Interreg North Sea

Co-funded by the European Union

WaterWarmth

WORKPACKAGE 6
Governance of collective energy systems

6.4 Vision and pathway development of aqua thermal energy in the EU North Sea region
Version March 2026

- *Barry Ness, Sara Brogaard, and Annsofie Micallef Nilsson, LUCSUS Lund University, Sweden*
- *Thomas Hoppe, University of Twente, The Netherlands*
- *Nthabi Mohlakoana, Delft University of Technology, The Netherlands*

ACCELERATING THE TRANSITION TOWARDS SUSTAINABLE HEATING AND COOLING BASED ON COLLECTIVE SURFACE WATER HEAT PUMP SYSTEM

Table of Contents

Project WaterWarmth
20 partners from 6 countries: Sweden, Denmark, Germany, The Netherlands, Belgium, France
Lead partner Province of Fryslân
Period June 15, 2023 – September 15, 2026
Total budget: € 7,997,253,-
ERDF Budget € 4.798.358,-

Authors:
Barry Ness, Sara Brogaard and Annsofie Micallef Nilsson - Lund University, Sweden
Thomas Hoppe – University of Twente, The Netherlands
Nthabi Mohlakoana - Delft University of Technology, The Netherlands
Version: March 2026

Executive Summary

This report presents the outcomes of Work Package 6 (WP6) within the EU Interreg North Sea WaterWarmth Project, focusing on governance, innovation, policy frameworks, and stakeholder engagement for the advancement of aqua thermal energy (AE) systems in the EU North Sea Region. The project aims to accelerate the transition toward sustainable, low-carbon aqua thermal heating and cooling by developing shared strategic knowledge and actionable pathways for AE deployment across six European countries.

The central result of WP6 is a co-created vision for aqua thermal energy systems in 2050, supported by country-specific and unified transition pathways spanning the period 2025–2050. The vision was formulated with the WaterWarmth project partners to elicit individual and group level ideas. To enhance the co-creation process, and to apply an innovative mixed methodology approach, Generative Artificial Intelligence (GenAI) was integrated in the process of vision formulation. The vision depicts a fair, sustainable, and community-driven heating system in which decentralized yet interconnected AE networks are owned and managed by local, non-profit cooperatives. These systems ensure affordability, resilience, and secure access to clean heat, while safeguarding aquatic ecosystems. Technological development is another pillar of the vision augmented through smart management systems.

To operationalize this vision, participatory pathway development workshops were conducted with project partners from Belgium, the Netherlands, and France. The resulting pathways identify phased actions across four transformation domains: cultural and behavioural change; structural, institutional, and regulatory reform; technological and knowledge development; and organisational, market, and user-practice change. This report was initially intended to create a unified EU North Sea region pathway using GenAI to integrate national perspectives into a coherent regional timeline. Due to the limitations of GenAI, recorded as methodological learnings, the pathway for this report is presented in text format, outlining the chronological timeline.

The pathway outlines three key phases: foundation-building and early pilots (2025–2030), scaling and governance integration (2030–2040), and full deployment and system transformation (2040–2050). While the pathway provides a logical and actionable roadmap, the report acknowledges methodological limitations. These include time constraints, partial actor representation, and the exclusion of some analytical dimensions. As such, the pathway is considered an interim outcome, with further refinement planned through follow-up workshops and continued stakeholder engagement.

Keywords

Aqua thermal energy, aqua thermal energy, socio-technical transitions, energy system transformations, governance frameworks, participatory methods, visioning, pathways, Generative Artificial Intelligence (GenAI)

Introduction

Interreg North Sea WaterWarmth Project

The Interreg North Sea WaterWarmth Project, part of the Interreg North Sea Programme funded by the European Union (EU) and co-funded by the consortium project partners, is designed to foster transnational collaboration in pursuit of a sustainable and environmentally responsible future. Central to the project's mission is advancing aqua thermal energy (AE) as a viable and scalable solution for heating and cooling applications. The overarching project objective is to generate strategic, multi-perspective knowledge to inform and accelerate AE system development within the European Union. By promoting awareness and facilitating adoption among energy cooperatives, municipal authorities, private enterprises, universities, and other stakeholders, WaterWarmth aims to catalyze the transition towards AE systems. Also critical to the project's ambitions include reductions in carbon dioxide (CO_2) emissions, mitigation of air pollution, diversification and localization of energy systems, and enhanced resource efficiency. The project, which spans from June 2023 to September 2026, is supported by a budget of nearly €8 million; it is driven by a consortium of over twenty partners across six EU member states: Belgium, Denmark, France, Germany, the Netherlands, and Sweden. Its six work packages address critical dimensions such as optimizing local energy system development, scaling AE technologies, and streamlining regulatory and permitting processes to facilitate AE expansion.

Work Package 6

This report presents an outcome of Work Package 6 (WP6) dedicated to the analysis and enhancement of governance frameworks, innovation, policy instruments, and stakeholder engagement mechanisms pertinent to AE development in the EU North Sea Region. WP6 employs a multi-methodological approach, integrating literature reviews, stakeholder interviews, empirical analyses of AE pilot initiatives, and knowledge co-creation processes with guidance from different analytical frameworks. Further documentation and scholarly outputs related to these themes are accessible via the project website (`https://www.interregnorthsea.eu/waterwarmth`).

Beyond retrospective and diagnostic analyses, WP6 adopts a prospective orientation, emphasizing the co-design of future AE system visions and the delineation of context-specific pathways to realize these envisioned endpoints. The approach is informed by direct contributions from regional and local authorities, academic experts, technology developers, and other relevant actors within the AE stakeholder ecosystem. The principal aim of this report is twofold.

