needed in general	x		x														x						

3.2 Summary of findings

In the following section, we detail the ranking (first 15) of the technology requests and innovation needs identified, when assessing the DK2020 reporting of Region Zealand and Region South, which also include a short generic description of the nature of the solutions. The existing climate adaptation solutions already deployed, as shown in the tables above, are not included in this summary, as the focus here is identification of future pathways of the adaptation work ahead.

3.2.1 Requested/future climate adaptation focus areas

1. Measures to handle high GW & near-surface GW

Number of requests: 30 (11 in Region Zealand, 19 in Region South

Description: Measures to handle high groundwater (GW) and near-surface GW levels are crucial for climate adaptation, as they prevent soil saturation and flooding, protecting various infrastructure and agriculture. Addressing high GW maintains water quality and availability, which are important for drinking and irrigation and hence assist in enhancing community resilience to extreme weather and long-term environmental changes.

2. Manage water local e.g., fascine/ditch/plants/BGI (LAR)

Number of requests: 24 (11 in Region Zealand, 13 in Region South)

Description: Local management of rainwater reduces the risk of flooding by handling water close to where it falls. This reduces the load on sewerage systems and decreases the need for costly upgrades or overflow risks. By filtering rainwater through natural processes, water quality is improved before it returns to rivers and lakes. This approach also supports the urban environment by maintaining groundwater levels, in areas where needed, and promotes greener areas (blue/green) with more sustainable landscapes in urban settings.

3. Flood low-lying farmland (multifunctionality, BD & GHG

Number of requests: 24 (5 in Region Zealand,19 in Region South)

Description: Flooding low-lying farmland is important for climate adaptation due to its multifunctionality. It can create wetlands that enhance biodiversity (BD) by providing habitats for various species. These wetlands act as carbon sinks, reducing greenhouse gas (GHG) emissions, and besides this, offer flood storage, mitigating flood risks to nearby areas. This approach promotes sustainable land use, balancing agricultural needs with environmental conservation, and contributes to the overall resilience of ecosystems and communities against climate impacts.

4. Tree planting for water protection & BD & GHG

Number of requests: 24 (6 in Region Zealand, 18 in Region South)

Description: Tree planting for water protection is crucial for climate adaptation. Trees enhance biodiversity (BD) by providing habitats for various species, and protect water resources by reducing runoff, preventing soil erosion and improve water quality. Additionally, trees act as carbon sinks, absorbing GHG and mitigating climate change. This multifaceted approach supports ecosystem health, promotes sustainable land use, and increases resilience against climate impacts.

5. Measures to avoid flooding from water courses

Number of requests: 23 (8 in Region Zealand, 15 in Region South)

Description: Effective flood management preserves water quality by preventing pollutants from spreading. It also safeguards ecosystems and biodiversity by maintaining natural habitats. These measures reduce the economic costs associated with flood recovery and support sustainable land use planning. Enhancing flood resilience is crucial for adapting to the increased frequency and intensity of extreme weather events due to climate change.

6. Enhanced water drainage and/or waterpipe capacities

Number of requests: 21 (7 in Region Zealand, 14 in Region South)

Description: Enhanced water drainage and increased waterpipe capacities are crucial for climate adaptation. They prevent flooding, protect infrastructure, and maintain agricultural productivity. These measures reduce contamination, ensure efficient water management, and enhance resilience to more intense and frequent rainfall events due to climate change.

7. Roof & fortified areas with retention/permeable surface

Number of requests: 21 (8 in Region Zealand, 13 in Region South)

Description: Same as above.

8. Coastal and open land water-nature projects (NBS)

Number of requests: 19 (6 in Region Zealand, 13 in Region South)

Description: Same as above.

9. Wild nature & biodiversity in urban environment

Number of requests: 18 (8 in Region Zealand, 10 in Region South)

Description: This measure helps to regulate temperatures through shading and cooling, reducing urban-heat-islands. Biodiverse green spaces improve air quality, mitigate flooding by enhancing water absorption and evaporation, besides support pollinators essential for urban agriculture. These areas also provide recreational and mental health benefits for residents. Enhancing urban biodiversity increases resilience to climate impacts, creating healthier and more sustainable cities.

10. Reduce urban-heat-island effects
Number of requests: 15 (9 in Region Zealand, 6 in Region South)
Description: Such measures can provide lower temperatures within cities and thus decrease heat-related illnesses and improving overall public health. Cooler urban areas reduce energy consumption for air conditioning, reducing greenhouse gas emissions, and creating more hospitable environments for urban wildlife and plants. Additionally, reducing heat islands enhances the resilience of cities to extreme heat events, contributing to a more sustainable and livable urban environment.

