Journal of Cleaner Production 538 (2026) 147252

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Balancing reality, meaning, and play for water governance transformation: A triadic game design perspective on the Aquaconnect serious game

K. Holstead [a,*], G.J. Ellen [b], W.J. Van Doorn-Hoekveld [b], L.E. Van den Bergh [c]

[a] Public Administration and Policy, Wageningen University and Research, the Netherlands
[b] Deltares, Utrecht, the Netherlands
[c] Province of Zuid-Holland, the Netherlands

HIGHLIGHTS

- Operationalises Termeer et al.'s governance transformation pathways in game design.
- Applies Triadic game design to balance realism, play, and learning outcomes.
- Shows how gameplay helps players recognise actor roles, risks, and trade-offs in water governance.
- Offers practical insights for designing games that support sustainability transitions.

ABSTRACT

Serious games are increasingly used to engage stakeholders with complex social-ecological challenges and to support transformative learning. Their effectiveness depends on achieving a careful balance between play, reality, and meaning, ensuring that games are not only engaging and enjoyable (play), but also credible in their representation of real-world systems (reality), and capable of producing reflective, actionable insights (meaning). This study evaluates the design and performance of a serious game on future water supply in drought-prone regions of the Netherlands. The game translates Termeer et al. (2024)'s three governance transformation pathways: big plans, small wins, and rule change, into interactive decision options with actor-specific risks and interdependencies. By embedding governance theory directly within gameplay, the game enables players to experience and negotiate the tensions, trade-offs, and uncertainties inherent in transformation processes. While previous water-domain games have sought to reconcile play, reality, and meaning, few have systematically documented the iterative design and evaluation processes needed to sustain this balance. Guided by Triadic game design, the development process advanced through iterative cycles, each aimed at maintaining a productive balance of the three elements. The study makes two key contributions. First, it provides a concrete operationalisation of governance transformation pathways within game mechanics. Second, it provides a structured and empirically grounded assessment of balancing play, reality, and meaning in serious game design, serving as a guide for others. Together, these contributions enhance the methodological rigour and practical relevance of serious games as instruments for transformative water governance and other sustainability transitions.

1. Introduction

Sustaining healthy water systems is fundamental to the wellbeing of the planet. Today, however, these systems are increasingly strained due to climate change. To address these challenges, policy, practice and research actors call for transformative change in water provisioning and governance towards circular water management (Larsen et al., 2016; Lasseur et al., 2025). Circular water management involves managing water to maximise its use through continuous use, recovery, and regeneration of water resources. Instead of the traditional linear model, circular water management promotes a closed-loop system where, for instance, water is reused, rainwater is captured, and resources such as nutrients and energy are recovered from wastewater (Kirchherr et al., 2017; Morseletto et al., 2022). This approach integrates technology, ecology, and governance to minimise environmental impacts and enhance resilience to climate and drought. To achieve these goals, actors, including citizens, public officials and utility managers, must make decisions on how to adapt water systems, and in doing so encounter dilemmas (Lasseur et al., 2025; Holstead et al., submitted).

Navigating these complex decisions to achieve transformation in water governance requires an understanding of how change can occur within water systems, and which pathways actors support. Termeer et al. (2024) identify three pathways to transformation: big plans (where change occurs through comprehensive, large-scale and long-term

* Corresponding author.
E-mail address: kirsty.holstead@wur.nl (K. Holstead).

https://doi.org/10.1016/j.jclepro.2025.147252
Received 22 July 2025; Received in revised form 21 October 2025; Accepted 3 December 2025
Available online 23 December 2025

planning), small wins (where incremental actions drive change), and rule change (where change happens through alterations in policies, law and institutional arrangements). Each pathway involves trade-offs between the depth, scale, and breadth of change, highlighting the need for strategic choices in how water systems are governed and improved.

An increasingly important tool that can aid transformative change is serious games. A serious game is developed for a purpose beyond entertainment and aims to represent real-world issues and capture complex interactions whilst being entertaining (Powell et al., 2021; Flood et al., 2018; Aubert et al., 2018). Serious games are often employed for education, training, and problem-solving to address complex socio-economic challenges such as natural resource governance (see Aubert et al., 2018 for a review). Interest is growing due to their ability to aid learning and reflection (Aubert et al., 2019; Madani et al., 2017; Mittal et al., 2022). Some games related to water systems currently exist, including role-playing games, simulation games, applied games, and educational games, each demonstrating that serious games can provide insight into water governance decision-making and transformation to support stakeholders to move towards more sustainable and circular water systems (Forrest et al., 2022; Mittal et al., 2022). However, relatively few examples that operationalise governance transformation frameworks as in-game decision structures exist. Termeer et al.'s (2024) three transformation pathways have not been used in a serious game context to the best of our knowledge.

Authors have reiterated the need to systematically study the design and evaluation of serious games in the water sector and in relation to other natural resources (Savic et al., 2016; Aubert et al., 2018; Savic et al., 2016; Valero et al., 2025). Serious games are becoming more common; but a limitation is that their impact and the quality of their design are often not studied or evaluated (Medema et al., 2019; Aubert et al., 2019). Surprisingly, serious games are frequently made without a systematic understanding of game and design theory (Harteveld et al., 2010). An outcome of this is that they might be developed in isolation, limiting the connection made by the player between the game and the area of natural resources on which the game focuses, resulting in the learning content not being integrated into the game (Forrest et al., 2022). So, although there are successful water-related games, the absence of theory in their development and transparency in their design makes improving serious game design and learning from each other challenging (Harteveld et al., 2010).

Harteveld et al., (2010) and others (Harteveld, 2011) argue that the effectiveness of serious games depends on achieving a careful balance between play, reality, and meaning, ensuring that games are not only engaging and enjoyable (play), but also credible in their representation of real-world systems (reality), and capable of producing reflective, actionable insights (meaning). Prior water-domain serious games have recognised and addressed trade-offs among these design elements (e.g., Harteveld et al., 2010) and demonstrated learning about risk, roles and coordination (e.g., reviews by Aubert et al., 2018; Mittal et al., 2022). However, while transparency in game design is often encouraged, game iterations that shows how balance decisions were made (and why) remain scarce. This research makes two contributions. First, we address the content-related gap by integrating Termeer et al.'s (2024) three pathways into a serious game. Second, we address a design-related gap by making the design process transparent through a Triadic game design lens, detailing how balance was iteratively sought, tested, and adjusted to support learning about circular water governance under time pressure and uncertainty. Ultimately, this research contributes to improving the design of serious games that aim to foster systemic and governance transformations.

The outline for the paper is as follows: we outline the literature that forms the theoretical basis for this work, including pathways for transformative change and Triadic game design. We describe the game and the methodology used to gather data on which this research is based. We end with a discussion and conclusions, outlining key (imbalances) in serious game design, how these balances were managed, limitations to this study and areas for future study.

2. Insights from the literature: Pathways for transformative change and triadic game design

2.1. Pathways for transformation

Delta regions worldwide face the challenges of climate change. While circular water management is a possible response, it requires transformation understood as a "fundamental, system-wide reorganisation across technological, economic and social factors, including paradigms, goals and values" (IPBES et al., 2019).

