Futures 181 (2026) 103852



Contents lists available at ScienceDirect

Futures

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





Agency and directionality in circular futures: Evidence from a serious game–based scenario exploration

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ARTICLE INFO

Keywords:
Circular futures
Scenario exploration
Techniques of futuring
Sustainability transitions
Public participation
Serious games

ABSTRACT

Circular futures scholarship has begun to unpack the contested notion of the circular economy by articulating a range of plausible scenarios. However, much of this work remains conceptual, focusing on describing end-state futures and the actors expected to dominate them, leaving the question of how actors could navigate these scenarios underexplored. This article addresses this gap through an empirical foresight action mediated by a serious game. We apply a circular-economy adaptation of the European Commission Joint Research Centre's Scenario Exploration System (SES) to explore four scenarios that combine (i) centralised versus decentralised governance and (ii) growth versus post-growth orientations. Two participatory workshops (Brussels and Pontevedra) generated evidence from game traces (resource and influence tokens, collaboration patterns, and scores) alongside qualitative observations. The findings show that scenario framings redistribute actors' influence; participants tend to enact agency through pragmatic adaptation; cooperation is typically pursued through alignment rather than self-sacrifice for collective benefit; and, despite initial constraints, agency is not fixed but evolves through time and interaction among actors and context. Regarding directionality, scenarios initially channel transition pathways, social acceptance becomes a key mediator of both individual and collective expectations, perceived moral thresholds can pivot trajectories, and overall directionality is continually reshaped through interaction. The paper provides evidence on how serious-game design features connect to workshop outputs and how games can mediate foresight actions. It also argues that circular futures research should move beyond scenario conceptualisation towards analysing how different circular trajectories are enacted and stabilised in practice.

1. Introduction

During the 2010s, the transition to a circular economy became a critical priority on global political and scientific agendas

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https://doi.org/10.1016/j.futures.2026.103852
Received 31 October 2025; Received in revised form 23 March 2026; Accepted 15 May 2026
Available online 18 May 2026
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(Korhonen et al., 2018). Broadly, the circular economy is presented as an alternative to linear production and consumption patterns, which have contributed to escalating socio-ecological pressures through increased material extraction and the expansion of waste and emissions (Geissdoerfer et al., 2017). The circular economy aims to reduce resource use and waste by keeping resources and products in circulation for as long as possible (Suárez-Eiroa et al., 2019), for example through repair, reuse, remanufacturing, repurposing, and recycling (Hobson & Lynch, 2016). However, the circular economy is a polyvalent and contested concept, inherently political, and multiple forms of circular economy can be constructed according to diverse underlying framings and institutional designs (Pansera et al., 2021). This motivates inquiry into circular futures, understood here as the exploration of multiple possible circular economies based on diverse imaginaries (e.g. see Bauwens et al., 2020; Calisto Friant et al., 2020).

Building on this understanding, a growing body of scholarship has recently explored circular futures beyond business as usual. Scenario analyses map divergent imaginaries, ranging from ecomodernist circularity rooted in technological optimism and continued growth to convivial and community-led variants that emphasise sufficiency, redistribution and democratic governance (Bauwens et al., 2020; Calisto Friant et al., 2020; Friedrich & Hendriks, 2024). Related work examines how theories of value and ownership arrangements can underpin different circular futures (Lowe & Genovese, 2022), and how policy imaginaries and instruments shape the pursuit of circularity in specific contexts (Leipold et al., 2021; Pinyol Alberich et al., 2023). This literature politicises anticipatory debate about who has the capacity to steer transitions and towards what ends. Even so, much of the work remains largely conceptual, tending to say more about what circular futures might look like than about how they are negotiated in practice and how they might be advanced, leaving two gaps that matter for both scholarship and action.