11. Measures to deal with heat in general needed
Number of requests: 14 (6 in Region Zealand, 8 in Region South)
Description: Various measures enhance urban and rural resilience to increasing heat, and heat waves and promote sustainable living environments.

12. Erosion protection of beach/roads (e.g., foreshore)
Number of requests: 13 (5 in Region Zealand, 8 in Region South)
Description: Same as above.

13. Rainwater basins or lakes for water storage/retention incl. recreational area
Number of requests: 12 (4 in Region Zealand, 8 in Region South)
Description: Same as above.

14. Climate resilient buildings in general (dry/wet/heat)
Number of requests: 11 (5 in Region Zealand, 6 in Region South
Description: Climate-resilient buildings are vital for adapting to extreme weather. They use flood-resistant designs and effective drainage for wet climates, drought-resistant landscaping and water-efficient systems for dry climates, and reflective roofing and natural ventilation for warm climates. These options enhance safety, reduce environmental impact, and improve sustainability in response to climate change.

15. Measures for surface water penetrating to groundwater
Number of requests: 8 (3 in Region Zealand, 5 in Region South)
Description: Helps 'recharge' groundwater resources, ensuring a sustainable water supply during droughts, besides improved infiltration reduces surface runoff, minimizing flood risks. These measures also enhance water quality by filtering pollutants through soil. Additionally, they support ecosystem health by maintaining groundwater-dependent habitats. Overall, they contribute to water security and resilience against climate impacts.

3.3 Themes identified
When identifying technology request and innovation needs of the two regions assessed, some themes can be identified - and possibly future pathways - when looking at the summary above.
The *first* theme, being revealed by the mapping of forthcoming climate adaptation solutions, revolves around measures to ***adapt to surface water challenges***, by better handling of water close to where it falls (#2), establish storage of water by flooding farmland (#3), plant trees (#4), reduce flooding of water courses (#5), enhance drainage and waterpipe capacities (#6), greener and permeable fortified areas capturing and retaining water (#7), nature based projects to manage water flows and prevent flooding (#8), wild nature in urban settings absorbing and evaporating water (#9), and recreational water basins or lakes retaining water (#13). The *second* theme addresses measures to ***adapt to flooding risks caused by higher or near-surface groundwater levels*** (#1) being the most requested future climate adaptation solution. Not all municipalities are exposed to such risks, and requests for measures to deal with water 'recharging' groundwater resources, are thus also identified (#15).
The *third* theme revolves around ***adaptation to increasing temperatures*** and request measures for reducing urban-heat-island effects (#10), to handle a warner environment with heat, heat waves and drought in general (#11), and measures for the build environment to deal with more extreme weather conditions being more wet, dry or warm (#3). The limited focus on measures to adapt to ***sea level rice and storm surge***, the *fourth* theme, being identified as requests for coastal erosion protection (#12), is most likely due to the fact, that such measures are a vital part of the existing climate adaptation solutions deployed within DK2020 municipalities, as outlined in Table 1 and 2.

4. Discussion
The analysis reveals municipal technology and innovation needs that address the development and deployment of enhanced flood defenses, such as improved levees, seawalls, and storm surge barriers, to combat rising sea levels and increased storm surges. Nature-based solutions (NBS), like wetland restoration and green infrastructure—including urban green spaces, green roofs, and permeable pavements—are regarded as crucial for managing flood risks, stormwater, and urban heat island effects. Updated building codes are essential to ensure structures can withstand extreme weather events. Integrated water management systems require comprehensive solutions for water cycle management, including advanced water storage and efficient irrigation systems to address drought conditions. Further development of erosion control measures using techniques like geotextiles and retaining walls is vital for protecting vulnerable areas. Additionally, more advanced water technologies for recycling and storage should be innovated to ensure efficient water resource management and prevent saltwater intrusion.
The findings further revile that none of the DK2020 municipalities within the regions addressed request specific *'technology innovation'* and hence use such notion. The themes above are identified as interesting or forthcoming areas, which the municipalities find important to address. The notion *'innovation'*, when used in the DK2020 plans, address such more generic thematic areas, like for example the need to look at heat-island-effect in the future or the management of higher groundwater levels. Besides this, the municipalities request stronger collaboration with various stakeholders to deal with climate adaptation challenges, as a type of *'social-innovation'* need. This could be stronger collaboration between public-private actors, or stronger knowledge sharing between municipalities across regions. There are always exceptions, and a few DK2020 plans express specific technical innovation needs, like for example

Solrød municipality, who request development of advanced road asphalt being more durable in a warmer environment hence reduce future road maintenance costs.