Termeer et al. (2024) identify three pathways towards transformation (see Fig. 1). The big plans pathway begins with deep, system-wide changes, including major public service reforms, infrastructure investments, and land-use planning. These plans take significant time to develop and implement, and often depend on policy entrepreneurs to navigate political cycles. An example is large-scale flood protection to address climate change. The small wins pathway focuses on quick, in-depth work, which, while modest individually, can accumulate into transformative change, such as community-led conservation efforts. Finally, the rule change pathway starts with quick, system-wide, but relatively superficial rule changes, such as new regulations or incentives. Each of these pathways has limits in terms of depth, speed, and scale (Termeer et al., 2024). Depth refers to the extent to which change challenges a system's foundational values and structures, distinguishing between superficial adjustments and profound, systemic transformations. Speed refers to the rate at which change occurs, with some situations requiring rapid responses while others benefit from gradual, sustained efforts. Scale addresses the reach of change, ranging from localised, small-scale interventions to broad, system-wide transformations. Together, these aspects influence the effectiveness and feasibility of implementing deep and lasting change. Achieving simultaneously deep, rapid, and large-scale change is an inherently challenging task due to trade-offs among these dimensions (Termeer et al., 2024).

While transformation and pathways have been influential in policy and academic scholarship (Termeer and Dewulf, 2019; Berglund et al.,

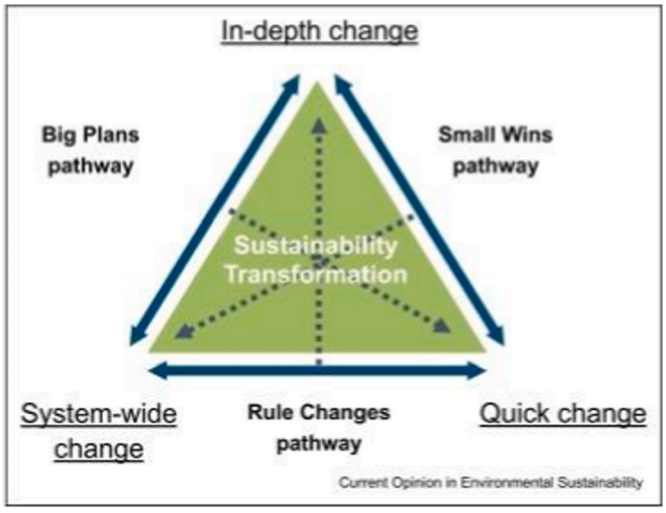

Fig. 1. Pathways and dimensions of transformative change (Termeer et al., 2024). The solid lines represent the governance pathway, and the direction of the dotted lines points toward the next step needed to ensure sustainable transformations. For example, quick and system-wide change can be achieved simultaneously (Rule Change pathway), but as a next step, it requires deepening the change (direction of the dotted line) to ensure sustainability transformation. The figure is reproduced unchanged under the Creative Commons Attribution 4.0 International License.

2022) to the best of our knowledge, no serious game uses the pathways to examine transformation in a circular water system. In this paper, we examine the development of our serious, which focuses on pathways, by using Triadic game design theory.

2.2. Triadic game design

Triadic game design is a structured way of thinking about serious game design that emphasises the integration of three fundamental elements: play, meaning and reality (Harteveld et al., 2010). *Play,* encompasses the interactive and experiential qualities that define games. A game's ability to engage players relies on its capacity to create immersive and dynamic experiences. The design of the play encompasses various considerations, including the game's objectives, the challenges presented to players, the environment in which the game unfolds, and the technological tools used in its development. Relevant game features here include rules, scores and competition. The second element, *meaning*, involves intentionally creating a meaningful impact that extends beyond the game experience. Games convey some form of meaning, for instance, through cognitive skill development, historical representation, or strategic thinking. To ensure that their intended message or intended outcomes translate beyond the game environment, serious games require a deliberate and structured approach to creating meaning for players (Tene et al., 2025). The construction of meaning involves defining the goals to be achieved, devising aspects of the game that align with these objectives, and situating the game within a broader real-world context to facilitate knowledge transfer or behavioural application (Harteveld, 2011). This ensures that knowledge is acquired and the message is received.

Finally, *reality* refers to the world outside the game, linking to the representation of the world in the game, and how these resonate. All games are inherently linked to reality in some form. But, in the context of serious games, this connection must be pronounced, as the ultimate objective is to influence real-world understanding, reflection, behaviour or decision-making (Hammady and Arnab, 2022). Reality can be built into games through engagement with external stakeholders, such as subject-matter experts and professionals, or by representing systems such as hydrological systems or policy frameworks (Harteveld et al., 2010). Doing so ensures that the lessons learned within the game environment are transferable to actual decision-making contexts, enhancing the game's impact on players.

Serious games can from this view, be seen as a system of play, meaning and reality that needs to be in harmony, or at least in appropriate balance depending on the objectives of the game (Harteveld, 2011). An overemphasis on reality may result in a rigid and overly didactic experience, while a disproportionate focus on meaning can make a game feel instructional or prescriptive. Conversely, prioritising play at the expense of the other elements may lead to an entertaining but superficial gameplay that fails to achieve its intended outcomes. The balance and priority of these features depend on the goals of the serious game, yet getting the balance right is a challenging and underexamined aspect of game design (Harteveld et al., 2010; Harteveld et al., 2010). Serious game research in the domain of water management and natural resource management does to some extent, often in passing, recognise the importance of different aspects of balances such as complexity and usability, realism and playability and balancing stakeholder engagement with technical rigor (e.g., see Mittal et al., 2022; Forrest et al., 2022; Valero et al., 2025). In their Levee Patroller game, Harteveld et al., (2010) discusses the importance of addressing serious games by systematically acknowledging the trade-offs in Triadic game design.

Despite growing scholarship on both governance transformation pathways and triadic approaches to serious game design, there remains limited integration between these two bodies of work. Existing serious games in the water domain have to some extent examined trade-offs between realism, playability, and learning outcomes, yet few have systematically grounded their design logic in established theories of governance transformation. Likewise, studies that conceptualise transformation pathways (e.g., Termeer et al., 2024) have rarely translated these abstract governance processes into experiential, interactive learning tools. This gap limits the methodological rigour and practical relevance of serious games intended to support sustainability transitions. Without an explicit operationalisation of transformation pathways within game mechanics, such games risk remaining illustrative. They are unable to capture the interdependencies, trade-offs, and sequencing of change that characterise real-world transformation processes.

The present study addresses this gap by developing and evaluating a serious game that embeds Termeer et al.'s (2024) three governance transformation pathways as the structuring logic of gameplay. Guided by Triadic game design (Harteveld et al., 2010), the study documents the iterative design process used to balance play, meaning, and reality in representing circular water governance. In doing so, it contributes both a conceptual innovation, linking transformation pathway theory with serious game mechanics and a methodological advancement in the forms of a transparent design-science process for achieving a form of equilibrium among the triadic design dimensions. Together, these contributions extend the analytical and pedagogical potential of serious games for exploring transformative change in water governance and other sustainability domains.

3. Studying transformational change towards circular water management in the Aquaconnect serious game

This section outlines the specifics of a game developed to explore water transformation and circular water management in the Netherlands. We provide a brief introduction to the context within which the research took place. We then outline the methods used in developing the game. Finally, we describe the game and its design, as well as the validation and game session processes.