The first gap concerns the limited empirical grounding of circular futures research. While typologies and scenarios have been valuable for opening up imaginaries and clarifying what is at stake, there is still relatively little empirical evidence on how stakeholders engage with alternative circular futures when confronted with concrete trade-offs, constraints, and conflicts. Where empirical work exists, it often focuses on discourses and imaginaries (see e.g. Hermann et al., 2022), which is insightful but still leaves open questions about how agency is mobilised and transitions are steered. This is important because the political character of circular economy transitions generates multiple conflict points and distributional questions that must be negotiated if circular futures are to translate into institutional change. Empirical approaches able to capture interaction and strategic adaptation are therefore important for understanding how circular futures are socially produced rather than simply described.

The second gap concerns how circular futures might be steered once alternative futures have been articulated. Much current research maps plausible and desirable endpoint scenarios, yet offers less insight into the processes through which pathways are mobilised. Addressing this requires clearer engagement with agency and directionality, concepts well established in sociology, transitions research, and innovation studies. In this article, agency refers to the capacity of actors to make individual choices in contexts where social structures are in place (Giddens, 1984). More specifically, we talk about agency as a purposeful, future-oriented action under conditions structured by institutions which are in turn affected by agency (Stirling, 2014). Directionality refers to how the orientation of change is produced and governed, including how priorities are set, how some innovation pathways are accelerated while others are marginalised, and how plurality can be kept open rather than closed down too early (Schot & Kanger, 2018; Sovacool et al., 2020; Stirling, 2024). In this sense, directionality is not a neutral alignment towards sustainability, but an object of contestation, because steering always entails choices about which values, interests, and social groups are privileged in defining what circularity should become and how quickly. Thus, both directionality and agency are interconnected in a mutually constitutive influence. Recognising this helps move circular futures research from mapping alternative imaginaries towards a better understanding of how circular pathways are actively made and unmade.

This article addresses these two limitations by applying an empirical, interaction-focused perspective to circular futures through a foresight design based on a serious game. Serious games have been used in foresight and anticipatory governance to translate scenario narratives into structured decision spaces where participants inhabit roles, negotiate strategies, and reveal tacit assumptions and trade-offs that are otherwise difficult to observe (Vervoort et al., 2022). We build on the Scenario Exploration System, a scenario-based role-playing game developed by the European Commission's Joint Research Centre (Bontoux et al., 2016, 2020), and tailor it to explore four contrasting circular futures [Reference to the project document]. The method places participants in differentiated societal roles within scenarios that vary along macro-institutional dimensions, including the degree of governance centralisation and the orientation towards growth or post-growth. In this setting, participants allocate resources, negotiate collaboration, and respond to social evaluation in real time, enabling examination of how agency is enacted and how directionality emerges through interaction under different governance orientations.

The analysis is guided by two research questions that connect agency, directionality, and circular futures:

- RQ1: How do participants enact and negotiate agency within each circular future scenario, and how do scenario framings shape what actions are treated as feasible, legitimate, and worth pursuing?
- RQ2: How do actors' strategic interactions shape, and are shaped by, the directionality that emerges within each scenario exploration?

Conceptually, the article draws clearer attention to the relationship between agency and directionality in circular economy transitions and shows how steering can be understood as a situated and contested process rather than as an attribute of a scenario. Empirically, it provides evidence on how agency is exercised in scenario settings that reflect distinct circular transition imaginaries, and on how directionality is produced through the interplay of governance configurations, actor strategies, and social evaluation. Methodologically, it shows how serious game-based scenario exploration can complement narrative and conceptual approaches by eliciting situated decision-making, surfacing tacit assumptions, and making visible the tensions between individual role performance

and collective sustainability aims.

The remainder of the article is organised as follows. The next section situates the study within futures research, with particular attention to foresight research, serious games, and the Scenario Exploration System. We then describe the research design and analytical approach, present the findings, and discuss their implications for circular futures scholarship and for governance designs aimed at steering more just and sustainable circular economy pathways. The conclusion summarises the contributions and outlines priorities for future research.