First, practically, it presents the developed vision and present strategies for development to further the implementation of AE in the context of the vision in selected areas within the EU North Sea Region. Second, methodologically, it presents and tests an innovative artificial intelligence (AI)-assisted anticipatory methodology employed in the visioning process. Specifically, the report details a process for co-creating a shared vision and delineating country-specific and unified decision-making steps required to realize that vision. As this process is still ongoing, the report is an account of the complete visioning process and approximately half of the pathway study. It is expected that the complete visioning and pathway work will be presented in an academic publication in the near future (i.e. Summer 2026).

Report structure

The report is organized as follows. The following section describes the theoretical motivation and methodological justification for the adoption of visioning and pathways development approaches, situating them within the broader context of future-oriented strategic planning. This is followed by a detailed account of the WP6 methodological framework, which unites conventional co-produced visioning and pathway mapping techniques with generative AI (GenAI) to augment the processes. The report then introduces the co-created AE system vision, succeeded by country-specific pathway descriptions for the Netherlands, Belgium, and France. Subsequently, the main components of an unified AI pathway for the North Sea Region are presented. The concluding section offers a critical discussion of the visioning and pathways outputs, evaluates the strengths and limitations of the employed methodology, and critically reflects on the integration of AI as a tool for anticipatory governance.

Approach background & justification

Anticipation & visioning

A central challenge in accelerating sustainable transitions is the tendency of stakeholders to focus on perceived barriers in the present, which can inhibit the capacity to conceptualize plausible and desirable alternative futures (Gaziulusoy and Ryan 2017). Visioning, along with other related foresight methodologies, is designed to bridge the gap between current unsustainable conditions and aspirational future states (ibid). Often central to visioning, is the participatory process that facilitates the creation of a shared "representation of a desirable (or inspirational) future" (Wiek and Iwaniec, 2014). Rather than predicting or forecasting, anticipatory approaches,such as visioning, scenario analysis, and narrative construction, engage with one or multiple alternative futures to inform strategic planning and solution design (UNDP 2018). Within this framework, a vision serves as an endpoint for a specific, pre-defined temporal horizon (e.g., 2040, 2075, or 2100), and the use of diverse anticipatory methods helps to reduce uncertainty regarding future developments.

The rise of visioning in the 1980s and 1990s coincided with the growing adoption of systems thinking and participatory engagement methodologies (Wiek & Iwaniec 2014). Among these, sustainable visioning has been recognized for its capacity to "put forward transformational goals, measure progress and build capacity and shared purpose" (Iwaniec et al., 2014). Such approaches are frequently applied to thematic domains such as energy system transformation and urban development. Visioning is not without its faults, however; it has previously been critiqued for its "lack of theoretical and methodological development" (Iwaniec et al., 2014). Even so , efforts over the past approximate decade have increased in these areas. Socio Technical Scenarios (STSc), for example, make explicit use of theory i.e. the Multi Level Perspective and Strategic Niche Management (Geels et al., 2020).

Pathways

Integral to the visioning process, pathways are employed to delineate a route, or routes required to realize a defined future vision. These pathways consist of sequences of actions, decisions, interventions, policies, and measures identified through the process, systematically connecting the envisioned future to present realities. They can work backwards (e.g., backcasting approach; Quist and Vergrat, 2006) from the vision at a stated point in the future, conversely, they can work forward from the current societal state to the future vision. Since the 1980s, backcasting and pathway mapping have evolved to complement visioning, emphasizing the necessary periodic steps and decisions.

Within the Interreg North Sea WaterWarmth project, sustainable visioning was used by project participants to better integrate and provide a pathway to scale AE (Interreg North Sea WaterWarmth, 2025). This approach enabled participants to articulate their perspectives on the future of AE.

GenAI as a generation aid

GenAI is rapidly emerging as a transformative technology within research contexts (Blanchard et al. 2025). GenAI is reshaping research practices by automating routine tasks, augmenting creativity, and enabling advanced data analysis. Its strengths include streamlining literature reviews, supporting both qualitative and quantitative data analysis, and facilitating evidence synthesis, thereby democratizing access to advanced methodologies and enhancing research productivity (Bjelobaba et al. 2025). However, GenAI also presents significant challenges: it can perpetuate biases, generate inaccurate or fabricated outputs, and it lacks transparency in its decision-making processes. Ethical concerns including privacy, copyright, and research integrity are prominent, and excessive reliance on GenAI may erode critical thinking and domain expertise among researchers. Moreover, AI-generated outputs are inherently limited to existing knowledge, often lacking the originality and depth characteristic of human insight (Cornelissen et al. 2024). Ultimately, while GenAI offers powerful tools for advancing research, its responsible use necessitates ongoing human oversight, ethical reflection, and a commitment to maintaining rigorous scholarly standards (Blanchard et al. 2025).

For this visioning exercise, AI was used primarily to conduct general content analysis to serve the purposes of accelerating and optimizing the process of integrating different participatory visions into one combined vision. It was also used to generate an EU North Sea Region wide common, broader pathway to that vision. Hence, in this method there was limited use of existing information and knowledge beyond the ideas articulated within project exercises.

WaterWarmth method description

The visioning co-creation process

The co-creation visioning process involves progressing through three steps: individual, group, and analytical, followed by step four, the pathway development process, as described below.

Step 1: Individual visioning

The initial step of the visioning co-creation process was designed to elicit individual-level perspectives and creative ideas. Participants were introduced to the theoretical underpinnings and practical relevance of visioning for energy sustainability through an introductory lecture.