3.1. Circular water management in South Holland, the Netherlands

The Dutch Delta, and especially South Holland (Zuid-Holland), located in the western Netherlands and serving as the setting for the game, is increasingly challenged by freshwater scarcity affecting agriculture, industry, and ecosystems. There, droughts are becoming more frequent alongside salinisation of surface and groundwater which affects drinking water quality, while rapid urbanisation and intensive agriculture, especially greenhouse horticulture, heighten demand (Nogurira et al., 2025; Rijksoverheid, 2025). Industrial use in the Port of Rotterdam further intensifies freshwater scarcity, particularly during low Rhine River flows. At the same time declining groundwater levels contribute to land subsidence and dike instability, threatening infrastructure (Erkens et al., 2015). An additional issue is that existing and innovative measures to protect water supply are also potentially hazardous to water quality. Decision-makers in Zuid-Holland face persistent uncertainty about PFAS and other emerging contaminants, including how much these substances threaten public health and how to proceed under limited regulatory guidance (Reinikainen et al., 2024). Experimental efforts are underway to address these challenges, but opinions differ on the best path forward, and the development of sustainable long-term alternatives remains under debate (Cosoveanu et al., submitted).

3.2. Game design process

The serious game was developed by the authors through a Dutch Research Council-funded project Aquaconnect in collaboration with the Province of Zuid-Holland. The Aquaconnect serious game aims to raise awareness about acting under uncertainty and time pressure in the context of circular water management, and utilises the concepts of transformation pathways outlined above. The game was conceived to engage sector professionals, particularly policy officers from

government and interest groups. It is designed to be played within 1.5 hours allowing it to fit into lunch or networking sessions.

We adopted an iterative, informant-based co-design approach, involving researchers and stakeholders at various stages of the design process, similar to approaches used by Valero et al. (2025). The process was user-centred and unfolded in four stages (1) deliberative participatory stage, (2) preliminary design and prototyping, (3) pilot trial, and (4) game rollout and data collection. Throughout the process, research memos were used to document progress, and the authorship team engaged in continuous reflection, also on the elements of Triadic game design, which was used as a central conceptual frame throughout.

Stage 1 began with a three hour *deliberative participatory workshop in September 2023* involving four stakeholders (representatives from the province, port authority, drinking water company and horticulture sector) and three researchers. The research team fulfilled distinct roles: a facilitator, who guided the activities and managed timing; a lead designer, who translated workshop outputs into game mechanics, and an observer/notetaker, who recorded field notes and captured artefacts. The stakeholders were selected because they were part of the research consortium and they all had the role of policy advisor/maker in their respective organisations in regional government, non-profit organisations and the private sector.

The workshop focused on identifying key governance challenges, interdependencies among actors, and actor-specific risks in circular water management in the area. Participants explored two contrasting scenarios for the future of freshwater management in Zuid-Holland: (1) a business-as-usual scenario and (2) one in which circular water systems were prioritised. The contrasting narratives stimulated discussion on existing institutional constraints and future opportunities. Representatives from the province expressed concern about uncertainty in future water policy and the adequacy of current legislation, noting that the lack of clear guidance on water reuse creates ambiguity for both policymakers and society. Stakeholders from industry, ports, and the horticultural sector highlighted limited flexibility within the current system. In contrast, the drinking-water company emphasised that the risks of independent action without coordinated government direction remain too high. Together, these exchanges exposed the tensions and trade-offs inherent in governing transitions towards circular water systems, mirroring governance dilemmas reported elsewhere in the literature (e.g., Lasseur et al., 2025; Holstead et al., submitted). The insights from this workshop informed the initial prototype of the game, which captured the key governance dilemmas, actor interdependencies, and linked to the transformation pathways discussed by participants.

In stage 2, *the preliminary design and prototyping took place*. Here, the concerns of the workshop participants and the pathways for transformation were translated into different elements of the game. A first draft of the game was discussed during several design-oriented meetings involving the authorship team, which includes a serious game designer from the Province of Zuid-Holland (fourth author).

Stage three involved a *pilot trial* to pilot the game and its conceptual foundations. The game was played with a group of 6 participants (project partners), asking a. What they found immersive, engaging and fun (play), b. What insights or value they retrieved (meaning) and c. how the game related to their real world (reality), alongside general feedback and suggestions for improvement. Feedback was provided. During this phase of development, the author learned that the game was too long, did not grab players' attention enough, and there was insufficient information about the 'measures' that players could choose between.

The outcomes of the design stages until this point informed the development of the game prototype. The feedback gathered was incorporated into the game through several more meetings involving the authorship team as well as informal game plays with collegues. Throughout the design process, some weaknesses of the game were identified (see further information in the discussion). The iteration process stopped when the entire project team agreed on a final version, considering the balance of resources used (e.g. staff time and financial resources for the game components) and the level of engagement achieved. We considered that we had reached a suitable final game when the team felt that the right balance of meaning, play, and reality was achieved (Triadic game elements), and feedback from the iterative plays became 'saturated', i.e., there were no new comments and suggestions.

Finally, the *game rollout and data collection* were conducted in person at the University of Wageningen with 24 individuals, including students and researchers, from April to June 2025, and later in October with 27 people who attended a circular water knowledge day related to the authors' institutions. In total, four plays were conducted in Wageningen, and each game session lasted two hours. The authors served as game masters, leading the gameplay and as minute takers. Participants were offered a €15 voucher as compensation for their time, covering gameplay, survey completion, and group discussion. They were recruited through advertising the game via university internal communication channels, such as advertising in buildings on campus. This was deemed appropriate due to the time commitment and to ensure sufficient numbers. The participants completed a survey before and after the game, and following the game, a group discussion occurred to discuss the participants' experiences. (see Appendix 1). Four game sessions were held, generating 100 pages of data, including questionnaires, discussion notes, and researcher reflections. Participants of the knowledge day who played the game were not financially compensated for the gameplay.

To assess learning outcomes linked to the meaning dimension of Triadic game design, we operationalised four constructs in the pre- and post-game survey (see Appendix 1): (M1) understanding of actor roles and interdependencies, (M2) recognition of trade-offs and risk, (M3) perceived transfer to practice, and (M4) confidence/knowledge regarding water governance. Pre- and post-game Likert items measured (M4), and open-ended survey questions (1–8) captured insights for (M1-M3), which formed the basis for descriptive analysis. These constructs provided an analytical link between gameplay experiences and learning objectives, allowing us to interpret how effectively the game conveyed its intended meaning and supported learning.

3.3. The Aquaconnect serious game

Having outlined the game development process, we now describe the game. The game is set in the fictitious 'Delta region', which has been flourishing, but the region's freshwater is now under stress. Different spatial and economic functions compete for the availability of the fresh water there. This puts the various stakeholders in a position where they have to decide how to ensure their freshwater availability aligns with their use. These decisions must be made together: a majority must vote in favour of a measure for it to be implemented. To address future freshwater demand, they can take various measures or interventions, ranging from technological to spatial to policy measures. The main challenge is that collective choices have to be made to transform how water is managed and to keep the Delta Region future-proof.

The game is played with six characters, which are described on a card that is handed out to the six game participants randomly, including: i) Government: a regional governmental authority responsible for the environment, spatial planning and economic development in the region. ii) Industry: a multinational company located in the port of the Delta region, which needs fresh water of high quality for its production processes; iii) Nature: a nature organisation which owns large areas and also carries out nature conservation activities; iv) Food sector: farmers/greenhouse owners who produce flowers and vegetables for export; v) Drinking water company: a drinking water company responsible for the production and delivery of drinking water to private homes and companies; vi) Knowledge institute: knowledge institutes such as higher education, research institutes and universities related to water(technology), subsurface, and spatial planning (Fig. 2, and Appendix 2 for remaining cards).