2. Background

2.1. Foresight research

Futures research provides a systematic, interdisciplinary approach to understanding, envisioning, and preparing for the future (Bell, 2003a, 2003b). It can address multiple aspects of the future (e.g. possible, probable, and preferable futures) through different epistemic commitments and methodological families (e.g. trend-based, normative, and interpretive approaches), depending on diverse purposes (e.g. anticipation, preparedness, strategic orientation, and social learning). This orientation has become particularly salient in contemporary contexts, where socio-ecological challenges are characterised by deep uncertainty, contested values, and non-linear change (Vecchiato, 2012), which limits the usefulness of purely extrapolative reasoning and increases the need for future-oriented research that can work explicitly with indeterminacy (Suárez-Eiroa, 2025). In this context, futures studies have broadened over time and increasingly explored plausible futures, debating alternatives and desirable outcomes (Slaughter & Hines, 2020).

Within this evolution, foresight research is especially relevant because it renders uncertainty manageable while remaining action-oriented. The concept of *foresight* in futures research was coined in 1983 by the Science Policy Research Unit (SPRU) at Sussex University, in contrast to the concept of *forecasting* (Martin, 2010), which has been extensively used to envision technological trajectories to date (Miles, 2010). While forecasting draws on relatively stable present situations to capture the most probable trends and project them into the future, foresight aims to envision, navigate, and steer plausible futures in a way that is close to the French notion of *la prospective* (Coates et al., 2010). In the 1990s, foresight research expanded and gained prominence worldwide (Popper, 2008). Drawing on the principles of anticipation and preparedness, alongside plurality and inclusivity in the construction and appraisal of futures, foresight became widely applied in policy and strategic thinking, planning, and action (Miles, 2010).

Over time, foresight has proved particularly valuable for (1) complex problems with no straightforward solutions and (2) future trajectories dependent on economic, environmental, social, political, and technological disruptions, directly linking with scholarship on wicked problems (Alford & Head, 2017; Head, 2019). In such contexts, integrating multiple perspectives is not only desirable but necessary to identify blind spots, reveal conflicting values, and test the robustness of options under divergent assumptions. Accordingly, foresight studies emphasise the active involvement of heterogeneous actors in shaping collective visions of the future, whether through consultancy, contribution, collaboration, or co-creation (Popper, 2008).

Since the 1980s, foresight methodologies have become particularly prominent in strategic foresight for organisational decision-making (Iden et al., 2017) and in policy foresight to enhance preparedness and anticipatory capacity in domains marked by complexity, controversy, and uncertainty (European Parliament, 2021). In parallel, an expanding academic literature has consolidated foresight as a relevant research programme across multiple fields, such as corporate and organisational studies (Gordon et al., 2020), innovation studies (Andersen & Andersen, 2014), and science and technology studies (Borup et al., 2006).

This paper speaks directly to the latest stream in the context of circular futures and sustainability transitions, where change unfolds through complex, non-linear trajectories and where futures are shaped not only by structural constraints but also by agency (who is positioned as able to act) and directionality (which normative orientations and end-states are prioritised). Using a co-creation foresight approach within exploratory futures, we examine how agency and directionality vary across plausible scenarios, linking foresight to contemporary debates that call for making taken-for-granted assumptions and the politics of transition pathways explicit.

2.2. Serious games

Games have been integral to human societies since ancient times, serving various purposes including fun, leisure, and socialisation (Huizinga, 1950). Serious games are a particular type of game intentionally designed for objectives beyond entertainment, such as experiential learning, collective sense-making, and deliberation on shared problems (Janssen et al., 2023). Although serious games have been used for centuries (for example, for military purposes during World War II), Laamarti et al. (2014) note that the term was first coined by Abt (1970) in the 1970s.