The essential characteristics of robust visions were described to participants as being "visionary, sustainable, systemic, coherent, plausible, tangible, relevant, nuanced, motivational, and shared" (Wiek & Iwaniec, 2014). Following the introductory lecture, ample time was allocated for questions to ensure conceptual clarity and participant understanding of both the visioning process and its intended outcomes. Subsequently, the WP6 convenors established clear temporal and spatial boundaries for the exercise. Each participant was tasked to independently formulate a personal vision for themselves and/or society, with the aim of articulating broader core values, societal developmental states, and other desirable attributes of society in a five minute reflective exercise. This exercise was supported by a period of silent, mindfulness-inspired contemplation, fostering focused and independent thought. Participants were then allotted several additional minutes to document the key attributes of their visions.

Step 2: Group deliberation process

Step 2 involved collaborative vision creation at the group level. It built on the individual outcomes and outputs of the individual visioning from the initial step. Prior to the session, participants were randomly assigned to five groups of five to six members, a strategy intended to prevent dominance by any single region or perspective. Each group was facilitated by a WP6 team member to maintain focus and ensure productive discourse. Groups were provided with dedicated spaces, refreshments, and supportive materials (e.g., flip charts, pens, paper, written instructions) to support their work. Within the materials included a list of guiding questions based on the socio-technical transitions framework. These guiding questions drew on the analytical foundation of the work package, which was grounded in the socio-technical transitions framework (cf. Rotmans et al. 2001; Frantzeskaki and de Haan 2009; Geels 2010). This theoretical orientation also underpins the visioning activities conducted by the group. In particular, and drawing on Geels (2002), the multi-level perspective (MLP) on transitions was employed to structure the visioning process, enabling participants to develop a holistic and nuanced representation of society in 2050. The MLP framework delineates six key regime-level dimensions: *actor networks, techno-scientific knowledge, markets and user practices, culture and norms, technology,* and *policy and regulation*. These regime aspects collectively constitute the constellation of cultures, structures, and practices that define the dominant configuration of societal systems (Frantzeskaki and de Haan 2009). Within the visioning exercise, these six dimensions served as analytical guides, assisting participants in systematically identifying the transformations required across critical domains to realize the envisioned future. For each regime component, specific guiding questions were formulated to facilitate focused and comprehensive group deliberation. Each regime component and guiding questions for the respective visioning groups were defined as follows:

- ***Actor Networks:*** Who are the actors and networks that should be included to reach your vision? You may consider actors that have so far not taken part in any development. What roles do they have?
- ***Techno-Scientific Knowledge:*** What aspects regarding techno-scientific knowledge (e.g., research programs, public information, pilots, experiments, etc.) are needed to reach the vision?
- ***Markets and User Practices****:* What aspects of how heat is currently used and experienced make it difficult for potential end-users to consider and adopt AE (i.e. to create market demand)? What are the efficiency and cost-optimization and development in current economic systems? Economic risks of AE production, related to financing, or the supply chain. How long does it take for economic return on investments to be expected, etc.? For example, consider alternative markets, for example via renewable energy communities.
- ***Culture and Norms:*** What cultures and norms in society generally or in actor-networks specifically need to be changed or emphasized in or reach your vision?
- ***Technology:*** Which aspects of AE technologies/systems need to be considered or redesigned? Are there aspects that are important when implementing these systems in the local physical environment or in the "energy system environment", for your vision to be fulfilled?
- ***Policy and Regulation:*** Which sectoral (at the different levels) policies and goals, as well as regulations, such as those concerning land ownership, are needed to fulfil your vision?

During the group deliberations, groups were granted the flexibility to adopt an approach to their liking: top-down, bottom-up, or mixed. In the top-down approach, groups first articulated an overarching vision and subsequently mapped the relevant socio-technical regime aspects onto this vision. Conversely, the bottom-up approach entailed beginning with the systematic analysis of regime aspects—such as actor networks, techno-scientific knowledge, markets and user practices, culture and norms, technology, and policy and regulation—before synthesizing these insights into a comprehensive vision for 2050. Importantly, participants also integrated individual ideas and priorities generated during the initial visioning exercises into the group deliberations, thereby enriching the collective process. This structure promoted both diversity of input and cross-group learning. The groups worked through their guiding questions on the flip charts during a session lasting approximately 75 minutes.

Upon completion of the session, all materials—including completed tables and other written outputs—were collected and digitized by WP6 researchers to facilitate subsequent analysis. The research team undertook a dual-phase analytical process: first, they systematically reviewed the documents produced during the group sessions, focusing on both the overarching vision statements and the inclusion of sociotechnical regime aspects; second, WP6 researchers divided into two independent groups to conduct parallel analyses, with the objective of identifying thematic similarities and recurring patterns across the various group outputs.

Step 3: AI-supported synthesis & validation

The third step of the vision co-creation process involved synthesizing a unified WaterWarmth project vision for 2050. To achieve this, all summarized data from the visioning workshop groups were organized according to the six regime-level aspects. Utilizing a GenAI tool, the researchers generated concise narrative storylines for each aspect, employing targeted prompts such as, “Who are the key actor networks in the vision?” and “What goals are achieved in the vision?”. These AI-generated descriptions were then integrated into a single, cohesive vision statement. Initially, a comprehensive 1,000-word narrative was produced; however, recognizing the need for accessibility and clarity, the researchers subsequently instructed the GenAI tool to generate a more succinct, 250-word vision for AE development in the EU North Sea Region by 2050, ensuring the endpoint description remained both sufficiently comprehensive and user-oriented.

The synthesized vision was validated by sharing the resulting text with participants through an online survey and an online project workshop. The survey showed that the majority of participants supported the outcome of the vision. An online project workshop was convened in October 2025 to solicit further input from project partners. However, due to technical difficulties and scheduling confusion, attendance was limited and no substantive comments were received.

