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Title	Adaptive and interactive climate futures: systematic review of 'serious games' for engagement and decision-making
Authors	Flood, Stephen;Cradock-Henry, Nicholas A.;Blackett, Paula;Edwards, Peter
Publication date	2018
Original Citation	Flood, S., Cradock-Henry, N. A., Blackett, P. and Edwards, P. (2018) 'Adaptive and interactive climate futures: systematic review of 'serious games' for engagement and decision-making', Environmental Research Letters, 13(6): 063005, (20pp.) DOI: 10.1088/1748-9326/aac1c6
Type of publication	Article (peer-reviewed)
Link to publisher's version	https://iopscience.iop.org/article/10.1088/1748-9326/aac1c6 - 10.1088/1748-9326/aac1c6
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Environmental Research Letters

TOPIPCAL REVIEW

Adaptive and interactive climate futures: systematic review of 'serious games' for engagement and decision-making

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OPEN ACCESS

RECEIVED
21 June 2017

REVISED
29 April 2018

ACCEPTED FOR PUBLICATION
2 May 2018

PUBLISHED
5 June 2018

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Keywords: serious games, climate change adaptation, social learning, climate services, decision-making

Abstract

Climate change is already having adverse impacts on ecosystems, communities and economic activities through higher temperatures, prolonged droughts, and more frequent extremes. However, a gap remains between public understanding, scientific knowledge about climate change, and changes in behaviour to effect adaptation. 'Serious games'—games used for purposes other than entertainment—are one way to reduce this adaptation deficit by enhancing opportunities for social learning and enabling positive action. Games can provide communities with the opportunity to interactively explore different climate futures, build capability and capacity for dealing with complex challenges, and socialise adaptation priorities with diverse publics. Using systematic review methods, this paper identifies, reviews, synthesises and assesses the literature on serious games for climate change adaptation. To determine where and how impact is achieved, we draw on an evaluation framework grounded in social learning, to assess which combinations of cognitive (knowledge and thinking), normative (norms and approaches) and relational (how people connect and network building) learning are achieved. Results show that factors influencing the overall success in influencing behaviour and catalysing learning for adaptation include generating high levels of inter- and intra- level trust between researchers, practitioners and community participants; strong debriefing and evaluation practices; and the use of experienced and knowledgeable facilitators. These results can help inform future game design, and research methodologies to develop robust ways for engaging with stakeholders and end users, and enhance learning effects for resilient climate futures.

1. Introduction and background

The adverse effects of climate change are already becoming clear. Higher average temperatures, more frequent extremes and increased climate variability are being documented globally, with attendant effects on a range of ecosystems, and coupled human-environmental systems including urban infrastructure, agriculture, and more (IPCC 2013, IPCC 2014a, IPCC 2014b). Despite more detailed scientific understanding of the impacts of anthropogenic climate change, and growing awareness of the need for widespread adaptation across multiple domains and sectors there remains a knowledge-action gap, to catalyse adaptation behaviours (Lesnikowski *et al* 2015, Eisenack *et al* 2014, Clayton *et al* 2015). One way to reduce this adaptation deficit is through the development and application of 'serious games', to enhance opportunities for learning, and practice and behaviour change.

Serious games—games used for purposes other than entertainment—are becoming more widely used in climate change research and practice (Chew *et al* 2007, Crookall 2013, Eisenack and Reckien 2013, Schenk and Susskind 2015). In a recent review of serious games for climate change, Reckien and Eisenack (2013) observed that the number of climate-related

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games increased rapidly prior to the 2009 UNFCCC meeting in Copenhagen. In their review, the authors focused on a range of climate change games, discussing 52 of them in detail (Reckien and Eisenack 2013). Among the gaps they identified was a lack of climate adaptation games—an area that has developed substantially in the intervening years.

Climate change games typically have three primary objectives: teach knowledge and provide familiarity with the issues of climate change; make players aware of the challenges associated with global warming and encourage players to develop solutions (Reckien and Eisenack 2013). Games also act as safe innovation spaces (Johnson *et al* 2011) to interactively engage with alternate climate futures, build capability and capacity for resolving difficult problems and socialise adaptation with different publics.

Given the increased prominence of serious games in recent years, and the need for novel and robust ways to promote adaptation behaviours, the following review systematically identifies, reviews, and appraises the global literature on serious games for climate change adaptation. The review focuses more specifically on engagement and decision-making for adaptation, across diverse sectors, activities and ecosystems. Using a social learning-based evaluation framework (Baird *et al* 2014, Baird *et al* 2016), we assess the effects of gameplay on learning outcomes, and how that might link to and enhance aspects of environmental governance.

The paper is organised as follows. An overview of the systematic review methodology and results are next. We then discuss eight emergent themes arising from our review and synthesis of the global literature on serious games; followed by a more detailed discussion of the social learning effects of serious games, and their impact. In so doing, the paper makes a unique contribution to the literature, combining systematic literature review with evaluation to identify the learning outcomes empirically associated with serious game play. The research advances our understanding with respect to which of these components serious games should aim to include to achieve learning outcomes. It also addresses the challenge of evaluating games' impacts and outcomes, and provides recommendations for practice, based on examples from the literature. Finally, the summary and conclusions provide guidance for best practice for game design and points to future research directions.

2. Methods

Systematic reviews (SRs) are an important tool for gathering, screening, and analysing large bodies of knowledge. They provide a baseline to measure advances in understanding and are structured in such a way as to summarise existing evidence while identifying gaps and directions for future research. They differ from generic literature reviews in three main ways: they begin by defining a review strategy, they explicitly identify inclusion and exclusion criteria, and they aim to exhaustively assess the literature available and relevant to a particular topic (Cochrane Collaboration 2008, Petticrew and Roberts 2006, Booth *et al* 2016, Ford *et al* 2011). Systematic reviews have been widely used in the health sciences (Greenhalgh and Peacock 2005, Heller *et al* 2008)—to evaluate the effectiveness of medical interventions for example—but more recently have been adapted for use in other fields (Ford and Pearce 2010). In the climate change literature, SRs have been applied to diverse topics including adaptation (Ford *et al* 2011), projecting future heat-related mortality under climate scenarios (Huang *et al* 2011), vulnerability in the Canadian Artic (Ford and Pearce 2010), and impacts on crop productivity (Knox *et al* 2012). Other reviews in the environmental and social sciences more generally, are being published with more frequency.

A review begins with defining the parameters of the search, followed by the collection, appraisal and compilation of relevant literature. To identify the relevant literature, inclusion and exclusion criteria were defined (table 1), and a template for recording metadata about each item prepared (table 2). Search terms, including wild cards, were used to identify literature on serious games with a climate change adaptation focus, using five search engines (Scopus, Web of Science, Science Direct, Google Scholar, and Google) (table 3).

Data from the literature was extracted, organised and analysed using the categories listed in table 2 below.

Table 3 details the search terms and initial returns after the five databases were interrogated.

Search results were manually screened for relevance. In the first instance, titles were read, and abstracts of relevant titles reviewed. Articles also scanned, in some cases to determine relevance for the current study. Screening steps and results are shown in table 4.

A total of 43 research outputs (including working papers and reports) provide the basis for the review. Items were read multiple times, and manually coded to identify emergent themes and commonalities. A social learning-based evaluation framework was then applied to determine games' effectiveness in promoting cognitive, normative and relational learning among game participants (Baird *et al* 2014, 2016). We begin by discussing our findings in terms of shared characteristics of adaptation games, followed by the results of the assessment of learning effects.

3. Results

Analysis of the publication characteristics of the 43 selected papers (table 5) revealed the recent emergence of climate change adaptation focused serious games as a research endeavour (see also figure 1), a dispersed geographic distribution of research activities, and a

Table 1. Inclusion and exclusion criteria used in the literature search and document selection phase.