Serious games are defined analytically by the deliberate coupling of serious purposes with concrete gameplay structures. Through design, they operationalise intended outcomes via configurations of goals, rules, roles, feedback systems, narrative framing, and interaction dynamics that structure what players can do and how consequences unfold (Arnab et al., 2015). While more systematic work is still needed to link specific game features to outcomes (such as knowledge acquisition, social skills, and behavioural change) (Boyle et al., 2016), research and practice in serious games have expanded rapidly since the 1970s, especially in the twenty-first century, consolidating their relevance across domains such as knowledge acquisition (Bellotti et al., 2013), public motivation (Connolly et al., 2012), expert training (Graafland et al., 2012), community building (Wouters et al., 2013) and collaborative governance (Ampatzidou et al., 2018).

These properties make serious games particularly relevant to foresight and anticipatory governance, as they function as social technologies that mediate interaction, organise deliberation, and create safe environments in which participants can experiment with

decisions, test assumptions, and surface conflicts under conditions of uncertainty (Mayer, 2009; Vervoort et al., 2022). Indeed, serious games are increasingly used in sustainability transitions governance to reflect on collective action problems and to support social learning – cognitive, normative, and relational (Käyhkö et al., 2025; Motlagh et al., 2025). Building on this literature, this paper examines how serious games can support foresight in the context of circular futures and sustainability transitions, comparing how distinct plausible futures mobilise different agencies and directional logics, thereby making the politics of transition trajectories empirically traceable within the game-mediated deliberative space.

2.3. The scenario exploration system

Scenario-based approaches occupy a central place in foresight. Scenarios are typically treated as internally coherent accounts of how the future might unfold, supporting strategic conversation about what could happen in different contexts (Amer et al., 2013). They are valued not because they predict what will happen, but because they help participants rehearse implications, challenge tacit assumptions, and broaden what is considered plausible under conditions of uncertainty. Importantly, scenarios only become valuable when they are pertinent, coherent, and plausible, and when the choices underpinning them are made sufficiently transparent for participants and audiences to trust and use them (Durance & Godet, 2010).

Scenario research, therefore, includes a broad repertoire of techniques for developing and exploring scenarios, such as two-by-two matrices, morphological analysis, backcasting, and participatory workshop formats that translate scenario narratives into strategic reflection and deliberation (Bishop et al., 2007; Börjeson et al., 2006; Lord et al., 2016). There is currently an experiential turn in futures practices, with futures research increasingly shifting from producing scenarios as stand-alone outputs towards enabling encounters with scenarios through facilitated interaction (Candy & Dunagan, 2017). In this context, scenario exploration can be understood as a family of methods that use scenarios as structured environments for engagement and learning, enabling participants to surface tacit assumptions, test strategies, and negotiate trade-offs while remaining anchored in scenario plausibility.

The Scenario Exploration System (SES), developed by the European Commission's Joint Research Centre, is a serious game that operationalises the systemic exploration of uncertainties within scenarios by placing participants in situated roles and structured decision spaces, allowing them to inhabit alternative futures (Bontoux et al., 2016, 2020).[1] In its original design, four scenarios were produced through a two-by-two methodology and then used as the basis for a serious game intended to promote systemic thinking, stimulate the discovery of alternative futures, and provide a platform for stakeholder engagement and experimentation. A key motivation behind the SES was to move beyond the limited afterlife of scenario reports by translating scenarios into a facilitated experience that can be used with stakeholders who were not involved in the original scenario-building process. This potential has meant that the game has already been used across a broad range of settings.

A typical session brings together scenario explorers representing different stakeholder groups, commonly policy makers, business, and civil society, alongside a public voice role that evaluates actions as the exploration unfolds. Under the guidance of a game master, participants explore two contrasting scenarios while keeping their roles and long-term objectives constant. At the start of each scenario, the scenario card sets the framing conditions and the distribution of resources across roles, so that differences in influence and capacity are not only discussed but built into the decision space. The exploration proceeds through multiple time horizons – in the original design, five, ten, and twenty years – which encourages participants to think beyond immediate responses and to articulate intermediate moves that might plausibly connect actions to longer-term aims. In each round, participants propose actions consistent with their role and the scenario context, invest limited resource tokens in those actions, and can later form collaborative actions that require agreement and pooled resources across roles. Scenario exploration is further animated through contextual prompts, including drivers and event cards, which introduce additional developments that participants must incorporate into their strategies as the scenario deepens.