Building on the WaterWarmth 2050 vision prompted by GenAI researchers, a visual representation was created to more clearly convey the vision to viewers and support a deeper understanding of its implications. This image was generated using the same GenAI system that produced the original WaterWarmth 2050 vision. Rather than introducing new elements, the model was guided by carefully defined parameters and instructed to generate the image using only the text from the original vision, ensuring visual consistency with the conceptual framework.

Step 4: Pathways co-creation

The subsequent pathway co-creation focused on country-specific sociotechnical avenues to reach the 2050 vision. This was facilitated through an additional project partner workshop, wherein participants were reorganized into groups primarily by country. This structure acknowledged the distinct national contexts—such as policy frameworks, governance structure, permitting processes, market conditions, and cultural factors—that necessitate tailored developmental pathways for each country to achieve the shared vision.

The workshop took place in November 2025, during the WaterWarmth project partner meeting in Kortrijk, Belgium and was organised by the WP6 team. The workshop was planned as a continuation of the visioning exercise. The session lasted 1-½ hours in total, including an approximate 15-minute vision work recap and explanation of the new task, and a one hour and 15-minute pathway co-creation session. For the session, project partners were separated into three country groups: Belgium, France and the Netherlands. Two of the groups (i.e., Belgium, the Netherlands) consisted of participants from multiple pilots, again with diverse roles in the project (e.g., academics, pilot initiators, consultants, government officials). The main aim of the session, based on the knowledge and experiences of each participant, was to ensure that each group discuss and identify actions needed for the vision to be achieved for their respective regions and countries and how this would contribute to the wider EU North Sea Region vision pathway development.

Once separated, the partners in their groups were asked to first think of and discuss key global events (i.e. 'landscape events' in the MLP) that may affect their countries, regions and local areas in the years leading up to 2050 and how this would affect the realisation of the vision. To achieve greater specificity and to better facilitate discussions, the groups were asked to co-create defining developments from three time periods: 2025-2030, 2030-2040 and 2040-2050.

After the discussion of the key global events, the groups were asked to work on the pathway development towards realising the shared 2050 vision. To develop this pathway, the partners had to outline and discuss what needs to be in place or achieved (actions that need to be taken) in the three respective time periods for the shared vision to be achieved. This was based on a streamlined set of regime level components adopted from the Backcasting framework (Quist et al., 2011) which is used to explore pathways to reaching desirable futures. The four key focal areas were extracted from the collective vision by 2050:

(i) Cultural and behavioral changes needed to fulfil the vision;
(ii) Structural, Institutional, Policy and Regulatory changes needed to fulfil the vision;
(iii) Technological and Knowledge needs to fulfil the vision, and
(iv) Organizational changes/Markets and User Practice changes needed to fulfil the vision.

Throughout the discussions, the groups identified the actions, developmental milestones, and/or policies required during each time period and the key actors necessary to achieve the vision.

Due to time limitations, not all the points could be discussed by all the groups. Hence, the decision was made by WP6 researchers to augment pathway development work through additional follow-up workshops. The workshops are to take place during winter/spring 2026 where the country-specific partners can also invite their local relevant networks and communities of practice to present the vision and to discuss and delineate the necessary milestones needed to achieve the vision by 2050. These additions will come after the publication of this report.

Unified pathway timeline using GenAI

A broader, integrated pathway using inputs from the workshop discussions mentioned above was meant to be created with the help of GenAI. This integrated pathway brings together the contributions from Netherlands, Belgium, and France into a single, coherent timeline across the four above shared transformation domains. Prompts were developed using a structured approach that assigned the AI a defined role, clarified the context of the pathway development, specified constraints and limitations, and included reference images to guide the visual structure. After defining these factors within the AI the GenAI was prompted to *"Create an unified pathway timeline based on the key components in text for 2025-2030; 2030-2040, and 2040-2050"*. This was done a total of six times across three commercial GenAI platforms. As the images were unsuccessful they were not included in the study as explained in the methodological reflections section below.

Ethical considerations

As collaborators in the WaterWarmth project, the WP6 researchers have prioritized adherence to the highest standards of research ethics, transparency, and integrity throughout all phases of the work. All research activities were conducted in alignment with the foundational principles of respect for persons, beneficence, and justice, as articulated in the European Code of Conduct for Research Integrity. The increased use of generative AI presents significant challenges for researchers. To ensure this is done responsibly, several guidelines have already been issued, such as those from UNESCO (Holmes and Miao, 2023). This study takes these into account. The integration of GenAI tools was approached with diligence: all AI-generated content was explicitly identified, and its use was communicated transparently to project participants. The WP6 researchers ensured that GenAI served as a complement to, rather than a substitute for, participant contributions and creative input. Data processed by GenAI systems were managed in strict accordance with the General Data Protection Regulation (GDPR), ensuring compliance with prevailing data protection standards. The research team remains vigilant regarding potential biases or inaccuracies introduced by GenAI, instituting regular reviews and critical assessments to mitigate such risks. By fostering open communication, critical reflection, and a shared sense of responsibility, the WP6 researchers have sought to establish a research environment characterized by ethical rigor, trustworthiness, reliable, transparent research, and a commitment to meaningful innovation.

Process results

Co-created WaterWarmth vision

The WaterWarmth 2050 vision based on the group vision exercises and compiled is presented below:

By 2050, the North Sea Region has achieved a fair, sustainable, and community-driven energy future built on aquathermal energy (AE). Energy is no longer a product sold for profit but a service provided as a human right. Communities own and manage their local heating networks through non-profit cooperatives. These networks are decentralized but interconnected, ensuring resilience: if one system falters, another supports it. People feel unburdened, knowing their warmth is secure, clean, and affordable.