Inclusion criteria	Exclusion criteria
Must be a game or role-play	Does not include game or role-play
Type of study: Article, book, book chapter, working paper, report, conference paper or thesis	Type of study: NOT article, book, book chapter, working paper, report, conference paper of thesis
Must be focused on climate change adaptation	NOT climate change adaptation focused
English language publication	Non-English language publication
Date range: Post-1990 to present	Date range: Pre-1990

Table 2. Criteria used in the data extraction, organisation, and analysis phase.

Category	Details
Bibliographic details	Author(s), title, publication data
Game (s)	Title
Study context	Research question(s)
	Type(s) of games used
	Study findings
	Study limitations
Case context	Location
	Developed world
	Developing world
	Both
Social learning present	Cognitive
	Normative
	Relational
	Measurement and evaluation methods for success or failure
Impact	Positive contributions
	Negative contributions
Other	Suggested further work

Table 3. Search terms and meta-results.

Subset	Search terms[a]	Databases Scopus	Web of Science	Science Direct	Google Scholar[b]	Google[c]
1	Climate change adapt∗ game∗	189	347	35	100	100
		7/4/17	20/4/17	1/4/17	2/5/17	2/5/17
2	Climate change adapt∗ role-play∗ game∗ gaming	3	12	7	100	100
		7/4/17	20/4/17	1/4/17	2/5/17	2/5/17
3	Climate change adapt∗ gaming simulat∗ game∗	3	72	8	100	100
		7/4/17	20/4/17	1/4/17	2/5/17	2/5/17
4	Climate change adapt∗ game-based learn∗	3	2	4	100	100
		7/4/17	21/4/17	1/4/17	2/5/17	2/5/17
5	Climate change adapt∗ decision-making game∗	32	47	10	100	100
		7/4/17	21/4/17	1/4/17	2/5/17	2/5/17
6	Climate change adapt∗ governance game∗	13	14	1	100	100
		7/4/17	21/4/17	1/4/17	2/5/17	2/5/17
	Totals[d]	243	494	65	600	600

[a] All searches carried out for abstract, title, keywords.
[b] Search under relevance and first 200 results considered.
[c] Search under relevance and first 200 results considered.
[d] Note that duplicates have not been screened from these totals.

Table 4. Screening steps.

	All returns	After de-duplication	After title screen	After abstract read/article scan	Total returns after cross-reference with other database searches
Scopus	243	98	32	17	17
Science Direct	65	35	12	11	3
Web of Science	494	234	25	16	6
Google	600	298	34	19	8
Google Scholar	600	305	42	21	9
TOTAL	**2002**	**970**	**145**	**84**	**43**

range of publishing journals. However, few well cited papers exist. The literature on serious games and climate change adaptation is emergent but accumulating quickly, with the majority of publications since 2010. The top five research outputs (based on citation counts) are Patt *et al* (2010) (83), Martin *et al* (2011) (61), Haug *et al* (2011) (46), Reckien and Eisenack (2013) (45), and Ahamer (2013) (29). Figure 2 shows the five most represented journals. *Simulation and Gaming* features most prominently, with eight journal articles, due in part to a special issue on serious games and climate change (Reckien and Eisenack 2013).

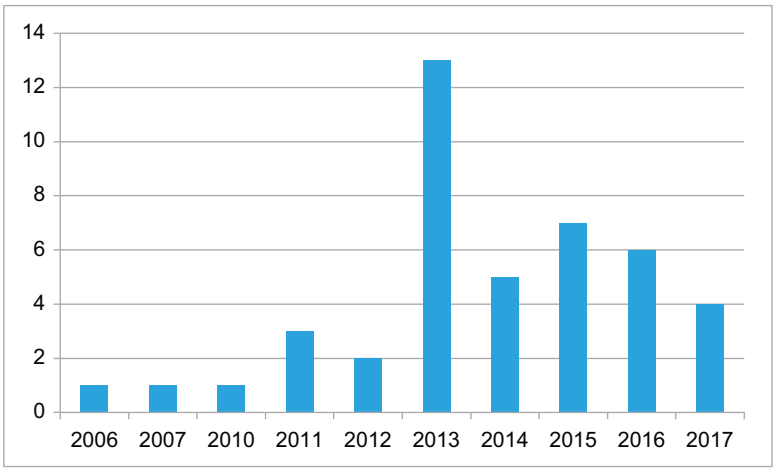


Figure 1. Date of publication of research outputs reviewed.

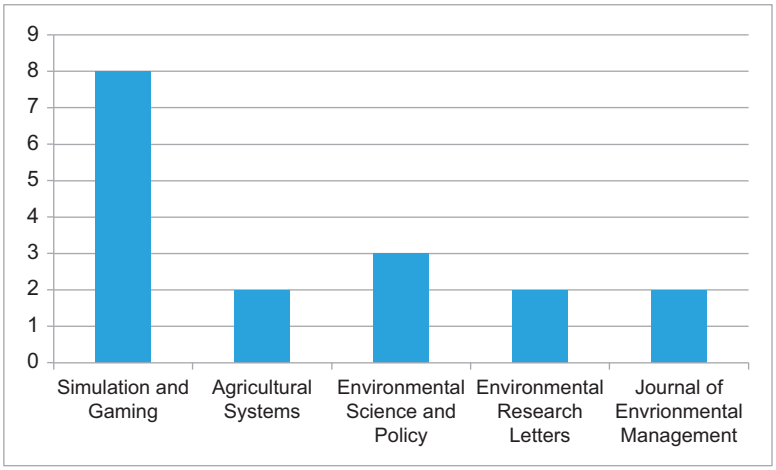


Figure 2. Five most represented journals from systematic search final returns.

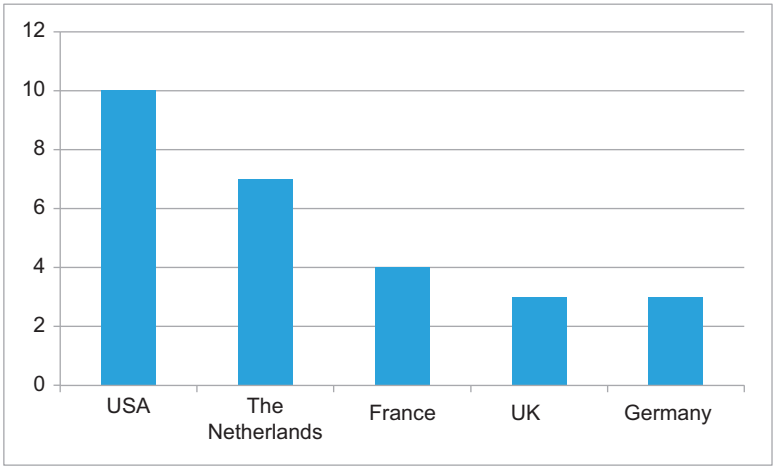


Figure 3. Top lead author affiliation countries.

Lead authors' primary affiliations are geographically dispersed, suggesting the international appeal of serious games. This includes both developed and developing country institutions (table 5). The top five lead author affiliation locations are presented in figure 3. The USA ranks highest with ten lead author publications, followed by The Netherlands with seven, France with four, and the UK and Germany with three each.

Review results show that 21 research studies focused on the application of serious games in developed countries, 14 were focused on developing countries, and eight looked at both developed and developing country applications. Five of the games in this review are set at global or international scale, 14 at national, 42 at regional scales. Six of the papers were exploring game theory rather than focusing on a specific scale.

The majority of the research outputs in this review are focused on either water resource management (eight papers) or farming in the face of climate change (14 papers). Risk management including climate resilient coastal development, supply chain logistics and transport, disaster preparedness and response, food security also feature strongly (six papers). Big picture impacts with biophysical, political and economic framing are the topics of three papers. General environmental management, and urban infrastructure and investment are covered in two papers each. The following topics are covered in one paper each: global change with climate change as a component; climate policy; drought management; shrimp farming; land management; and climate services.