Across these rounds, participants develop actions, allocate limited resources, and respond to evolving contextual cues, while the public voice scores actions using a token-based system that makes evaluation explicit and socially situated. The scoring mechanism combines resource tokens associated with each role and future impact tokens controlled by the public voice, thereby creating an evaluative structure that can reward certain strategies while dampening others and can make visible how legitimacy and influence are enacted within the game space. Because future impact tokens work as a multiplier on the resources invested in an action, public voice judgements do not merely comment on actions, but materially shape what becomes consequential in the session, making societal expectations an explicit force within the exploration. The quality of moderation is considered critical, both for maintaining scenario logic and for crafting a narrative that enables participants to inhabit the scenario world with sufficient credibility. There are also practical constraints regarding role design, session duration, and the extent to which actions can shift the scenario framing itself.

Although the set-up necessarily simplifies reality, participants often find it realistic enough to engage with complexity. This is partly because resource scarcity and turn-based action limit the tendency to propose everything at once, instead compelling choices about what matters most. The comparative design, which explores two contrasting scenarios, helps participants understand how strongly contextual framing conditions shape which actions appear feasible or impactful from the same role position. The SES leaves a trace of interaction that can be collected and analysed. The standard set-up includes templates in which participants record role descriptions and actions across rounds, alongside written reflections from the public voice on the reasoning behind evaluations, and session scores recorded by the facilitator. Together, these provide a basic dataset for debriefing and analysis. This trace can be

[1] The overview of the Scenario Exploration System that follows is based primarily on Bontoux et al. (2016) and Bontoux et al. (2020).

strengthened through systematic observation and structured note-taking that captures the negotiations and justifications accompanying action proposals, which are often central to understanding how strategies are assembled and contested.

The SES is particularly relevant for circular futures research because it brings the politics of possible circular economies into view, not only as narratives about end states, but as contested pathways shaped by who can act, with what resources, and under what expectations. In turn, it provides an appropriate methodological bridge to examine agency, as enacted capacities to intervene under uneven resources and institutional conditions, and directionality, as the emergent orientation of change shaped by scenario constraints and by what is rewarded as legitimate or effective within the exploration.

3. Research method

This study applied a circular economy tailored version of the Scenario Exploration System (SES) to examine how agency and directionality unfold across contrasting circular futures. The methodological process followed three connected phases: (1) the adaptation of the SES by developing the scenarios and translating them into a coherent game architecture, (2) the collection of data through two participatory workshops complemented by pre and post surveys, and (3) the analysis of the resulting material by combining game outputs with observational and survey data.

3.1. Design

The study employed a circular economy-adapted version of the Scenario Exploration System, developed within the [name of the project] project and documented in the SES adaptation booklet (Reference to the project document). The adaptation aimed to create a set of contrasting yet plausible circular futures and to translate them into a coherent game architecture that could be played comparably across sessions, while maintaining sufficient openness for participants to define role identities, negotiate priorities, and experiment with strategies. The design retained the core SES logic of exploring alternative scenarios through role play and constrained decision-making, but was customised in three ways crucial for this research: constructing circular economy-specific scenarios, defining role constellations that reflect salient stakeholder positions in circular economy debates, and developing scenario- and role-specific game materials that structure action, constraint, and evaluation.