Measures form the core component of the game. These are the interventions that the players choose to address water scarcity in the

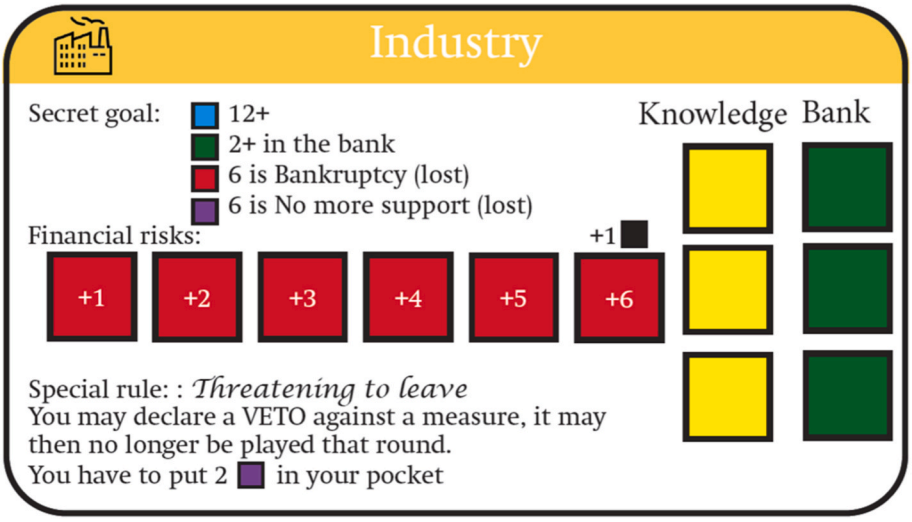

Fig. 2. Example of an actor card.

future of the Delta region, which will lead to an increase in water availability. In total, there are 12 measures from which they can choose. These measures consist of three elements: the effect they have on water availability, the knowledge (if any) required to develop and implement the measure, a brief description of the measure, and finally, the different types of risks associated with implementing the measure. Here, the distinction is made between the following risks: angry citizens, financial, environmental, and implementation risk (Fig. 3). The 12 measures are distributed over the three pathways as described by Termeer et al. (2024) (Tables 1 and 2). In each round, the players can suggest measures. They then have to decide by majority vote which measures will be selected and implemented. In the case of a tie vote, the government's vote is decisive. Each actor card also has a secret assignment that comes with their role. Each assignment is different. The secret assignment might influence the measures the player takes. See Appendix 3 for all measure cards.

In the game, the risks, knowledge, means, and disasters are symbolised by small cubes handed out after each round (see Appendix 5). The participants have a small bag in which they must place the risk cubes they receive after a measure is implemented, at the end of the round. During the game, a template sits on the table that shows four rounds, each representing a 10-year time frame (Fig. 4). Each of these timeframes has its own characteristic. In the first round, the government has to take an extra risk with angry citizens. The reason they have to take a risk is that a negative reaction is assumed to be a likely outcome based on the changes needed in society. The government is sensitive to public opinion and gaining or maintaining public support (XX). In the second round, Industry and Food must take an additional financial risk for every

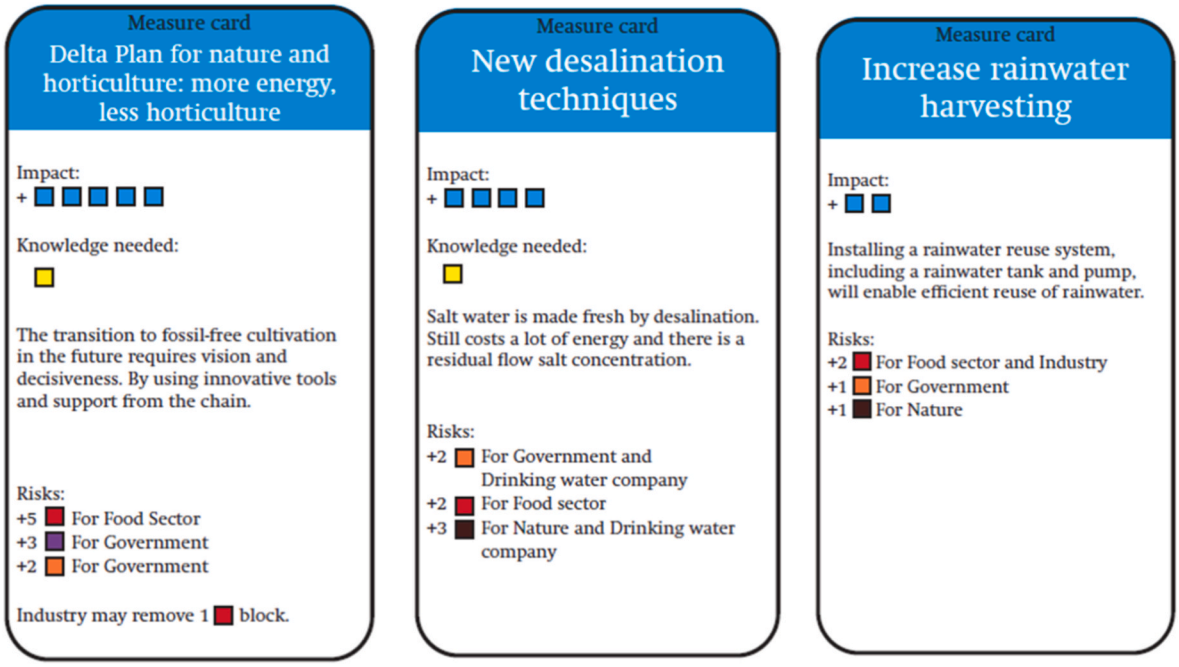

Fig. 3. Examples of measures: describing their impact (number of water sources added), the amount of knowledge needed to implement the measure, a short description and finally the risks that have to be distributed over the different actors/players.

Table 1
Game elements of the Aquaconnect game according to Triadic game theory.

Triadic element	Narrative element	Description	Representation in the game
Reality	Measures	Possible actions consisting of technology, policy and spatial/ economic measures to address freshwater availability.	Measures to address drought.
	Role	The main stakeholders in the region have their own interests relating to freshwater availability.	Each game participant has an assigned role.
	Time	This simulates the different time scales through which managing freshwater availability is evolving, requiring participants to see the connection between short-term and long-term perspectives.	The four rounds in the game each represent a 10-year timeframe, each of which elapses in 10 minutes.
	Asymmetrical resources & goals	To experience interdependencies between the stakeholders.	All players have one shared goal (enough water availability). Each role also has specific goals to adhere to. No player has the same resources or goals.
Meaning	Three pathways	The 12 measures in the game are divided into three pathways following Termeer et al. (2024).	Integrated into the game through the measures.
	Collaborative approach	This links to the asymmetrical means and goals. Also showing that a collaborative approach is necessary.	Players must choose between taking more risks for the collective goals or prioritising their own goals. If they take no action or prioritise their own gain, the system will collapse.
	Measures	Brief descriptions of the measures, along with a reflection on the game.	Creating insight into the different measures that can be taken and their possible effects and risks.
Play	Secret mission	To keep the participants focused, they get a secret mission.	Secrets as a method for engagement/ attentiveness.
	Negotiation & voting	Players collectivly decide and vote on measures to be taken. Some roles can threaten actions and bring in unexpected abilities (such as extra angry citizens for the government).	The yes/no card and the discussion with the other participants.
	Game tangibles	Cards describing the roles, yes/no cards, and cubes in different colours to represent means and risks were added.	These make the game fun to play.
	Pulling cubes	After each round, each player takes risk cubes out of a bag.	This creates excitement and has a direct influence on reaching the secret goal.

measure taken, as the demand for labour and materials to implement change increases, increasing the risk of scarcity and thus higher costs (Dunford and Han, 2025). Because of this scarcity, the risk of higher increases and governmental organisations have to pay more. Therefore, in the third round, an extra cost is incurred with each measure. Finally, in the last round, the government and drinking water companies face an additional implementation risk due to a large increase in urgency to meet goals, which increases the chance that implementation is 'rushed' and, therefore, measures are not tested enough. Their impacts may prove less effective than anticipated.