4. Discussion

The 43 research outputs (including working papers and reports) that provide the basis for the review were read multiple times, and manually coded to identify emergent themes and commonalities. A social learning-based evaluation framework was then applied to determine games' effectiveness in promoting cognitive, normative and relational learning among game participants. We begin by discussing our findings in terms of shared characteristics of adaptation games, followed by the results of the assessment of learning effects.

4.1. Features of serious games for climate change adaptation

Based on the synthesis, eight common characteristics or features of adaptation games were identified: ability to capture complexity; challenge existing beliefs; the importance of effective facilitation and communication; space for reflexive learning, collaboration and dialogue; negotiation conflict resolution; autonomous learning; and harnessing local knowledge.

4.1.1. Capturing complexity

All of the games sought to capture and convey complexity to participants. Climate change adaptation and decisions relating to climate risk management are complex and contested often with diverse and competing values at stake. To test and explore a range of futures, games enable participants to navigate decision-contexts where tensions exist between long- and short-timescales; individual or collective problems; local and/or national issues; at regional to global scales. Moreover, games synthesise diverse data sets to allow players to get a feel for the relationships between variables without having to engage in technical quantitative analysis or integrate date sets themselves (de Suarez *et al* 2012). By assigning players a role in the system of the game, with quantifiable decisions and outcomes one can allow them to 'inhabit' the complexity of risk management decision-making and climate change through gameplay (ibid). Games must not fall into the trap of however of including inadequate simplification of real-world complexity (Parker *et al* 2016).

4.1.2. Challenging beliefs

Understanding peoples' values, beliefs and norms, and challenging them to change behaviour and take action is central to climate change adaptation (Gifford 2011). The delayed effects of many of the processes and impacts of climate change leads to a direct impact of individual's beliefs and resulting actions in the face of climate change (Fennewald and Kievit-Kylar 2012). To design is to create meaning and to engage with games helps to challenge questionable mental models, challenge beliefs and unpack values (de Suarez *et al* 2012). It is well documented that inadequate mental models lead to poor performance in addressing complex systems.

'No pilot would dare to fly a commercial airliner without significant training in a flight simulator … yet decision-makers are expected to make critical decisions relying on 'theory', 'experience', 'intuition', 'gut feeling', or less' (de Suarez *et al* 2012, p 12).

Serious games may be more effective at challenging and reframing existing poor mental models or false beliefs by ensuring that they are designed to meet the needs of specific communities. Games can achieve this by including elements that resonate with a community's diverse attitudes, perceptions, behaviour and cultural values (de Suarez *et al* 2012). Updating and reconfiguring these mental models can challenge and change individual beliefs, removing some potential barriers to adaptation action (Moser and Ekstrom 2010).

4.1.3. Role of facilitation and communication

Skilled facilitation is crucial to successful gameplay. A facilitator's task is to create a safe space for meaningful dialogue that emphasizes co-learning and generates a sense of both empowerment and personal responsibility (de Suarez *et al* 2012). Issues of power, gender and hierarchy are often challenging to manage, especially when operating in the context of substantial social and environmental change with associated high levels of uncertainty. Games researchers have highlighted therefore the importance of ongoing support for these methods and processes suggesting that they need to be embedded in existing systems action research practices (ibid).

Salvini *et al* (2016) also describe the value of skilled facilitation in their farmer focused role player game. At the start of the game the facilitators place the farmer

Table 5. Details of the 43 research outputs including bibliographic details, citation count, developed or developing world focus and game title where given.

Author(s)	Title	Journal or Research Output Description	Year	Citations[6]	Institution	*City* and Country	Developing Developed Both	Game (s) Title
Ahamer	Game not Fight: Change Climate Change	Simulation and Gaming	2013	29	Austrian Academy of Sciences	*Salzburg* Austria	Developed Austria	Surfing Global Change
Chew et al.	An interactive capacity building experience – an approach with serious games	Working Paper	2007	3	DHI – Institute for Water and the Environment	*Hørsholm* Denmark	Developed Denmark South Africa	Aqua Republica
Crookall	Climate Change and Simulation/Gaming: Learning for survival	Simulation and Gaming (Editorial)	2013	8	Université de Nice Sophia Antipolis	*Biot* France	Both	N/A
d'Aquino & Bah	Land Policies for Climate Change Adaptation in West Africa: A multilevel Companion Approach	Simulation and Gaming	2013	11	Centre de coopération Internationale en Recherche Agronomique pour le Développement	*Dakar* Senegal	Developing Senegal	Game unnamed
de Suarez	Games for the New Climate: Experiencing the Complexity of Future Risks	Report	2012	10	Pardee Center, Boston University	*Boston* United States	Developing Africa	Upstream/downstream, Rockefeller Resilience Game, Paying for Predictions
Driscoll & Lehmann	Scaling innovation in climate change planning: Serious gaming in Portland and Copenhagen	Book Chapter	2015	0	Alborg University	*Copenhagen* Denmark	Developed Denmark USA	Broken Cities
Eisenack	A board game for interdisciplinary training and dialogue	Working Paper	2006	1	Potsdam Institute for Climate Impact Research	*Potsdam* Germany	Developed Germany	Keep Cool
Eisenack	A Climate-Change Board Game for Interdisciplinary Communication and Education	Simulation and Gaming	2012	28	Carl von Ossietzky University Oldenburg	*Oldenburg* Germany	Developed Germany	Keep Cool

[6] Google Scholar Jan 19th, 2018

Table 5. *Continued.*

Eisenack & Reckien	Climate Change and Simulation/Gaming (Editorial)	Simulation and Gaming	2013	8	Carl von Ossietzky University Oldenburg	*Oldenburg* Germany	Both	Surfing Global Change, Keep Cool
Fennewald & Kievit-Kylar	Integrating Climate-Change Mechanics Into a Common-Pool Resource Game	Simulation and Gaming	2013	13	Indiana University-Bloomington	*Missouri* United States	Both	The Farmers
Gunda et al.	Impact of seasonal forecast use on agricultural income in a system with varying crops costs and returns: an empirically grounded simulation	Environmental Research Letters	2017	3	Vanderbilt Institute for Energy and the Environment and Department of Civil and Environmental Engineering	*Tennessee* United States	Developing Sri Lanka	Unnamed
Haasnoot et al.	Transient scenarios for robust climate change adaptation illustrated for water management in the Netherlands	Environmental Research Letters	2015	15	Deltares	*Delft* The Netherlands	Developed The Netherlands	Sustainable Delta Game
Haug et al.	Learning through games? Evaluating the learning effect of a policy exercise on European climate policy	Technological Forecasting and Social Change	2011	46	VU University Amsterdam	*Amsterdam* The Netherlands	Developed Europe	ADAM Policy Game
Hill et al.	The Invitational Drought Tournament: What is it and why is a useful tool for adaptation	Weather and Climate Extremes	2014	11	Agriculture and Agri-Food Canada (Saskatoon)	*Saskatchewan* Canada	Developed Canada	The Invitational Drought Tournament (IDT)
Joffre et al.	Combining participatory approaches and an agent-based model for better planning shrimp aquaculture	Agricultural Systems	2015	5	Aquaculture and Fisheries Group, Wageningen University	*Wageningen* The Netherlands	Developing Vietnam	Role Playing Game based on Coastal Aquaculture Spatial Solutions (CASS)
Jones et al.	Planning for an Uncertain Future: Promoting adaptation to climate change through flexible and forward-looking Decision Making	Africa Climate Change Resilience Alliance (ACCRA)	2014	8	Overseas Development Institute (ODI)	*London* United Kingdom	Developing Uganda Ethiopia Mozambique	Unnamed game
Jones et al.	New approaches to promoting flexible and forward looking	Africa Climate Change Resilience Alliance	2013	0	Overseas Development	*London* United Kingdom	Developing Uganda	Unnamed game