Scenario development followed a two-by-two matrix approach, selecting two macro-institutional axes to capture meaningful variation in the conditions under which circular economy transitions might occur. The first axis concerned the type and structure of governance, ranging from centralised and top-down to decentralised and bottom-up configurations. The second axis concerned socio-economic goals and policy logics, ranging from continued growth to post-growth approaches. Continuous economic growth proposals usually address ecological pressures based on the assumption that it is possible to substitute natural capital with human capital. In contrast, post-growth proposals tend to centre on assumptions emphasising the existence of ecological thresholds and the inability to substitute natural capital with human capital. These axes were identified through a targeted review of the circular futures literature conducted up to September 2025 using the Scopus and Web of Science databases. Using search strings combining "circular economy" with "futures", "scenarios", and "imaginaries", the review yielded eight publications directly focused on circular futures, which were used to synthesise recurring dimensions of variation and to justify the choice of axes. The axes were then refined through internal discussions and participatory work within the project. The selection prioritised minimal overlap between scenarios, internal coherence, and sufficiently clear differentiation to allow participants to recognise distinct pathway logics while inhabiting futures that remain plausible.

Crossing the axes produced four archetypal scenarios that form the substantive backbone of the tailored SES. Centralised Circularity Uptake depicts a centralised, growth-oriented future in which national governments and large corporations align around technological optimism, building large-scale recycling and logistics infrastructures while leaving prevailing production and consumption patterns largely intact. The scenario foregrounds efficiency gains and state–corporate coordination, but also highlights risks associated with planned obsolescence, restricted participation, and surveillance-oriented consumer governance. Decentralised Circularity Uptake retains a growth orientation but shifts power towards decentralised governance, with municipalities, cooperatives, start-ups, and civil society fostering diverse local circular initiatives such as repair ecosystems and sharing platforms. The scenario emphasises experimentation and plural innovation, while also problematising fragmentation, scaling difficulties, inconsistent regulation, and rebound dynamics that can dilute environmental additionality. Planned Circular Loops combines centralisation with a post-growth orientation, where states and large firms establish binding ecological and economic constraints through technocratic planning, including strong regulatory steering, high taxation, and measures such as product-as-a-service and universal basic income. The scenario reduces throughput but raises tensions around democratic legitimacy, autonomy, and concentration of power. Bottom-up Circular Loops combines decentralisation with a post-growth orientation grounded in sufficiency and wellbeing, where decision-making is organised through local assemblies, cooperatives, and federated commons institutions that prioritise shorter supply chains, community-owned infrastructures, and strategies of refusing, reducing, and rethinking alongside conventional circular practices. It highlights democratic participation and resilience, while recognising coordination challenges and uneven capacities across territories.

The scenarios were then translated into playable materials that provide participants with a structured yet evolving context. In the tailored version, each scenario unfolds across three consecutive time horizons – ten, twenty, and thirty years ahead – anchoring discussion in intermediate steps rather than only end states. Scenario discs and scenario detail cards summarise the framing conditions and key developments at each horizon, while megatrend and variable driver cards introduce additional contextual dynamics that the facilitator weaves into the narrative as the exploration progresses. This combination is intended to preserve scenario coherence while still allowing uncertainty and surprise to enter the session in a controlled way, creating opportunities for participants to revise

strategies and reassess which forms of circularity appear feasible or desirable under shifting conditions.

Role design was tailored to reflect stakeholder positions salient in circular economy discourse and plausibly carrying different capacities to shape transitions. The game includes five scenario-explorer roles: Established Business, Circular SME (Small and Medium sized Enterprises), Policy Maker, Circular NGO (Non-Governmental Organisation), and Consumer Organisation, plus a Public Opinion role that evaluates actions as the exploration unfolds. Participants are invited to instantiate their role by defining whom they represent, what values guide them, and what long-term vision they pursue, creating a basis for analysing how agency is enacted through situated interpretation of role mandates and scenario constraints. Importantly, the Public Opinion role does not act as a neutral observer. It is designed as an active evaluative force in the game space, articulating societal expectations and allocating influence in ways that shape which actions become consequential. As for the action structure, each scenario is explored through three iterative rounds, one per time horizon, in which scenario explorers select actions from predefined action cards aligned with their role, invest limited resource tokens to support those actions, and can form collaborative actions by pooling resources with other roles. Public Opinion then assigns influence tokens to actions, which multiply the effect of invested resources and thus shape overall scores. This token mechanism is not treated as a performance metric in itself, but as a design choice that makes legitimacy and contestation materially visible. Participants must therefore navigate not only resource constraints and institutional conditions but also anticipated public reactions, which is central for examining how directionality is produced through interaction and evaluation. Fig. 1 summarises the gameplay flow of the SES version employed in this research.