Ten minutes are allotted per round for participants to reach a decision on which measure(s) to choose in that round. A game master is present, keeping track of the time and distributing risks after each round. Also, some actors receive knowledge and take risks each round. After the four rounds are completed, there is a reflection on how the participants experienced the game and what learning aspects were evident. A summary of all the game elements are described in Table 2.

Table 2
Outline of measures in the Aquaconnect game and their relation to Termeer et al. (2024).

Measure	Big plans	Small wins	Rule change
Desalination techniques		X	
Brackish water as a source	X		
Use of effluent	X		
Encourage reduced water usage			X
Saltwater-resistant crops		X	
Rainwater harvesting		X	
Increase price of water usage			X
Raise awareness of water usage		X	
Delta Plan for nature and horticulture: more nature, less horticulture	X		
Delta Plan for energy and horticulture: more energy, less horticulture	X		
Increase efficiency of water usage through models/control systems		X	
Policy initiative to ease reuse regulations			X

3.4. Game evaluation

Different pathways were selected during the game rollout and evaluation (see Table 3 and Appendix 5 for further information). While a limited sample played the game, there appears to be a tendency for the first selection of measures to lean towards the big plans approach, and in later rounds, it shifts towards small wins and rule changes. In a way, this is quite contradictory, as one would expect resistance to change to be much higher if urgency is low, especially if there is still a time between the current situation and the expected limits of the freshwater system.

Reflections were embedded in collective sensemaking moments during the game, led by the game master. In addition each session concluded with a facilitated discussion during which the game master debriefed participants and unpacked key events. These reflection moments helped players step out of their roles, process challenging experiences, and contribute to a safe and supportive learning environment. The appendices provide all role and measure cards, the risk key, the pre-/and post-survey instruments.

The feedback from the game sessions was generally positive. Most participants demonstrated good prior knowledge of water management and reported a similar level of understanding afterwards. Those without previous experience of circular water management noted that the game helped them develop a more fundamental understanding. Survey responses indicated that the game supported learning about water governance, particularly regarding the roles of different actors, trade-offs, and risks.

Feedback showed that the game encouraged participants to reflect on their own roles and those of others in addressing circular water management in the context of drought, and to consider the challenges faced by different stakeholders. This reflection was embedded within the roleplay element, which required players to negotiate based on both shared and individual interests. In the feedback reported that they

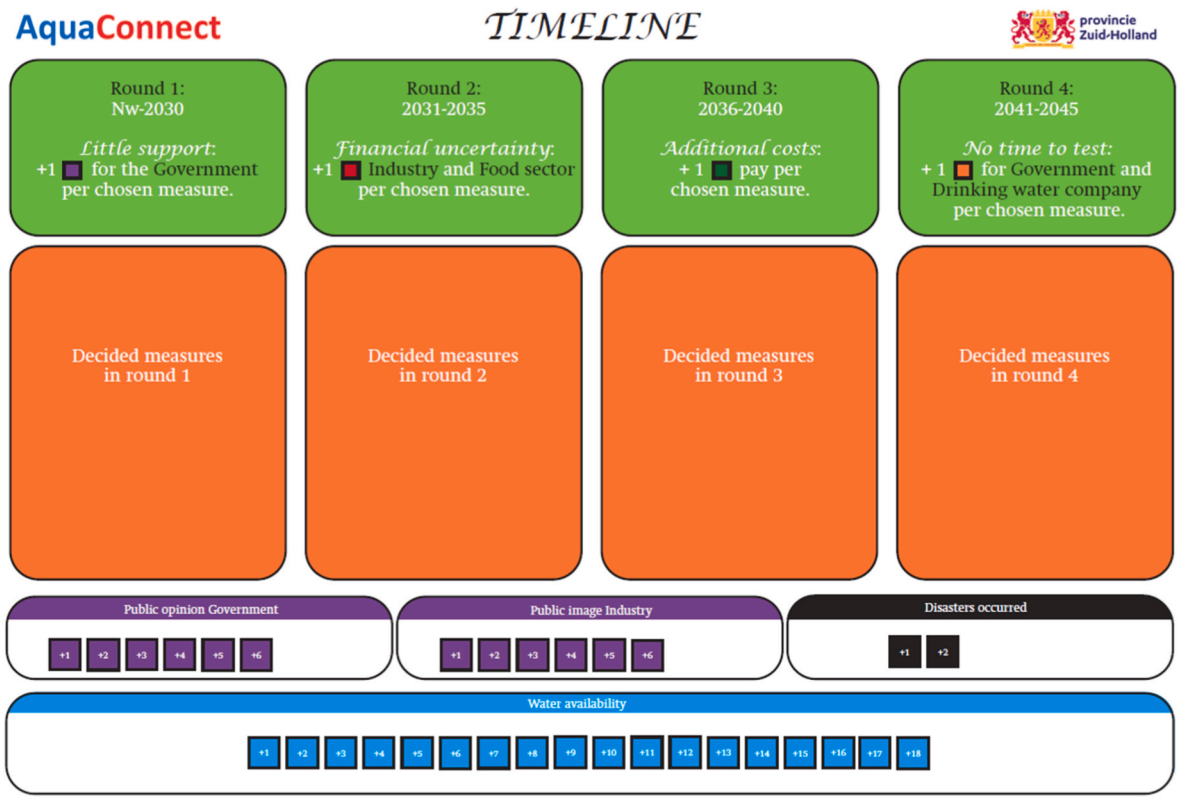

Fig. 4. Template for game play where cards and cubes are laid. This sits in the middle of the table.

Table 3
Pathways selected during four game plays.

	Round 1	Round 2	Round 3	Round 4
Play 1	No measures	1 Big plans	1 small wins	2 Small wins
Play 2	1 Big plans	1 Big plans	1 Small wins	2 Small wins
Play 3	1 Big plans	1 Small wins 1 Small wins 1 Big plans	1 Rule change 1 Small wins	1 Rule change
Play 4	1 Big plans	1 Big plans 1 Small wins	1 Rule change	No measures

recognised the challenges faced by government actors, the influence of policy in shaping outcomes, and the inherent difficulties of these roles though the game play. One participant observed that "there is no one way for the government to do it exactly right. With every measure someone is disadvantaged, and you never know what comes next" (player 3, play 2). At the same time, another reflected that "agreeing in a time crunch is hard, that restoring government popularity is hard, and what the government prioritises has a lot of impact" (player 2, play 4) also demonstrating an understanding of the challenges faced by governments facing drought. The roleplay also helped some players adopt new perspectives; one explained, "I would usually be more keen for riskier nature positive solutions, but this role helped me consider the lower risk and more hesitant role represented by the government" (player 5, play 1). Others reported being more attentive to cross-sectoral dynamics, stating that they would pay more attention to the way different sectors talk about policy, undertake activities related to water management and how these impact others (player 3, play 4). The complexity and multistakeholder nature of water governance also became more apparent to plays as one highlighted how suprised they were about "the diversity of actors that need to be at the table when deciding on water management measures/solutions" (player 3, play 4). Despite these challenges, the game instilled a sense of optimism, as one participant noted that "it is possible to discuss and negotiate to reach a collaborative decision" (player 1, play 4). Others expressed a desire going forward to better understand the roles of different actors in circular water management and called for greater transparency about government-supported measures (player 3, play 1).