Table 5. *Continued.*

	decision making: Insights from complexity science, climate change adaptation and serious gaming	(ACCRA)			Institute (ODI)		Ethiopia Mozambique	
Juhola et al.	Social strategy games in communicating trade-offs between	Urban Climate	2013	19	Department of Real Estate, Planning and Geoinformatics, Aalto University and Department of Environmental Sciences, University of Helsinki	*Helsinki* Finland	Developed Denmark Finland United States	Broken Cities
Lamarque et al.	Taking into account farmers' decision making to map fine-scale land management adaptation to climate and socio-economic scenarios	Landcape and Urban Planning	2013	24	Laboratoire d'Ecologie Alpine, LECA, CNRS Université Joseph Fourier	*Grenoble* France	Developed France	Unnamed
Lawrence & Haasnoot	What it took to catalyse uptake of dynamic adaptive pathways planning to address climate change uncertainty	Environmental Science and Policy	2017	9	New Zealand Climate Change Research Institute, Victoria University of Wellington	*Wellington* New Zealand	Developed New Zealand	Sustainable Delta Game
Martin	A conceptual framework to support adaptation of farming systems - Development and application with Forage Rummy	Agricultural Systems	2015	26	INRA, UMR	*Castanet Tolosan* France	Developed France	Forage Rummy
Martin et al.	Forge Rummy: A game to support the participatory design of adapted livestock systems	Environmental modelling and software	2011	61	INRA, UMR	*Castanet Tolosan* France	Developed France	Forage Rummy
Medema et al.	Exploring the Potential Impact of Serious Games on Social Learning and Stakeholder Collaborations for Transboundary Watershed Management of the St. Lawrence River Basin	Water	2016	10	Department of Bioresource Engineering, McGill University	*Montreal* Canada	Developed Canada USA	Testing of concept phase. No specific game engaged with

Table 5. *Continued.*

Nay et al.	A review of decision-support models for adaptation to climate change in the context of development	Climate and Development	2014	24	Program in Integrated Computational Decision Science and Institute for Energy and Environment, Vanderbilt University	*Tennessee* United States	Developing	Review of Gaming concepts and application rather than specific game
Onencan et al.	WeShareIt Game: Strategic foresight for climate-change induced disaster risk reduction	Procedia Engineering	2016	1	Delft University of Technology, Policy Analysis Section, Faculty of Technology, Policy and Management	*Delft* The Netherlands	Developing Kenya	WeShareIt
Parker et al.	Using a Game to Engage Stakeholders in Extreme Event Attribution Science	Intl Journal Disaster Risk Science	2016	2	Department of Meteorology, University of Reading	*Reading* United Kingdom	Both Africa Europe	Climate Attribution Under Loss and Damage: Risking, Observing, Negotiating (CAULDRON)
Patt et al.	How do small-holder farmers understand insurance, and how much do they want it? Evidence from Africa	Global Environmental Change	2010	83	International Institute for Applied Systems Analysis	*Laxenburg* Austria	Developing Africa	Unnamed game
Reckien& Eisenack	Climate Change Gaming on Board and Screen: A review	Simulation and Gaming	2013	35	Columbia University, New York	*New York* United States	Both	Review of multiple games
Rumore & Susskind	Collective Climate Adaptation: Can Games make a Difference	Solutions	2013	7	Massachusetts Institute of Technology	*Cambridge* United States	Developed USA	The Institutionalizing Uncertainty project (IUP) and the New England Climate Adaptation Project (NECAP)
Rumore et al.	Role-play simulations for climate change adaptation education and engagement	Nature Climate Change (Perspective)	2016	7	Quinney College of Law, University of Utah	*Utah* United States	Developed USA	

Table 5. *Continued.*

Salvini et al.	REDD+ and climate smart agriculture in landscapes: A case study in Vietnam using companion modelling	Journal of Environmental Management	2016	12	Laboratory of Geo-Information Science & Remote Sensing, Wageningen University,	*Wageningen* The Netherlands	Developing Vietnam	Role-playing board game unnamed
Salvini et al.	A role-playing game as a tool to facilitate social learning and collective action towards climate smart agriculture: lessons learned from Apui, Brazil	Environmental Science and Policy	2016	3	Laboratory of Geo-Information Science & Remote Sensing, Wageningen University,	*Wageningen* The Netherlands	Developing Brazil	Role-playing board game unnamed
Sautier et al.	Exploring adaptations to climate change with stakeholders: A participatory method to design grassland-based farming systems	Journal of Environmental Management	2017	1	AGIR, Universite de Toulouse, INRA	*Auzeville* France	Developed France	FARMORE
Schenk	Boats and Bridges in the Sandbox: Using Role Play Simulation Exercises to Help Infrastructure Planners Prepare for the Risks and Uncertainties Associated with Climate Change	Book Chapter	2013	0	Department of Urban Studies and Planning, Massachusetts Institute of Technology	*Cambridge* United States	Developed USA Singapore	A range of role-playing simulation games mostly unnamed) including *A New Connection in Westerberg*
Schenk and Susskind	Using role-play simulations to encourage adaptation: Serious games as tools for action research	Book Chapter	2014	0	Department of Urban Studies and Planning, Massachusetts Institute of Technology	*Cambridge* United States	Developed USA	*A New Connection in Westerberg* and the New England Climate Adaptation Project (NECAP)
Suarez	Using games to experience climate risk: Empowering Africa's decision-makers	Report	2013	3	Red Cross/Red Crescent Climate Centre	The Hague	Suarez	Using games to experience climate risk: Empowering Africa's decision-makers
Suarez et al.	Serious fun: Scaling up community-based adaptation through experimental learning	Book Chapter	2014	11	Red Cross/Red Crescent Climate Centre, Boston University	*Boston* United States	Both	A range of games (mostly unnamed) including *Humans versus Mosquitoes* and *Dissolving Disasters*

Table 5. *Continued.*

Valkering et al.	A Perspective-Based Simulation Game to Explore Future Pathways of a Water-Society System Under Climate Change	Simulation and Gaming	2013	28	Maastricht University	*Maastricht* The Netherlands	Developed The Netherlands	A number of unnamed games
van Pelt et al.	Communicating climate (change) uncertainties: Simulation games as boundary objects	Environmental Science and Policy	2015	20	Weather Impact, Stadsring	*Amersfoort* The Netherlands	Developed The Netherlands	Sustainable Delta Game
Villamor & Badmos	Grazing game: a learning tool for adaptive management in response to climate variability in semiarid areas of Ghana	Ecology and Society	2015	6	Department of Ecology and Natural Resources Management, Center for Development Research, University of Bonn	*Bonn* Germany	Developing Ghana	Grazing Game
Vincent et al.	Identifying climate services needs for national planning: insights from Malawi	Climate Policy	2017	7	Kulima Integrated Development Solutions (Pty) Ltd	*Pietermaritzburg* South Africa	Developing Malawi	Paying for Predictions
Angell	Decision Making in a Changing Climate: Adaptation Challenges and Choices	World Resources Institute (Report)	2011	0	World Resources Institute	*Washington DC* United States	Developing Africa and Asia	Several unnamed games including *Early Warning, Early Action* and *Weather or Not*
Wu et al.	Climate change games as tools for education and engagement	Nature Climate Change	2015	22	Department of Mathematics, Science, and Technology, Teachers College, Columbia University	*New York* United States	Both	Many games considered and reviewed

participants within an engaging narrative. They explain that alternative farm practices may lead to more robust farm management systems and increase of profit. Players also receive game resources reflective of their own situation and are instructed to use the 'as they would in reality' (ibid). The careful facilitator's framing can help to create a space for meaningful dialogue for participants that echo their reality.