The transformation was driven by cross-sectoral cooperation. Municipalities, social housing organisations, waterboards, and activists worked alongside investors and philanthropists to pioneer early projects. Research institutions and policymakers standardized AE knowledge, creating open and transparent frameworks. By making heat extraction free and penalizing waste, governments ensured resources were used wisely.

Technology has advanced to the tenth generation of heating networks. These open-source systems connect rivers, aquifers, wastewater, and storage technologies like Aquifer Thermal Energy Storage (ATES) and Borehole Thermal Energy Storage (BTES). Smart management and high energy density make them efficient, while environmental safeguards ensure harmony with ecosystems.

Markets have shifted. Fossil fuel subsidies vanished, and taxes moved from gas to electricity. Instead of ownership, service models like Heating-as-a-Service and ESCOs became the norm. Investments follow Donut Economy principles: equitable, long-term, and ecological.

Culturally, people embrace inclusiveness and collective achievement. Energy festivals celebrate local milestones. Youth, educated from an early age in sustainability, now lead innovations. Sharing resources is natural, reconnecting society with nature.

The North Sea Region in 2050 shines as a living vision of eco-positive energy, where technology, policy, and culture align to provide warmth for people and the planet.

Figure 1. GenAI created image based on AE system co-created vision (including adjustments by the authors).

Country-specific pathways

The Netherlands

The discussion about "cultural and behavioral changes needed to fulfil the vision" in the Netherlands focused on the actions needed in 2025-2030, such as the emergence of energy communities, more pilot projects to showcase AE and other renewable energy technologies and a change in fossil fuel prices, that would inspire increased adoption of renewables. For 2030-2040 actions that would be taken include choosing a resilient political stance to convince people of resilient, yet sustainable energy services.

For achieving 'Structural, Institutional and Regulatory changes needed to fulfil the vision', actions that were identified in 2030-2040 included better management of common goods to fairly optimize efficiency and maximize use of renewable energy services.

For achieving the "technological and knowledge needs to fulfil the vision", the actions identified by the group for the 2025-2030 timeline included increased efficiency of AE technology and the adaption of AE systems to be used by larger installers and more commonly distributed in the heating mix. For the 2030-2040 timeline, the actions identified by the group included upgrading of (AE) technology to new systems as combining and optimizing heating source mix to make the heating system more resilient towards the advanced stage of development.

For achieving "organizational changes, markets and user practice needs to fulfil the vision", the actions identified by the group for the 2025-2030 timeline included suggestions on RE alternatives and an end to fossil fuel subsidies as well as committing to policy changes as announced to create stability and trust in policy processes. For the 2030-2040 timeline, the actions that were outlined included more support for energy communities and continued shift in subsidies for fossil fuels.

The group outlined a list of actors for the mentioned actions as part of this pathway development. The actors include voters, politicians, research institutes, industry, start-ups and different levels of government.

Belgium

As for the discussions about "cultural and behavioral changes needed to fulfil the vision", the Belgium group focused on the actions needed on the different and specified timelines. For 2025-2030, the group discussed that it would be ideal to create a sectoral integration of urban planning and energy/heat/AE energy planning such as making obligations at a neighbourhood level for better commitment. Coherence of different strategies and approaches was also seen as necessary in order to deliver multi-level collaboration. It was also discussed that front runner AE pilots were important during this phase of realising the vision. Tax shifts were also seen as necessary at this phase in order to promote business case feasibility. For 2030-2040 actions that would be taken include the continuation of implementing obligations at neighborhood level for better commitment to renewable energy goals.

For achieving "Structural, Institutional and Regulatory changes needed to fulfil the vision", actions that were identified in 2025-2030 included having a financial plan for heat transitions in the Flanders region as well as developing a phase-out timeline for fossil fuels. Due to lack of time, the discussion did hardly include actions needed for the time lines of 2030-2040 and 2040-2050.

For achieving the “technological and knowledge needs to fulfil the vision”, the actions identified by the Belgium group for the 2025-2030 timeline included a need for clear communications about AE for future planning, including advanced planning towards sustainable heat goals. The actions needed also included acceleration of writing off heat grids and to learn from geothermal innovation development. Drawing attention to permitting organisations and engineering companies as well as encouraging familiarity with the ESCO models in order to deliver on AE systems. The group also encouraged the sharing of best practices, tools as well as explorative and feasibility studies during this time line.

For achieving “organizational changes, markets and user practice needs to fulfil the vision”, the actions identified by the group for the 2025-2030 timeline included fiscal tax shifts and integration of regulation in energy infrastructure planning. As water is an important component of AE, the groups suggested digital twinning of water systems and finding a better solution to the ‘water capture’ fee charged for AE systems water use. During this timeline, the group also identified a need for an effective investment fund for heat networks that would advance AE as one of the preferred sustainable energy services. For the 2030-2040 timeline, the action that was reemphasized to continue with from the previous timeline, was to find a better solution for the ‘water capture’ fee, which would in turn add value to the water treatment processes. The group also suggested integration of regulations on water infrastructure as another action.

The list of actors that were outlined by the group for the actions mentioned above include Flemish Waterways, the Flemish Energy and Climate Agency, municipalities, grid infrastructure companies, politicians, ESCOs, private developers as well as the installation and construction sector.

France

For France, the pathway development discussion turned to the broader and current societal trends that could inhibit movement toward the 2050 vision.

For this group, the “cultural and behavioral changes needed to fulfil the vision” discussion focused on the actions needed in 2030-2040, which included creating a people’s assembly to facilitate discussions and propose new policies. This would ensure citizens and community involvement in energy decision making.