As far as request for tools (digital tools measuring e.g., levels of water in courses or lakes), we have identified specific requests for new tools to be developed, as seen in Table 1 and 2 in the heading 'Others'. The focus of this assessment is however not to identify requests for digital tool, but to identify technical applications and innovation needs (non-digital) being requested by municipalities as future adaptation solutions. It is however clear, when assessing the DK2020 plans etc., that municipalities request better tools to conduct higher quality risk assessments and in general to be better equipped with data to be able to manage future climate related events.

Several municipalities utilize the notions (in Danish) 'merværdier', 'synergier', 'sammentænkning', 'multi-funktionalitet' and 'sektorkobling'), translated to English; 'added value', 'synnergies', 'integraded thinking', multi-functionality and 'sector coupling' in their DK2020 reporting. This tap into the thinking of gaining as many benefits as possible when deploying solutions adapting to climate change, hence applying cost-effective measures benefitting and solving more than one challenge at a time, by cross-cutting and integrating different sectors. We believe that major innovation needs will be requested within this area in the future, and that forthcoming climate adaptation solutions applying such thinking, will be chosen over other solutions. Thus, future innovations must apply a *systemic approach* to climate adaptation with the purpose of facilitating synergies and bridging sectors, where technical solutions address several of the themes identified above simultaneous. Governing such planning and effectuation require participation from multiple stakeholders. In that sense the need for 'social-innovation', as being addressed by several DK2020 municipalities, are highly relevant.

The first tree themes identified, as outlined in section 3.1, could potentially all benefit from such *systemic approach*, by applying NBS entailing e.g., sponge city and BGI concepts capable of managing intensified surface water, groundwater and near surface water levels and reduce urban heat-island-effect (CONCITO, 2024b) [1]. Thus, a more systemic approach will increase rainwater management by emphasizing more energy efficient and climate resilient buildings with green roofs and vegetation, and fortified areas with permeable surfaces and LAR solutions (manage water locally), hence reducing water runoffs, capable of 'recharging' groundwater levels in areas where needed. And, opposite, assist in stabilizing areas with high groundwater and near surface water levels, by deployment of retention ponds and/or lakes and restauration of wetlands to provide 'parking place' for water.

Such NBS will provide more natural areas and green spaces with water bodies that absorb heat, which increase evaporation and lower local temperatures. Additionally, they can improve urban biodiversity and air quality, while at the same time benefit with recreational spaces for community members. By integrating natural processes into urban settings, these solutions enhance resilience against extreme weather events, supports sustainable water management, and mitigate the heat-island-effects by natural shading and lower temperatures making cities more livable and climate-resilient. Sector coupling is e.g., provided to areas like healthcare sector, building and construction sector, energy, and environmental sectors.

Thus, a pathway for the future municipal climate adaptation work could likely revolve around innovations related to NBS, as this approach provide solutions to more than one climate adaptation request at a time, as identified within the case regions. The multi-functionality of such climate adaptation solutions, and the need for space - within cities and rural areas - requires further development of natural and technical systems, and hence further innovation. The inclusion of various stakeholders to deploy such projects require, on the other hand, social innovation and new ways of collaborating.

5. Conclusion

In conclusion, the mapping of technology requests and innovation needs in the POSEIDON program regions have revealed several key themes detailed in the following. The primary theme involves climate adaptation solutions for *managing surface water* challenges through diverse strategies, such as enhancing drainage capacities and implementation of NBS projects to absorb and retain water. A significant focus is also on addressing flooding risks due to *high or near-surface groundwater levels*, emphasizing the need for measures to avoid or enhance 'recharge' of groundwater resources. Another critical theme is *adapting to increasing temperatures* and how to deal with urban heat-island effects. *Coastal erosion protection* measures are less highlighted by the two program region municipalities but are to a large extend already an integrated part of the existing climate adaptation solutions. We also see that municipalities prioritize future measures for high groundwater levels and increasing temperatures more than the broader DK2020 plans seems to do.

It is further concluded that municipalities tend *not* to address needs for specific technological innovations, but request solutions related to broader thematic areas, as emphasized above, as well as the need for stronger collaboration between stakeholders for enhanced 'social innovation'. The two program region municipalities seek to maximize the benefits of climate adaptation solutions by using notions as for example integrated-thinking, sector coupled and multi-functional solutions, suggesting that future innovations should have a more systemic, cross-sectoral approaches. Hence, NBS solutions, with BGI and sponge city concepts, are recommended for better management of surface water and higher groundwater and near-surface water levels, as well as for reducing heat-island effects. This can provide multiple benefits like urban biodiversity, improved air quality and lower temperatures in urban settings. Overall, the findings underscore the need for comprehensive, multi-benefit and cross sectoral climate adaptation solutions that integrates more natural processes requiring enhanced collaboration across sectors.

6. Acknowledgement

This paper was conducted as a part of the EU Interreg Project POSEIDON nr 03-2.2-232 (24/2390).

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