Clear and intuitive communication also reduces the barriers to effective serious game engagement and helps to catalyse the learning process. The KEEP COOL board game was developed as a scientific communication tool among disciplines (Eisenack 2012). The board game (KEEP COOL) on climate change covers biophysical, economic, and political aspects of the issue. It developed a common language that enabled discussions about the game between scientists from different disciplines and allowed misconceptions on game design to be resolved. The authors highlight the importance of creating a jargon free environment that engages a range of players with different levels of domain knowledge.

4.1.4. Reflexive learning, collaboration and dialogue

Reflexive learning is a powerful tool in challenging decision-making practices, increasing learning outcomes, and also increasing the levels of player engagement and involvement. Driscoll and Lehmann present serious gaming as a method to engage researchers and stakeholders in a self-reflexive exercise to bring unconscious decision-making behaviour into the conscious domain (Driscoll and Lehmann 2015). The 'Broken Cities' game was played in Copenhagen, Denmark, and Portland, Oregon, USA with planners, students, and interested citizens. The game covers both mitigation and adaptation options. Significant findings included the nature of the double-loop learning that was evidenced by gameplay; players demonstrated a high level of understanding between their complex in-game decisions and the real-world climate change impacts. The game also encouraged a complex dialogue between players about the positive and negative possible consequences of investment decisions.

Results indicated that serious games within an action research framework has a significant ability to enable co-production of knowledge, and encourages reflexive approached to learning by doing so (ibid). One of the most powerful drivers of social learning is the intense social interaction necessitated by the mechanism and structure of gameplay; players must think, plan, and act in a dynamic environment of competition and cooperation (ibid).

'… Serious games create a space for capturing complex social dynamics and verbalise though processes (talking while doing) that would be difficult to recreate in a normal interview situation' (Driscoll and Lehmann 2015, p 145).

High levels of collaboration and dialogue go hand-in-hand with this process that facilitates social learning. For example, the Climate Attribution Under Loss and Damage: Risking, Observing, Negotiating (CAULDRON) board game aims to communicate understanding of the science of attributing extreme events to climate change in a compelling manner, and also create a safe space for dialogue on policy decisions addressing climate change driven changing risks, loss and damage (Parker *et al* 2016). Findings suggest that experiential learning through serious gaming drives coproduced understanding and meaningful dialogue (ibid). The game is focused on farming, science, negotiation, and reflection and provided educational opportunities around probabilistic event attribution. Results suggest that it is a challenge to include an appropriate level of complexity. Skilled facilitators are needed who know their audience and are able to lead the game in a way that creates an atmosphere that facilitates participation, relation and a sense of fun (ibid). Providing adequate time for individual and group reflection following the play was considered a key component of the game. Engaging a range of stakeholders helps to create a 'level playing field' and lead to more dialogue, as players sharing the gaming experience can use this as a basic for discussing real-life issues.

4.1.5. Negotiation and conflict resolution

Serious games provide more equal access to a virtual negotiation or learning space to develop and share knowledge, integrate different knowledge domains, and provide opportunities to test an analyse the outcomes of novel management solutions. Serious games take both an ecological and governance perspective and can be useful in solving conflicts as they allow refection, information sharing and participation (Medema *et al* 2016). Social learning is less likely to occur in a one-off engagement, so it is essential that serious games offer mechanisms and processes that become a part of an ongoing process of stakeholder interactions; though game design and development, facilitated interactions, gameplay, post-game discussions and briefings (ibid). Visualisation in role-playing games is presented as a tool that potentially allows instantaneous understanding especially when visualising not only in geometric and geographic space, but also in the space of opinions, roles, perspectives, visions, and paradigms (Ahamer 2013). Roles are highlighted as allowing players to adopt several standpoints at a time and to perceive ongoing social processes in an original manner, allowing the navigation of the argumentative landscape, and arguably enabling an ethics of negotiation (ibid).

4.1.6. Autonomous learning and harnessing local knowledge

One of the exciting potential outcomes of engaging with serious games is their ability to catalyse autonomous learning. Games that generate high levels of social learning empower game participants to take their new knowledge (cognitive learning), updated mental models (normative learning), and newly formed

or enhanced networks (relational learning) and apply these learnings in the real world.

The use of self-designed role-playing games leads to noticeable autonomous organisational learning (d'Aquina and Bah 2013). Researchers d'Aquina and Bah, for example, present a multilevel modelling process based on 10 years of participatory modelling that links national policy makers, local councils, and grassroots stakeholders using a combination of games and computerised simulations. The process allowed stakeholders to co-design frameworks tailored to their own behaviours and rules. In the experiments in Senegal the communities tailoring collective rules, organised follow-up and monitoring of land uses and decided when to introduce new infrastructure and stopped inadequate state programs. Following the initial learning-by-doing process, they became able to design and use their own maps for environmental management (ibid). In addition, communities progressively shifted from fruitless conflict with overlapping authorities to active involvement within new power and responsibility structures. Finally, from the experiences exploring and experimenting with different environmental management options through game simulations, they became awake of technical thresholds (for example, fodder availability), and they autonomously contacted scientific advisors to select and adapt technical options of their own (ibid).

The embedding of local knowledge in serious games can increase their ability to accurately reflect reality and can also help to gain the trust of local participants and create a strong sense of ownership and belief in the value of the game in question.

Villamore and Badmos report on action research involving a grazing game played with farmers to explore adaptive management in response to climatic uncertainty in semiarid farmland in Ghana (Villamore and Badmos 2015). The tool was designed to be simple to use and the vast majority of participants found it accurately reflected reality. Results suggest that it increased local understanding of perceptions, behaviours and improved farm management practices. The game was a highly effective social learning tool, greatly increasing farmer knowledge through visualising uncertainty and clarifying farm systems processes and interactions. It also clearly highlighted the potential consequences of farm decisions on livelihoods and welfare (ibid). Traditional ecological knowledge (TEK) was combined with existing scientific ecological knowledge to create a more robust understanding of the farm systems under examination (ibid).

Gunda *et al* (2017) discuss an unnamed game investigating how farmers in the developing world respond and interpret seasonal weather forecasts within their immediate environments. Specifically it asks farmers which crops (if any) they would plant for a particular season. The game was complemented with a survey of over 800 dry zone rice farmers to increase the understanding and accuracy of the game's assumptions. The results show that on average an 'adaptive farmer' has higher profit returns than a 'non-adaptive farmer' (Gunda *et al* 2017).

Joffre *et al* (2015) tested a role-playing game coupled with an agent-based model (unnamed) played by Vietnamese shrimp farmers. The significant risk to shrimp farming posed by climate change has prompted a number of farmers to switch to Integrated Mangrove Shrimp farming systems. The role-playing game provided a useful approach for integrating scientific and local knowledge into decision-making. It helped to articulate this knowledge within a specific environment, socioeconomic and policy context (ibid). The adequacy and validity of the agent-based model was bolstered by the support of the local farmers who participated in the game playing workshops and found the role playing game and agent based model to be fair representations of reality. Results strongly indicate that a participatory approach is crucial for decision-makers and stakeholders to acquire ownership of the model and game. However, they point out that significant investment in time and workshops are needed to realise this (ibid).

4.2. Serious games and learning outcomes

Serious games are emerging as a powerful tool in engaging and educating, generating collective intelligence and realising climate change adaptation action more rapidly than through other existing means. The overwhelming majority of the 43 reports, book chapters and journal papers discussed above demonstrate that games add value and lead to impact. There is significant overlap in reported findings of literature consulted and three components of social learning: cognitive (changes in knowledge), normative (changes in values and beliefs), and relational (changes in networks and relationships). There are also significant challenges to designing and effectively engaging with serious games for climate change adaptation. This section begins by outlining some of those challenges. It then moves on to explore evaluation of serious games, the impact of serious games, and finally finishes by examining the effectiveness of serious games in achieving social learning outcomes.