The game also improved participants' understanding of the trade-offs and risks associated with circular water management. Several players reflected on the interconnectedness of different roles and the absence of clear-cut solutions, noting that: "there is no clear right or wrong way […] I now understand more about the high risks and uncertainty of each measure for different actors" and emphasising that action is needed to avoid inertia. Players assessed risks by making decisions between alternative measures and recognised that each pathway involves distinct trade-offs. They reported becoming "sensitised" to a range of possible measures (player 2, play 4) and to the inherent trade-offs between them (player 3, play 4). The unpredictable nature of drought was also made tangible through gameplay, as one participant explained, "we ended up going in a direction that was not good [for water availability] without intending this" (player 4, play 2).

In summary, the game helped participants to become more aware of

their own roles, the trade-offs and risks they face, and those experienced by others. These insights were reinforced through 'aha' moments embedded into the game (Steinrücke et al., 2023) such as recognising the relevance of different risks for different roles or understanding technical issues like the fact that desalination technologies produce a by-product that is difficult to dispose of.

4. Discussion

The Aquaconnect serious game explores transformative governance towards circular water systems in response to increasing water shortage. The novelty of the game lies in the incorporation of the three pathways for transformative change (Termeer et al., 2024). The Aquaconnect serious game and evaluation contribute to the growing body of research exploring how serious games can support transformative governance in environmental systems (Aubert et al., 2019; Termeer et al., 2017). Transformative governance involves fostering reflexivity, collaboration, and the capacity to act under uncertainty (Pahl-Wostl, 2015). The game provided an experiential setting where these principles could be enacted and observed, revealing how participants navigated competing values, risks, and time horizons in decision-making about circular water systems and drought resilience.

Preliminary testing of the game showed that participants' choices evolved from initially favouring big plans to later preferring small wins and rule changes. This shift mirrors findings in governance literature that suggest transformation is often not achieved through singular, large-scale interventions, but through incremental and adaptive steps that build momentum for systemic change (Termeer and Dewulf, 2019). The game thus provided an initial test bed of transformation processes, illustrating how actors' learning and perceptions of feasibility evolve through interaction. At the same time, we must acknowledge the limitations of our work in this regard. The game was primarily tested with a relatively small and convenience-based sample some of which were compensated for their participation. This limited group cannot be considered representative; however, it does provide insights into the relevance and importance of the game.

Beyond its immediate learning outcomes, the Aquaconnect game functions as a boundary object (Star and Griesemer, 1989). It provides a shared but flexible space where actors from diverse sectors might negotiate meanings, articulate their perspectives, and collectively engage with a common water governance challenge. People play different roles in the game, but interact within a common structure of rules and constraints. This resonates with findings by Jean et al. (2018), who contend that these situations can bridge epistemic and organisational boundaries by fostering dialogue without requiring consensus. In this way, Aquaconnect created a microcosm where participants could test decisions, negotiate trade-offs, and develop empathy for other roles. Such interactions are central to transformative governance, which depends on arenas that enable collective sense-making across institutional divides (Pahl-Wostl, 2015; Termeer et al., 2017; Jean et al., 2018). Thus, the game might not only facilitate learning about circular water systems but also enact the kind of cross-boundary collaboration that transformation processes require in practice.

Although serious games are increasingly important tools in the transformation towards circular water systems, transparency in design and evaluation is often missing and recongised as a gap in the literature (Aubert et al., 2019; Savic et al., 2016; Valero et al., 2025). And this is where the second contribution of the research lies. Triadic game design offers transparency into the creation of serious games that embed theoretical insights, considering meaning, reality, and play. In the discussion that follows, we outline how these elements were balanced, providing insights for future game designers.

As noted, the development of the Aquaconnect game unfolded through a co-creative methodological approach outlined above, during which the authorship team grappled with the core elements of Triadic game design. There were three key balancing iterations during the game development where an acceptable equilibrium of the Triadic game design elements was struck. We called these iterations: *grounding, expanding* and *refining*. These are each described below.

First, the initial game was created after our participatory workshop. Early versions of serious games typically require rebalancing, as they serve primarily as exploratory starting points for design (e.g., Harteveld et al., 2010). Thus this initial iteration focused on *grounding,* providing the game designer a trial version that allowed them to work with something concrete. This first iteration was centred on resource management, where players took on roles and used money, land and knowledge cards to implement drought measures. Although the mechanics were deemed to be realistic, they produced a rule-heavy and lengthy gameplay experience that was paradoxically too easy to master. The team were hesitant to shorten the game, concerned that reducing its duration would weaken players' understanding of water challenges and that players would fail to connect in-game experiences to the real-world systems they were meant to represent (Forrest et al., 2022).

In this iteration, the authorship team concluded the game lacked the frustration associated with real-world problems. Players failed to encounter the dilemmas of circular water management and transformation that the game was intended to illustrate. Problems were solved too easily and too fast and players felt good about themselves, but without experiencing the problems that hinder real-world water systems and associted risks. This was a combination of the lack of game mechanics that portrayed these risks (a play element) and the absence of information in the game about the measures and associated risks (a reality element). The authorship team identified a game mechanic that would help players understand how risks work - and in this way the risk cubes were added.

The second iteration focused on *game expansion*. This iteration focued on more effectively portraying the urgency of the problem and introduced a broader range of player choices. In response to the previous imbalance, new narrative elements were introduced, including more detailed roles and characters, and game measures were aligned with transformative pathways identified by Termeer et al. (2024). These design features made the game more playable, however, the narrative still remained underdeveloped, and the characters lacked relatability. What emerged in this round was that players approached the game measures as strategic tools rather than learning opportunities. For instance, although each measure card included associated risks, players failed to reflect on the implications of their choices or understand the differences between the measures and associated risks. As Naul and Liu (2020) argue, serious games must connect fantasy elements to learning objectives. The abundance of choices the design team had added created fun but diluted the intended learning outcomes. In Triadic game terms, there was an overfocus on playability.

Finally, in our third iteration - *game refinment* - an acceptable balance across the three design dimensions was sought by streamling and removing unnecessary complexity. Within the authorship team, this stage was informally called 'kill your darlings', referring to the ideas that the team purposefully removed and simplified parts of the game they were attached to create an elegant gameplay. For instance, the diversity of means was reduced, more comprehensive information was added to the measures, explicitly linking them to the underlying transformative change theory (Termeer et al., 2024) as well as structured reflection sessions. These sessions not only allowed players to make connections between in-game decisions and real-world concepts but also enabled the collection of data on their choices and perceptions. This change was

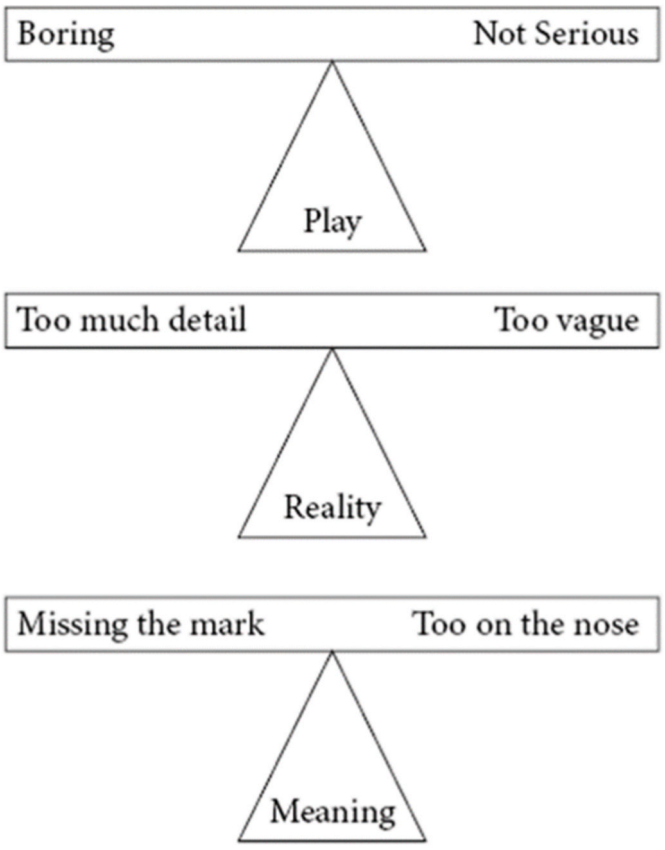

Fig. 5. The constant balancing the elements of Triadic game design emerging though iterations.