With regards to achieving “Structural, Institutional and Regulatory changes needed to fulfil the vision”, this group did not have sufficient time to discuss some points and it was decided that these were to be raised at the follow-up workshop session.

For achieving the “technological and knowledge needs to fulfil the vision”, the actions identified by the group for the 2025-2030 timeline included a need for ambition on new technologies as well as tests for competitions between new energy solutions. Another action suggested by the group was to develop a solid plan to build new energy labs and create interests among the future generations to work in these labs. For the 2030-2040 timeline, the action identified by the group was to run tests on different technologies and obtain results on what’s feasible and has potential for scaling. For the 2040-2050 timeline, the group agreed on the action to develop solutions for global scaling based on what has been piloted.

For achieving ‘organizational changes, markets and user practice needs to fulfil the vision’, the actions identified by the group for the 2025-2030 timeline included designing strategies to develop and support implementation of local energy grid including AE. For the 2030-2040 timeline, the actions that were outlined included initiating a period of tests on small and medium pilots in cities to show feasibility and advertise the projects to raise awareness.

Another identified action was to create local organizations and/or cooperatives with relative independence to deliver energy services and make their own decisions. Also for this period, an 'end of period' was identified as a period where mature policies are implemented based on practical feedback based on experience from the (pilot) projects. For the 2040-2050 timeline, the group identified large-scale implementation as an action to be taken.

Unified EU North Sea Region AE pathway

To formulate a national co-created unified pathway, we used GenAI, similar to the methodology followed to co-create the vision. The time periods from the exercise as outlined and discussed with the different country groups were maintained in this step. Furthermore, subcategories for each time period were also generated based on the more specific categorisations, which can be used to guide specific transition processes on multiple fronts. Due to GenAI's inability to generate suitable images, particularly for creating the infographic illustrating the pathway development, for this report after critical consideration and discussion, a pathway image was therefore not created.

2025–2030: Laying the Foundations & Accelerating Early Action

Cultural & Behavioural Change
- Emergence of **energy communities** and increased showcasing of AE and renewable technologies;
- Sectoral integration of **urban planning + energy/heat/AE planning;**
- Front-runner AE **pilot projects** to build familiarity and public trust.

Structural, Institutional & Regulatory Change
- Developing a **financial plan** for heat transition;
- Establishing a **phase-out timeline for fossil fuels**.

Technological & Knowledge Needs
- Improving **efficiency of AE technologies** and adapting them for widespread installation;
- Strengthening **knowledge sharing, tools, feasibility studies, and communications** around AE;
- Increasing **ambition and competition** for new energy technologies; establishing **energy labs** for future innovation.

Organisational, Markets & User Practice Change
- Ending **fossil-fuel subsidies** and committing to stable policy signals;
- Introducing **fiscal tax shifts** to support sustainable heat systems;
- Deploying **digital twin models for water systems**, addressing AE water-capture fees;
- Designing strategies for **local energy grids including AE**.

2030–2040: Scaling, Integration & Governance Transition

Cultural & Behavioural Change

- Establishing **citizens' assemblies** for participatory policymaking;
- Continued implementation of **neighbourhood-level energy obligations;**
- Adopting a **resilient political stance** that supports stable, sustainable energy services.

Structural, Institutional & Regulatory Change

- Improved management of **common goods** to optimise renewable energy use;
- Further development of **water-infrastructure regulation**.

Technological & Knowledge Needs

- Systematic **testing and evaluation** of different energy technologies to identify scalable solutions;
- Upgrading AE technologies and **optimising heating-source mixes** for resilience.

Organisational, Markets & User Practice Change

- Ongoing reform of **AE water-capture tariffs;**
- Strengthening **energy communities** and expanding pilot-based learning;
- Launch of **small–medium city pilots**, followed by policy refinement.

2040–2050: Full Deployment & Long-Term Transformation

Cultural & Behavioural Change

- Citizens' participatory structures mature as part of long-term governance.

Structural, Institutional & Regulatory Change

- Mature policies implemented based on decades of pilot testing.

Technological & Knowledge Needs

- **Global scaling** of technologies proven viable in earlier phases.

Organisational, Markets & User Practice Change

- Large-scale deployment of AE systems and local energy grids;
- Full transformation of energy systems and markets inspired by mature policy frameworks.

Reflections

The Vision

The result of the WaterWarmth visioning process shows an inspirational vision for aquathermal energy systems in the North Sea Region in 2050. The co-created vision emphasises a future heating system that is fair, sustainable, and strongly community-driven. More specifically, local communities own and manage decentralized yet interconnected heating networks through non-profit cooperatives, ensuring resilience, affordability, and secure access to clean heating. It furthermore shows a robustness in the system development: if one system experiences disruption, others can provide support, reinforcing system reliability.

Technological development plays a central role in the vision. Open-source heating networks will integrate rivers, aquifers, wastewater, and energy storage through smart management systems that optimize efficiency while safeguarding ecosystems. These technologies are supported by standardised and openly shared knowledge frameworks developed by researchers and policymakers. The vision also emphasizes transformed markets and governance structures. Fossil fuel subsidies have been eliminated, taxation has shifted from gas to electricity, and service-based models have replaced traditional ownership. Investments follow *Donut Economy* principles (Raworth 2017), prioritizing long-term social equity and ecological sustainability. Culturally, collective values, inclusiveness, and environmental stewardship are normalized, reinforced through education, local energy celebrations, and youth leadership. Overall, the result is an integrated sociotechnical system in which technology, policy, markets, and culture align to provide sustainable warmth and cooling for both people and the planet.