4.2.1. Challenges to designing and effectively engaging with serious games

A number of challenges to effective game design and engagement have been identified in the literature included in this review. Specifically, this includes: overcoming the limitations of one-off engagement (Medema *et al* 2016); capturing complexity (de Suarez *et al* 2012, Eisenack 2012, Fennewald and Kievit-Kylar 2012, Hill *et al* 2014, Juhola *et al* 2013, Lamarque *et al* 2013, Parker *et al* 2016), and the difficulties of long-term planning under deep uncertainty (Haasnoot *et al* 2015, Haug *et al* 2011, Jones *et al* 2014). These challenges and solutions, where identified, are discussed below.

A challenge for many forums aimed at collective learning, is the length of time and amount of engagement required (Cradock-Henry *et al* 2017). Given that social learning is less likely to occur in one-off engagements (Medema *et al* 2016), it is essential that serious games offer mechanisms and processes that become a part of an ongoing process of stakeholder interactions; though game design and development, facilitated interactions, gameplay, post-game discussions and briefings (ibid). Consequently, a game with successful learning outcomes takes considerable investment of time and resources. Organisers should plan for a series of engagement opportunities if learning is an objective.

When designing a serious game, careful consideration must be given to the representation and communication of science to aid comprehension. Conceptual frameworks, use of language, and communication strategies need to be attuned to the audience to provide an integrated perspective. The aim is to capture complexity without overwhelming players (Eisenack 2012, World Resources Institute 2011). Central to this task, is providing an overview of the science from different disciplines or perspectives, integrating knowledge about key features of climate change relevant to participants' needs and examining important processes rather than going into too much quantitative detail (ibid). It is especially important to consider how to incorporate longer-term delayed (climate) system effects which extend beyond normal decision-cycles and time frames. Mistakes here can lead to player confusion, disagreement, and increased likelihood of environmental degradation; i.e. the more delayed the effect the fewer players are able to coordinate their efforts (Fennewald and Kievit-Kylar 2012) and make connections between choices and outcomes. Careful consideration must be given to address this issue in game design (ibid). Additional challenges include integrating physical science with socio-economic impacts that are plausible and believable to laypeople (Hill *et al* 2014, Nay *et al* 2014, Patt *et al* 2010, Valkering *et al* 2012). The careful use of scenarios, narrative, indicators, and visualisation (ibid) may help in this regard.

Making decisions when the future is uncertain, and the climate may change unpredictably, is extremely difficult. An orthodox way to bridge this uncertainty gap is through scenario-based planning (Haug *et al* 2011, Jones *et al* 2014). Different types of scenarios can be easily incorporated into game design whereby 'future histories' are analysed via the interactive testing of alternative policies and actions that respond to the challenges presented. However, despite the intention to act pro-actively and to anticipate the future, climate adaptation actions are often determined in response to extreme events (Haasnoot *et al* 2015). Gaming participants, including experienced resource managers, tend to attempt to identify trends in a single transient scenario, and assume that this is what they will experience in the future (ibid). Games should be designed therefore to reflect future uncertainty and unpredictability to alter this mindset.

Determining the impact of serious games to generate outcomes and actions can be very challenging. As noted by de Suarez *et al* (2012), assessing after-action results from game playing is particularly problematic, given that the links to crucial measurable changes—such as policy interventions—are indirect. Both linkage and influence are difficult to attribute, and the time lag and often short funding timeframes means that the majority of project interventions cannot be measured. Furthermore, many of the interaction benefits with and between players—trust, empowerment and relationships for example—are difficult to assess. These are the very factors that one may wish to measure to determine attitude change, behaviour change and casual links to actions (ibid). The next section explores approaches to serious game evaluation.

4.2.2. Evaluation

Evaluation solutions for serious games include in-game evaluation data collection (de Suarez *et al* 2012), pre-game questionnaires (Eisenack 2012), and game-enabled reflection using pre- and post- game workshop survey tools (Jones *et al* 2013, 2014).

De Suarez *et al* (2012) suggest that if monitoring and evaluation is aimed at determining the learning or behavioural change generated by engaging with a particular game the game itself can generate assessment data (ibid). For example, if a game is played several times, or contains several rounds of play, the evolution of game strategies among players can serve as documented evidence. In other words, players' understanding, and application of real-world climate change management options can be used as a proxy for social learning. Games can also generate data to feed into wider monitoring and evaluation frameworks, generating evidence on the ability to process climate information for effective decision-making, and to test effectiveness of other capacity building efforts (Vincent *et al* 2017). One can play the same game with a group of decision-makers before and after a training workshop and note the results for example. One can also play the same game with a community before and after a risk management project aimed to increase their adaptive capacity or resilience, to determine whether a project has achieved the right combination of physical investments coupled with changes in decision-making and improved understanding of any new risk management strategies that community may have access to.

Another example of before and after game-play data gathering is provided by Eisenack (2012) KEEP COOL game. In KEEP COOL a pre-game playing questionnaire is used to test players' existing domain relevant knowledge (in this case on climate change adaption), problem framing, and interdisciplinary perspectives (ibid). During the debriefing phase, designed to make learning conscious, players demonstrated shifts in problem framing and domain knowledge,

and to some degree had acquired interdisciplinary perspectives. The game allowed the scientist participants, from various backgrounds and scientific cultures, the opportunity to talk though the issues at hand and share alternative perspectives. The entertainment character of the game and its graphics and physical design opened up new entry points for science communication in the public sphere. This was supported by the observation that various activities and spin-offs were created by the game, and also by the fact that a large number of private individuals have shown interest in purchasing the game.

'Although climate change is a serious, complex, and broad issue, and although different experts frame it in various ways, innovative instruments can contribute to closing the gap between scientific research, education, and public action' (Eisenack 2012, p 345).

The final evaluation example comes from the African Climate Change Resilience Alliance's game-enabled reflection approach to Flexible and Forward-looking Decision-Making (FFDM). The game was used in three case study countries—Uganda, Ethiopia, and Mozambique—where game-enabled reflection proved a useful tool for communicating a new and somewhat abstract concept of FFDM to district level development practitioners (Jones *et al* 2013, 2014). It helped to inspire action and promote broader understandings of decision-making and planning processes, promoted cross-sector collaboration, information sharing, and raised awareness regarding climate change risks in the broader context of international development and its influence at local levels. Pre- and post-workshop survey responses clearly demonstrated positive impacts associated with game-enabled FFDM approaches, and its value for district development planning (ibid). Evaluating a new approach often requires the balancing of research rigor with optimising capacity building opportunities. It became evident that the approach adopted was closely aligned with an action research model, with single-, double, and even triple-loop learning[6] evident.

4.2.3. *Measuring impact*

To measure the impact of climate change adaptation games, pre- and post- game-playing participant feedback approaches are used. Gameplay participant feedback is a quick and inexpensive method to measure immediate impact (Hill *et al* 2014, Lawrence and Haasnoot 2017, Rumore and Susskind 2013, Salvini *et al* 2016a, Salvini *et al* 2016b, Sautier *et al* 2017). This type of gameplay feedback is especially robust when collated over a large number of game workshops (Martin *et al* 2011, Martin 2015, Rumore *et al* 2016, Juhola *et al* 2013).