reinforced through concise explanations of the measures and new intervention points, where the game master explained the consequences of players' decisions after each round so that, in principle, players drew meaning from the measures. The iterations stopped when the team felt that the game sufficiently balanced the three Triadic game elements see (Fig. 5).

In summary, each design iteration exposed different trade-offs: realism without playability created limited engagement; play without reflection weakened learning; and excessive narrative and detail risked cognitive overload. These are summarised in Table 4, along side the design adjustments made and lessons lessons learnt which are further discussed next.

4.1. Lessons learnt and points for future game development

The development of Aquaconnect underscores that balancing meaning, reality, and play requires sustained design effort and iterative testing. Each design iteration revealed how adjustments to one component could easily shift the equilibrium and knock the others out of alignment (see Table 4). An early focus on resource management realism failed to convey authentic dilemmas. This resulted in a game that was technically accurate but not engaging or meaningful for players. Serious games must not lose sight of the entertainment value that draws players in and sustains participation (Mittal et al., 2022). Yet at the same time, there is a common pitfall in serious game design: mistaking strategic complexity for meaningful engagement (Flanagan, 2013). The second iteration improved playability yet diluted the conceptual focus. In the final version, through removing nonessential features, although the game designers enjoyed them, with the addition of reflection prompts, the game aligned the educational objectives with engaging mechanics. This process highlights that simplicity and coherence are important assets in game design, more so than, complexity for its own sake.

Thus, a key takeaway was that structured reflection moments, guided by the game master, played a crucial role in translating play into learning (mearning). These interpretive moments acted as bridges between the fictional game world and the real-world systems it represented, helping to tie together the triadic elements. Reflection should be seen not as a post-game add-on but as a core part of the design process that can restore balance in a serious game when one element dominates. New game designers would be wise to embed reflection within gameplay and not leave it reserved for debriefing, to maintain learning depth.

The importance of narrative and role-playing emerged as another crucial aspect of balance. Without a compelling narrative or relatable characters, players had little emotional or cognitive anchor for their decisions, reducing the depth of engagement with the game's underlying message. When these elements were improved and aligned with transformative learning frameworks, the game became more effective not just as a playful experience but as a pedagogical tool. This reinforces the notion that in Triadic game design, meaning is not transmitted solely through content, but also through the experiential structure of the game, i.e., how players are invited to inhabit roles, face dilemmas, and reflect on the consequences (Flanagan, 2013; Mittal et al., 2022).

Finally, a key practical insight concerns stakeholder engagement. The term 'game' sometimes triggered scepticism or a perception of unseriousness. The game was intended, as it was informally called within the project team, as 'a dessert, not a main course', meaning that it was to be played for an hour or two, during, for instance, a class, lunch break or staff meeting. Regardless of the time commitment, recruiting players to participate in the game and encouraging stakeholders to engage with it

Table 4
Iterative development of the Aquaconnect game and balancing triadic game design.

Game iterations	Focus	Imbalances identified	Design adjustments made	Lessons
1 Grounding	Establishing play, realism and structural coherence through a resource-management prototype. Gameplay involved roles, budgets, and measure cards over six 10-min rounds representing decades of environmental change.	Overemphasis on realism led to limited engagement and reflection. The system was rule-heavy but conceptually shallow, with players not experiencing authentic dilemmas.	Simplify and focus on dilemmas rather than technical accuracy. Realism without tensions weakens meaning.	A realistic prototype is insufficient without engagement and challenge. Balancing reality requires integrating uncertainty and meaningful decision-making.
2 Expanding	Introducing narrative depth, detailed roles, and diverse measures aligned with transformation pathways	Greater playability and strategy improved enjoyment but diluted meaning. Players treated measures as tactical tools without reflecting on underlying risks or learning objectives.	Enhanced player guidance and reflection prompts. Strengthened narrative to tie strategic choices to learning outcomes.	Engagement without structured reflection weakens learning. Narrative and role-play are vital for linking play to meaning.
3. Refining	Streamlining mechanics, linking measures explicitly to embedded theory and establishing structured reflection sessions. Removing attractive but distracting elements.	Risk of losing educational coherence through creative overcomplexity. Needed to preserve learning focus while maintaining engagement.	Added post-round interventions and reflection moments led by game masters. Prioritised theoretical coherence over detail.	Design maturity emerges through purposeful simplification. Reflection and facilitation are central to translating play into learning.

were challenging, and the team experienced resistance to the game. The resistance reflects the need for early engagement, as well as aligning and framing the game appropriately. The solution was to pitch the game as a learning experiment or an integrative learning session, thereby enhancing the legitimacy of the method in the eyes of the stakeholders. This was especially the case if there was a direct link between a problem the players faced and the central issues in the game. For instance, thoughout the game development process we found that potential players were more likely to engage if they saw how playing the game could help them solve a problem or better understand an issue. Aligning the game's framing with participants' objectives is thus central to its uptake.

5. Conclusions

This study bridges the gap between governance transformation theory and serious game design by integrating Termeer et al.'s (2024) transformation pathways within the mechanics of a game on circular water governance. Guided by Triadic game design, the research demonstrates how iterative development can balance realism, play and meaning while grounding gameplay in established governance theory. The resulting game and research reflection offers both a conceptual link between transformation pathways and game-based learning, and a methodological model for transparent design practice. In doing so, the study provides insights that can be used to enhance serious games' analytical depth and practical relevance as tools for understanding and supporting sustainability transitions.

Looking ahead, this work opens up several avenues for future research. Our primary audience is policy officers, water utility staff, and advanced students engaged in water governance. University and workshop participants formed a convenience sample; thus, our findings are preliminary and we encourage others to test them. Future work might compare outcomes across countries and professional cohorts. To date, the game has only been tested in the Netherlands. Many serious games are often played in a single country (Forrest et al., 2022), yet broader deployment, such as at international conferences and workshops could offer cross-cultural insights. For other regions, roles and measures should be localised (e.g. sector mix, regulatory levers, risk types) while preserving the pathway structure and reflection scaffolding. Comparative research on transformative pathways across countries remains limited, and wider application of the game could help uncover how different national contexts shape understandings and approaches to circular water management.

A central challenge moving forward is how to disseminate the game more widely. Currently, the game relies on a trained game master for facilitation, limiting its scalability. Drawing inspiration from other game models, future versions of Aquaconnect could be designed to allow players to learn and run the game independently, such as with peers or within organisations, or even online. This approach would reduce dependence on the research team and enable broader adoption. However, any such adaptation should also incorporate mechanisms for collecting data on player decisions and outcomes, ensuring that the game continues to serve both as a learning tool and a research instrument.