Pathways

The country-focused co-creation process produced a unified, participatory pathway for broader scale transition to AE systems for the region; it was structured across the three time periods from 2025 to 2050. In the initial phase (2025–2030), the focus was on laying foundations through cultural and behavioural change, early pilot projects, improved knowledge sharing, and the establishment of financial plans, policy meta plan and regulatory signals, including fossil-fuel phase-out timelines and fiscal reforms. For the second phase (2030–2040), emphasis is on scaling and integration, with strengthened energy communities, neighbourhood-level obligations, citizens' assemblies, and improved governance of common goods such as water infrastructure, alongside systematic testing and optimisation of AE technologies. Finally, in the last phase (2040–2050), AE systems push towards full deployment, supported by participatory governance structures, established policy frameworks, and scalable technologies. Across all phases, the pathway highlights the alignment of technology, policy, markets, and user practices to enable resilient local energy grids and a complete transformation of heating systems, positioning aquathermal energy as a cornerstone of long-term, sustainable energy transitions.

Result reflections

This report reflects on the robustness and validity of the co-created vision and pathways developed through the project's participatory process. The analysis focuses on the inclusiveness of the vision, the methodological constraints encountered, and the implications these factors may have on the unified pathway.

The resulting vision and pathways were primarily shaped by project participants, which may have introduced a degree of bias. In particular, the vision appears oriented toward a *local, collaborative, not-for-profit economic perspective*. This raises questions regarding whether the vision would have differed had additional societal actors beyond the project—such as commercial stakeholders or actors with profit-oriented interests—been involved. Although participants were given opportunities to comment on the vision, it remains unclear whether it is fully supported by all involved parties.

The country-specific and unified pathways represent interim outcomes of an ongoing process. The co-creation sessions were limited in duration, with follow-up sessions planned. Consequently, the current unified pathway, while providing a logical and actionable roadmap for advancing AE development, may evolve significantly as further engagement and refinement occur. Its long-term robustness therefore remains to be assessed.

Methodological reflections

Approach strengths

There are several reflections that stem from the methodology that was used for the study. They are divided into insights for the co-creation process and reflections on the use of GenAI. Although no direct comparison was made with AI-assisted coding, the process proved fast, taking under half an hour to one hour to generate the vision.

Co-creation process

The WaterWarmth project revealed that both visioning and pathway development processes require significant time commitment from participants. As WP6 was only allotted limited time slots during the two respective face-to-face partner meetings, scheduling ample time during these meetings for groups to work together was not possible. Practically, this led to abbreviated introduction lectures from WP6 initiators and shortened group work sessions for each of the meetings, as especially for the Kortrijk partner meeting where the first part of the pathways creation took place. Although the visioning co-creation work created ample material to generate the vision, the country-specific parallel pathway co-creation sessions only produced scattered pathways, missing key developmental aspects. For the WP6 pathways work, additional sessions have been planned for the near future. However, this has meant several months delays in the process as well as significant resources needing to be devoted to the arrangement of the planning processes.

A key take-away message from the different sessions is to allow sufficient time for discussions and the visions and pathways co-creation processes. It is suggested that this is done within single sessions as it can also be difficult to assemble the same group members for any follow up co-creation sessions.

GenAI use

The use of GenAI as a tool demonstrated that it was an efficient way to process the information from the respective groups into the visions and pathways. The time to do the work varied from several minutes for simple tasks to roughly thirty minutes to generate the 2050 vision. This can be seen as significantly faster than conventional coding techniques that are commonly used in academia. However, no attempts were made in this study to compare time differences and the outputs of the two approaches.

The use of GenAI did, though, reveal that it is not without its flaws. First, similar to insights from Blanchard et al. (2025), it is difficult to determine if what GenAI generated holds to academic standards for measurement validity and reliability. GenAI proved to be unsuitable for flawless image generation. The original vision image it created with the prompts given had illustrations of Aquifer and Borehole Energy Storage (ATES and BTES) instead of an AE system, hence the need for adjustments by the authors (Figure 1). The image generation deficiencies were also observed when creating the infographic illustrating the pathway development. This became evident after six unsuccessful attempts to generate the pathway development infographic across three different commercial AI platforms. Prompts were developed using a structured approach that assigned the AI a defined role, clarified the context of the pathway development, specified constraints and limitations, and included reference images to guide the visual structure. However, despite these inputs, the Gen AI still struggled to follow the assigned roles, constraints, and other instructions. Despite this systematic method, the generated images were inefficient and unsuitable for academic use. Each version contained at least 15 spelling and numerical errors, along with inaccuracies in time frames and color labelling. These issues prevented the figures from meeting academic reporting standards. This was, at minimum, the case for the commercial platforms used in this work. As the AI-generated images did not contribute any additional value to the study, they were not included in the report.

Conclusion

This report provides valuable insights on a multi-methodological approach adopted for a 2050 vision and pathway development for mainstreaming aquathermal energy in the EU North Sea Region. Methodologically, the report has presented an innovative, artificial intelligence (AI)-assisted methodology employed in the visioning process whereby a set of co-created primary data was qualitatively analysed and the results used to co-generate the overarching vision as a final output.

The report started by describing the theoretical motivation and methodological justification for the adoption of visioning and pathway development approaches, situating them within the broader context of future-oriented strategic planning. The report draws attention to the co-creation power of visioning that results in a shared representation of a desirable future. The method that the WP6 team developed and used is based on the following steps: The AE vision for the North Sea region was developed in a group process, it was then unified in an AI-assisted single vision development process including vision illustration, on-line verification, and finally a first step into the national (Belgium, the Netherlands and France) socio-technical pathway development process was carried out. The subsequent and final step, however, falls outside the scope of this report and will be presented in a subsequent publication.