The Invitational Drought Tournament (IDT) is a simulation adaptation framework that supports drought preparedness efforts (Hill *et al* 2014). The game provides a mechanism to present physical science information to decision-makers with varied professional backgrounds and levels of education in order to enable peer-to-peer learning and information synthesis using a team format. Results strongly suggest that the tool supports interactive learning for drought management, singling out the team format as a unique way to gain knowledge and explore creative ways to address drought systematically (ibid). Participant feedback overwhelmingly suggests that the IDT is extremely effective at bringing diverse stakeholders together with different perspectives to engage in meaningful dialogue and reach consensus decisions on management practices. The authors argue that the game helps players plan for drought using a framework that is approachable and accessible, allowing non-domain expert stakeholders to participate effectively.

The SUSTAINABLE DELTA GAME uses Dynamic Adaptive Policy Pathways (DAPP) to engage local government decision-makers (Lawrence and Haasnoot 2017, van Pelt *et al* 2015) with planning under conditions of uncertainty, in a simulated, but familiar problem setting. Findings suggest that the game increased knowledge and created interest in adaptive pathways, raised awareness and led to greater understanding of the complexities of decision-making when the future is unclear. A creative and safe engagement space conducive to learning was provided in part via the game, and the authors describe evidence all three types (cognitive, normative and relation) learning. Additional game impacts suggest that future risk was perceived differently by flood managers as a result of engaging with the game, with static replaced by dynamic representations of risk. Normative learning was demonstrated as changing practice norms lead to a convergence of group approaches to decision-making (Lawrence and Haasnoot 2017). Negotiations conducted using the game engaged players over a substantial period of time and provided them with 'real' feedback. This was done to build players' confidence in making decisions in uncertain conditions. Relational learning facilitated through listening and understanding others' perspectives. According to participants, the game required them to listen to different viewpoints, work closely together and identify avenues for cooperation. Key success factors included facilitation, detailed debriefing sessions and the strong role of knowledge brokering (ibid). Furthermore, debriefing is key to assessing impact; initial debriefing after playing the game, but also later follow-up through survey/interview to determine how the learnings are being used.

[6] Single-loop learning refers to incremental learning, double-loop learning refers to learning that involves reframing the problem, and triple-loop learning refers to transformational learning. Double-loop learning is used when it is necessary to change the mental model on which a decision depends. Triple-loop learning involves 'learning how to learn' by reflecting on how we learn in the first place. In a game example participants would reflect on how they think about the 'rules' and not only on whether the rule should be changed.

In Rumore and Susskind's THE FLOODING GAME, players assume different roles—from town mayor, planner, real estate developer to residents' association representative, for example—and evaluate local vulnerability to climate change (Rumore and Susskind 2013). Despite scientific uncertainty and conflicting community interests, results of gameplay showed agreement among players about the need to manage increased flood risk, and that this goal was attainable. Before and after survey results revealed that gameplay altered assumptions about the community's agency and capacity to address climate risks, including increased empathy for and understanding of the perspectives and interests of other parties likely to be involved in adaptation planning (ibid). The authors also show that bespoke role-play simulations based on significant contributions from scientists, local officials, and leaders of local organisations can help stakeholders see how different attitudes and interests can be reconciled to reach effective adaptation actions (ibid).

In Vietnam, Salvini *et al* (2016a) discuss the impact of a role-playing board game using an agent based model. The role-playing game allowed the researchers to ascertain how different land management policies might change land use decisions and what their adaptation effects might be in as driven by future climate scenarios (ibid). Overall findings suggest that the role-playing game initiated rich iterative discussions among local farmers that helped to inform policy-makers about how land use decisions are made at a local level. This enabled policy-makers to redesign policies to make them more locally tailored and hence more effective (ibid).

Elsewhere, Salvini and colleagues focus on Climate Smart Agriculture and role-playing games (Salvini *et al* 2016b). Pre- and post-game interview results suggest that farmers acquired technical knowledge, and that a clear distinction was found between those involved in the intervention and those who were not. Those farmers who were involved displayed a deeper understanding of the implications of a range of activities on farm management and an appreciation of longer term planning (ibid). Post-game playing farmers demonstrated a more detailed and future orientated responses on their future farm management plans; they also appreciated that despite higher initial costs associated with changing farming practices they would be more profitable in the medium to long term (ibid). Game playing also increased social engagement and collective action. Engagement in collective action was triggered by several factors during the role-playing game including the game's open atmosphere and dialogue facilitation, which fostered greater trust amongst the participating farmers. The authors highlighted the connection to reality made during the debriefing phase during which real world applications are discussed and collective learning acknowledged (ibid).

The FARMORE game is an iterative board game tool, designing farming systems and developed in conjunction with the French farming community, which is developed and refined with each additional workshop (Sautier *et al* 2017). The impact of these game-focused iterative workshops was a significant increase in the understanding of climate change and its implications on farm systems for the majority of farmers participating. Most of the farmers also indicated that the game helped them to identify farm adaptation solutions.

Another example is provided by Rumore *et al* (2016) who discuss the impacts of two projects: the New England Climate Adaptation Project, participatory two-year action research project testing the effectiveness of role-playing simulations as a public education and engagement tool in the US; and the Institutionalizing Uncertainty Project that worked with engaged transportation infrastructure planners, decision-makers and other stakeholders in the coastal cities of Rotterdam, Singapore and Boston to explore the dynamic and uncertain climate change risks they face and how best to work together to mitigate against those risks (ibid). The role-playing simulations were tailored to local communities by including real-world downscaled climate change projections in combination with findings from in-depth interviews with relevant stakeholders which was used to model realistic political tensions at the local level (ibid).

Results suggested statistically significant increases in both local participants' concern about local climate change risks and their sense that their town should take action to adapt (ibid). Many participants noted that the gaming help them to realise that adaptation needs to be mainstreamed into everyday local planning, rather than be bolted on to planning and decision-making (ibid). In both projects the role-play simulations had the greatest detectable impact on increasing awareness and concern about climate change among those who had the least concern and knowledge prior to the gaming (ibid). The authors suggest that role-playing simulations therefore are particularly useful for introducing climate change adaptation to the 'undecided middle'. Role-play simulations are especially effective at shifting opinions among those who are identified as 'concerned' and 'cautious' by the Yale Project on Climate Change Communications Six Americas categorisation (Maibach *et al* 2009). In both studies statistically significant results show participants' confidence in their towns, and counterparts in other organisations, being well placed to take meaningful adaptation action increased as a result of the intervention (Rumore *et al* 2016). Results also show the potential for role-playing to catalyse significant social learning. The role playing simulations acted as critical conversation starters that allowed participants to bypass the debate on the validity of climate change and start working towards solutions on how to respond to climate change risks (ibid).

The FORAGE RUMMY board game allows farmer groups to use their empirical knowledge to design livestock systems in the face of environmental stressors

including climate change drivers (Martin *et al* 2011, Martin 2015). The game has been used with over 200 French farmers, at over 50 workshops. Evaluation of the game's impact suggests it has allowed farmers to gain new knowledge and also reframe the farm management problems they face in new and useful ways. Martin and colleagues (ibid) report that the knowledge produced through the sharing of farmers' experiences is not just subjectively meaningful but also scientifically rigorous. For researchers and scientists game play provided two kinds of output. It provided a forum for developing the salience, credibility, and legitimacy of scientific knowledge and helped bridge the gap between science and practice. Participating and observing gameplay also provided researchers with an insight into on the ground farm management considerations and practices (Martin *et al* 2011).

Juhola *et al* (2013) explore how social games (BROKEN CITIES) can help people communicate trade-offs between adaptation and mitigation measures in urban environments in Denmark, Finland and the USA. After playing the board game with 100 participants in Europe and the USA the authors found that social games increase the ability of participants to understand complex information and dynamics. The learning took place in a rich social setting, which the authors suggest, required near contact communication and strategy formalisation for both individual and collective gain.

The final three sections examine the effectiveness of serious games in achieving social learning outcomes as captured by changes in cognitive, normative, and relational learning (Baird *et al* 2014, 2016).