CRediT authorship contribution statement

K. Holstead: Writing – review & editing, Writing – original draft, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **G.J. Ellen:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **W.J. Van Doorn-Hoekveld:** Writing – review & editing, Methodology, Investigation, Conceptualization. **L.E. Van den Bergh:** Writing – review & editing, Methodology, Conceptualization.

Declaration of competing interest

There are no conflict of interests to declare.

Acknowledgement

The authors would like to thank the participants for their time and feedback on the game as well as the reviewers, who helped to improve this paper with the insightful comments. This research was performed within the framework of the research program AquaConnect, funded by the Dutch Research Council (NWO, grant-ID P19-45) and public and private partners of the AquaConnect consortium and coordinated by Wageningen University and Research.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2025.147252.

Data availability

Data will be made available on request.

References

Aubert, A.H., Bauer, R., Lienert, J., 2018. A review of water-related serious games to specify use in environmental multi-criteria decision analysis. Environ. Model. Software 105, 64–78.
Aubert, A.H., Medema, W., Wals, A.E., 2019. Towards a framework for designing and assessing game-based approaches for sustainable water governance. Water 11 (4), 869.
Berglund, O., Dunlop, C.A., Koebele, E.A., Weible, C.M., 2022. Transformational change through public policy. Pol. Polit. 50 (3), 302–322.
Dunford, M., Han, M., 2025. Energy dilemmas: climate change, creative destruction and inclusive carbon-neutral modernization path transitions. Int. Crit. Thought 15 (1), 76–100.
Erkens, G., Van der Meulen, M.J., Middelkoop, H., 2015. The impact of subsidence on the water system in the Netherlands. Environ. Res. Lett. 10 (2), 024007.
Flanagan, M., 2013. Critical Play: Radical Game Design. MIT Press.
Flood, S., Cradock-Henry, N.A., Blackett, P., Edwards, P., 2018. Adaptive and interactive climate futures: systematic review of 'serious games' for engagement and decision-making. Environ. Res. Lett. 13 (6), 063005.
Forrest, S.A., Kubíková, M., Macháč, J., 2022. Serious gaming in flood risk management. Wiley Interdiscip. Rev.: Water 9 (4), e1589.
Hammady, R., Arnab, S., 2022. Serious gaming for behaviour change: a systematic review. Information 13 (3), 142.
Harteveld, C., 2011. Triadic game design: Balancing reality, meaning and play. Springer, London.
Harteveld, C., Guimarães, R., Mayer, I.S., Bidarra, R., 2010. Balancing play, meaning and reality: The design philosophy of LEVEE PATROLLER. Simulat. Gaming 41 (3), 316–340.
IPBES, 2019. In: Brondizio, E.S., Settele, J., Díaz, S., Ngo, H.T. (Eds.), Global Assessment Report on Biodiversity and Ecosystem Services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. IPBES secretariat, Bonn, Germany, p. 1148. https://doi.org/10.5281/zenodo.3831673.
Jean, S., Medema, W., Adamowski, J., Chew, C., Delaney, P., Wals, A., 2018. Serious games as a catalyst for boundary crossing, collaboration and knowledge co-creation in a watershed governance context. J. Environ. Manag. 223, 1010–1022.
Kirchherr, J., Reike, D., Hekkert, M., 2017. Conceptualizing the circular economy: an analysis of 114 definitions. Resources. Conserv. Recycl. 127, 221–232.
Larsen, T.A., Hoffmann, S., Lüthi, C., Truffer, B., Maurer, M., 2016. Emerging solutions to the water challenges of an urbanizing world. Science 352 (6288), 928–933.
Lasseur, N.M., Holstead, K., Huitema, D., 2025. How is the governance of circular economy of water organized? A systematic review of the literature. Ecol. Soc. 30 (3).
Madani, K., Pierce, T.W., Mirchi, A., 2017. Serious games on environmental management. Sustain. Cities Soc. 29, 1–11.
Medema, W., Mayer, I., Adamowski, J., Wals, A.E.J., Chew, C., 2019. The potential of serious games to solve water problems: editorial to the special issue on game-based approaches to sustainable water governance. Water 11 (12), 2562.
Mittal, A., Scholten, L., Kapelan, Z., 2022. A review of serious games for urban water management decisions: current gaps and future research directions. Water Res. 215, 118217.
Morseletto, P., Mooren, C.E., Munaretto, S., 2022. Circular economy of water: definition, strategies and challenges. Circ. Econ. Sustain. 2 (4), 1463–1477.
Naul, E., Liu, M., 2020. Why story matters: a review of narrative in serious games. J. Educ. Comput. Res. 58 (3), 687–707.
Nogurira, G.E.H., Meeusen, R., van Scheltinga, R.C.T., Hoogland, T., Jansen, S., Nijsten, G.J., et al., 2025. Flexible solution concepts for sustainable drinking water

production in the Netherlands. Neth. J. Geosci. 104, e11908. https://doi.org/10.70712/NJG.v104.11908.
Pahl-Wostl, C., 2015. Water Governance in the Face of Global Change: from Understanding to Transformation. Springer.
Powell, R.B., Ardoin, N.M., Monz, C.A., 2021. Serious games as a catalyst for boundary crossing, collaboration, and knowledge co-creation in a watershed governance context. J. Environ. Manag. 223, 110–123.
Reinikainen, J., Bouhoulle, E., Sorvari, J., 2024. Inconsistencies in the EU regulatory risk assessment of PFAS call for readjustment. Environ. Int. 186, 108614.
Rijksoverheid, 2025. Actieprogramma Beschikbaarheid Drinkwaterbronnen 2023 – 2030, Downloaded From: Actieprogramma Beschikbaarheid Drinkwaterbronnen 2023-2030 | Rapport | Rijksoverheid.Nl.
Savic, D.A., Morley, M.S., Khoury, M., 2016. Serious gaming for water systems planning and management. Water 8 (10), 456.
Star, S.L., Griesemer, J.R., 1989. Institutional ecology, 'translations' and boundary objects: amateurs and professionals in Berkeley's museum of vertebrate zoology, 1907–39. Soc. Stud. Sci. 19 (3), 387–420. https://doi.org/10.1177/030631289019003001.
Steinrücke, J., Veldkamp, B.P., de Jong, T., 2023. The effect of self-reflection on information usage and information literacy in a digital serious game. Computers and Education Open 4, 100133.
Tene, T., Vique López, D.F., Valverde Aguirre, P.E., Cabezas Oviedo, N.I., Vacacela Gomez, C., Bellucci, S., 2025. A systematic review of serious games as tools for STEM education. Front. Educ. 10, 1432982.
Termeer, C.J.A.M., Dewulf, A., 2019. A small wins framework to overcome the evaluation paradox of governing wicked problems. Policy and Society 38 (2), 298–314. https://doi.org/10.1080/14494035.2018.1497933.
Termeer, C.J.A.M., Dewulf, A., Biesbroek, R., 2017. Transformational change: governance interventions for climate change adaptation from a continuous change perspective. J. Environ. Plann. Manag. 60 (4), 558–576. https://doi.org/10.1080/09640568.2016.1168288.
Termeer, K., Dewulf, A., Biesbroek, R., 2024. Three archetypical governance pathways for transformative change toward sustainability. Curr. Opin. Environ. Sustain. 71, 101479.
Valero, D.E., McKeon, C.R., Bussière, L., Corniani, N., Colmenarez, Y.C., Hodgson, I., et al., 2025. A practical approach to developing and using online games for transdisciplinary research into complex social-ecological systems. Soc. Nat. Resour. 1–24.