The shared 2050 North Sea vision regarding aquathermal energy systems was presented in this report. It depicts a fair, sustainable, and community-driven heating system in which decentralized yet interconnected AE networks are owned and managed by local, non-profit cooperatives. The country-specific decision-making steps needed to realize this vision are developed through a pathway development process.

The report takes this further by linking the visioning process to socio-technical pathway development of aqua thermal energy systems, which focuses on sequences of actions in specific phases or timelines needed to connect the envisioned future to the present realities. For this project focus, pathways outline three key phases: foundation-building and early pilots (2025–2030), scaling and governance integration (2030–2040), and full deployment and system transformation (2040–2050). As part of pathway development, country-focused co-creation processes focused on outlining the actions needed for these three key phases.

In conclusion, this report has illustrated the significance of bringing together various co-creation processes in projects focusing on new energy innovations such as aquathermal energy. By collecting and compiling insights from the different project partners representing a wide range of actors from the Western North Sea Region, including municipalities, research and project developers, community practitioners, as well as technical experts – this report illustrates that when these insights are combined with AI analysis and co-generation, meaningful vision and pathway development processes can be produced. This co-creation methodology can also be useful for policy makers who are in the process of, or considering developing policy vision, goals and pathways, particularly in the domain of renewable energy.

Acknowledgements

We would like to thank the EU Interreg North Sea WaterWarmth project for supporting us in this work. Furthermore, we thank all the individuals who made the visioning and pathways creation happen during the partner meetings and other workshops.

References

Bjelobaba, S., Waddington, L., Perkins, M. *et al.* (2025) Maintaining research integrity in the age of GenAI: an analysis of ethical challenges and recommendations to researchers. International Journal of Education Integrity. 21(18). https://doi-org.ludwig.lub.lu.se/10.1007/s40979-025-00191-w

Blanchard, S. J., Duani, N., Garvey, A. M., Netzer, O., and Oh, T. T. (2025) New Tools, New Rules. Journal of Marketing. 89(6): 119. https://doi.org/10.1177/00222429251349882

Cornelissen, J., Höllerer, M.A., Boxenbaum, E., Faraj, S., and Gehman, J. (2024) Large language models and the future of Organization Theory. Organization Theory. 5:1–15. https://doi.org/10.1177/26317877241239056

Frantzeskaki, N., de Haan, H. (2009) Transitions: Two steps from theory to policy. Futures. 41(9):593-606. https://doi.org/10.1016/j.futures.2009.04.009

Gaziulusoy, İ.A., and Ryan, C. (2017) Shifting Conversations for Sustainability Transitions Using Participatory Design Visioning. The Design Journal. 20:sup1: 1916-S1926. https://doi.org/10.1080/14606925.2017.1352709

Geels, F. (2002) Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. Research Policy. 31(8–9):1257-1274. https://doi.org/10.1016/S0048-7333(02)00062-8.

Geels F.W. (2010) Ontologies, socio-technical transitions (to sustainability), and the multi-level perspective. Research Policy. 39(4):495-510. https://doi.org/10.1016/j.respol.2010.01.022.

Geels, F. W., McMeekin, A., & Pfluger, B. (2020). Socio-technical scenarios as a methodological tool to explore social and political feasibility in low-carbon transitions: Bridging computer models and the multi-level perspective in UK electricity generation (2010–2050). Technological Forecasting and Social Change, 151, 119258. https://doi.org/10.1016/j.techfore.2018.04.001

Holmes, W., & Miao, F. (2023). Guidance for generative AI in education and research. Unesco Publishing.

Interreg North Sea, WaterWarmth (2025) Co-funded by The European Union Pushing change, driving transitions. www.interregnorthsea.eu/. Accessed 21 Jan. 2026.

Iwaniec, D., Childers, D., van Lehn, K., Wiek, A. (2014) Studying teaching and applying sustainability visions using systems modelling. Sustainability. 6(7): 4452-4469. https://doi.org/10.3390/su6074452

Mohlakoana, N., Ness, B., Micallef Nilsson, A., Brogaard, S., & Hoppe, T. (2025). *6.2 Innovation and Governance arrangements of AE systems: A multi-case analysis of WaterWarmth pilots*.

Mohlakoana, N., Ness, B., Micallef Nilsson, A., Brogaard, S., & Hoppe, T. (2025). 6.3 Barriers and opportunities to AE system development: insights from WaterWarmth pilots.

Quist, J., & Vergragt, P. (2006). Past and future of backcasting: The shift to stakeholder participation and a proposal for a methodological framework. Futures, 38(9), 1027-1045. https://doi.org/10.1016/j.futures.2006.02.010

Raworth, Kate (2017). "A Doughnut for the Anthropocene: Humanity's Compass in the 21st Century". The Lancet Planetary Health. 1(2): 48–49. doi:10.1016/S2542-5196(17)30028-1

Rotmans, J., Kemp, R., van Asselt, M. (2001) More evolution than revolution: transition management in public policy. Foresight. 3(1): 15–31. https://doi.org/10.1108/14636680110803003

Thomforde, D. W. (2025) Generative artificial intelligence and sustainability - The challenges. Work. 82(3), 712. https://doi.org/10.1177/10519815251353456

UNDP (2018) Foresight Manual: Empowered Futures for the 2030 Agenda. UNDP Global Centre for Public Service Excellence. Singapore. https://www.undp.org/publications/foresight-manual-empowered-futures

Wiek, A. Iwaniec, D.M. (2014) Quality criteria for visions and visioning in sustainability science. Sustainability Science. 9: 497–512. https://doi.org/10.1007/s11625-013-0208-6