4.2.4. Cognitive learning

All of the studies reviewed report cognitive learning as a result of engaging with a serious game. Of particular note are: first, accelerated processes of learning, value sharing, communication of system complexity and decision-making are achieved (Lamarque *et al* 2013, CDKN 2013, de Suarez *et al* 2012, Driscoll and Lehmann 2015, Reckien and Eisenack 2013). This is because games can incorporate large data sets to allow players to get a feel for how variables interact without having to engage in strenuous quantitative activities (de Suarez *et al* 2012, Juhola *et al* 2013, Ahamer 2013). Also, rapid learning can occur because games offer immediacy through providing interactive models that allow players to participate in decisions and immediately see the resulting outcomes (Wu and Lee 2015, Ahamer 2013, CDKN 2013, Driscoll and Lehmann 2015, Hill *et al* 2014).

Second, acquisition of new knowledge coupled with the challenging of existing mental models was widely reported (de Suarez *et al* 2012, CDKN 2013, Driscoll and Lehmann 2015, Eisenack 2006, Reckien and Eisenack 2013, Hill *et al* 2014, Lawrence and Haasnoot 2017, Martin 2015). Principally because games offer access to virtual negotiation and learning spaces to develop, share and integrate difference knowledge domains (Medema *et al* 2016, Parker *et al* 2016). Through their self-reflexive approach, games help to bring unconscious decision-making behaviour into the conscious domain and provide opportunities for double-loop learning (Driscoll and Lehmann 2015).

Third, an enhanced interface between TEK and scientific ecological knowledge was possible so creating a more robust basis of the system complexities (Villamor and Badmos 2015, Joffre *et al* 2015). Similarly, role playing games provided a useful approach for integrating scientific and local knowledge into decision-making.

In short, serious games advance cognitive learning through encouraging and facilitating peer-to-peer learning and deep discussion (CDKN 2013, d'Aquina and Bah 2013).

4.2.5. Normative learning

Changing norms and values are one of the more challenging social learning components to assess, because they are hard to measure and may emerge over time. However, one can argue that changes in cognitive learning have a direct impact on normative learning outcomes.

A key feature of serious games is the creation of a safe space for people to voice opinions and beliefs and then take actions which express their values (Wu and Lee 2015, de Suarez *et al* 2012, Lawrence and Haasnoot 2017, Medema *et al* 2016, Parker *et al* 2016, Schenk 2014). The chosen action may achieve a desired outcome—or not. Either way changes in cognitive learning due to the acquisition of new information or the reordering of existing information can occur and may dispel long-held false beliefs and lead to changes in normative learning. Corresponding changes in participants' beliefs, or ways of seeing the world as result of changes in cognitive learning are well documented (Driscoll and Lehmann 2015, Lamarque *et al* 2013, Haasnoot *et al* 2015). BROKEN CITIES for example, clearly demonstrates this double-loop learning, where players engage in reflexive learning that challenges how they view their environment and associated environmental decision-making (Driscoll and Lehmann 2015).

4.2.6. Relational learning

By its very nature, gameplay necessitates intense social interaction, and this is a powerful driver of social learning; players must think, plan, and act in a dynamic environment of competition and cooperation (Driscoll and Lehmann 2015, Juhola *et al* 2013). This act of 'playing the game' requires participants to confront several relational issues. First, players are not alone. Games allow participants to inhabit the complexity of climate risk management decisions and, through role-play, challenge perspectives and offer insight into the motivations and actions of others (Ahamer 2013). They can also act as conflict resolution tools, through reflection, information sharing and debate across groups with diverging opinions and beliefs (Medema *et al*

2016). Second, the importance of trust, trust building, and limitations of trust are apparent (Onecan *et al* 2016, Salvini *et al* 2016b, Medema *et al* 2016) and affect the outcomes of the game. Third, understanding others is necessary to navigate serious games. A common language—as well as clear communication in terms of science input—as jargon free as possible is a critical component of effective relational learning that essential to prioritise in game design (Eisenack 2012, Jones *et al* 2014, Juhola *et al* 2013, Parker *et al* 2016).

5. Conclusion

As this review has shown, serious games for climate change adaptation are an emerging field of practice. As the effects of climate change become increasingly evident, a number of new adaptation games are being developed and applied in diverse contexts. There are limitations to this study. By focusing solely on the serious learning component of games additional benefits may have been overlooked. Furthermore, many of the games we reviewed are in early stages of application and may be further refined following piloting. Nevertheless, the research almost universally reports that the impact and value of serious games are very positive and there is significant scope and justification for continued growth in this research area.

To enhance the effectiveness of future games, to maximize impact, and create new opportunities for learning and innovation, it is timely to review the state of knowledge, and develop guidance for game design. The results of this review show that adaptation games are an effective tool for engaging with diverse publics and enable social learning. Research findings provide new insights into best practice for community engagement and the use of serious games affects adaptation actions. These findings can support the efforts of international development agencies, governments, policy makers, and the academic community to increase their impact in communities vulnerable to climate change in both the developed and developing world. Armed with these insights, game designers might increase the effectiveness of programmes and enhance value for money; save time; build community capacity to mitigate against the impacts of climate change and realise the opportunities associated with a changing climate.

Serious game playing opens up rich possibilities for data collection. If games are carefully developed and validated, they can help to progress the field by theory building and testing through empirical data collecting with the aim of understanding a wide range of human actions and behaviours (Juhola *et al* 2013). Moreover, games provide us with safe, engaging and interactive ways to explore diverse climate futures, to identify opportunities, and inform strategic adaptation planning to build resilience.

It is important however to continue to develop monitoring and evaluation processes that assess the extent to which games change actions on the ground. Many of the games reviewed here did not explicitly consider learning outcomes and behaviour change. Incorporating enhanced data collection with monitoring and evaluation of learning outcomes in prospective, rather than retrospective fashion, can further the case for serious games as a robust methodology for engagement.

Researchers also need to give careful consideration to the trade-off between gameplay length and complexity. There are clear trade-offs between quick and simple games and games that take longer to run but that capture complexities of the science in more detail. The best way to do this is to clearly identify the purpose of the game. Quick and simple games can be useful conversation starters and establish a basis for further engagement with players. Such interactions may lead players to consider climate change adaptation as an issue worthy of greater attention and consideration, leading to further inquiry or at a minimum, creating awareness of the issues. Longer games are more likely to create deeper player engagement that challenges existing mental models, changes player behaviour, and catalyses action by enabling players to make climate change adaptation decisions in the face of uncertainty.

As a researcher or game designer, it is important to strike a balance between quantitative and qualitative game components to create the right level of quantitative scientific detail within a convincing and compelling narrative. However greater interrogation of quantitative game elements prolongs gameplay, and may create tension between retaining player interest and ensuring sufficient time for evaluation and adequate debriefing.

Finally, a game must be able to represent real and reasonable options reflecting the motivations, values, aspirations and considerations of decision makers on the ground. At the same time, a game is an opportunity to challenge the status quo by exploring new possible arrangements, practices and outcomes. In short, the key is striking a balance between scientifically optimal outcomes and those that decision makers find palatable and reasonable. Keeping the critical issues for adaptation front and centre—adaptation of what to what, to what end, and adaptation for whom by whom—can enable serious games to realise their potential as robust and rigorous tool for enhancing social learning outcomes for climate-ready futures.

Acknowledgments

We would like to thank our respective institutions for their support. Stephen Flood and Nicholas Cradock-Henry were funded in part through the Resilience to Nature's Challenge National Science Challenge, New Zealand's Ministry for Business Innovation

and Employment. Stephen Flood was also supported through Manaaki Whenua Landcare Research Strategic Science Investment Funding. Paula Blackett was funded through New Zealand's Natural Hazards Research Platform.

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