Power differentials in the game are operationalised through resource scarcity, token-weighted public support, and scenario-specific structures. Scenario explorers receive fixed resource tokens, while Public Opinion allocates influence tokens that amplify or dampen actions in scoring. Each scenario also provides a distinct narrative and sets of prompts, along with role-specific action cards, which make some strategies easier to justify as feasible and others harder to pursue. The action cards suggested a general course of action (Innovate, Communicate, Invest, etc.). These actions were not explained by the moderators but were instead left open to the players' interpretation. For example, one SME player selected Innovate and explained that the choice was intended to take advantage of the market opportunity presented by the scenario – in this case, that start-ups were the main focus of funding. In addition, one action card was blank, to give complete freedom to the player. Overall, centralised scenarios make regulatory coordination and large-scale investment more readily actionable, whereas decentralised scenarios emphasise coalition building and local experimentation. Therefore, even when token endowments are equal, these scenario materials shape which actions are most likely to gain traction and why.

3.2. Data collection

Data were collected through two participatory workshops, supported by pre- and post-workshop surveys. The overall strategy combined quantitative and qualitative material gathered before, during, and after each session. All procedures complied with the ethical and legal requirements of the European Union General Data Protection Regulation. Participants received an information sheet outlining the aims of the study, the voluntary nature of participation, intended data uses, anonymisation procedures, and the handling of image rights. Informed consent was obtained prior to participation. Data were stored on encrypted university servers, and participant identifiers were replaced with anonymous codes before analysis.

Two workshops were organised in different European contexts: Brussels (Belgium) and Pontevedra (Spain). The choice of locations was pragmatic and comparative: it allowed the same scenarios to be played in different contexts. Pontevedra was the base of the research team coordinating the Scenario Exploration System workshops within the [name of the project] project, while Brussels enabled the study to draw on a partner organisation's networks and broaden participation to stakeholders working in European institutions and supranational organisations, adding institutional and cultural diversity to the settings in which the game was played. The Brussels workshop was hosted by ABIS, The Academy of Business in Society, on 17 April 2024 and included 20 participants. The Pontevedra workshop took place on 18 June 2024 as part of the European Society of Ecological Economics conference and included 18 participants, with a stronger regional focus on Galicia. In total, 38 stakeholders participated across the two sites, representing public administration, private sector organisations, research, and civil society organisations, with gender and age profiles reported in Table 1. Importantly, we acknowledge that different group compositions (including participants with ongoing working relationships) could plausibly shape dynamics and outcomes.

Participation in this study was designed as collaborative scenario exploration within a bounded, foresight set-up (Popper, 2008). The scenarios and core game architecture were pre-specified through the adaptation process, so participation was not intended to co-author scenario assumptions or drivers, but to explore their implications through structured role-play and deliberation. Instead, participants were invited to inhabit stakeholder roles, interpret and negotiate their mandates and values, and co-produce pathways through interaction (Bontoux et al., 2016, 2020). In practical terms, participation involved deliberation and negotiation among actors, experiential experimentation with strategies under constraint, and reflexive discussion of implications during debriefing. This design aligns with foresight approaches that use workshops to generate structured engagement and social learning, particularly through collective reflection on trade-offs, legitimacy, and the practical conditions under which alternatives can be pursued (Reed et al., 2010). In this case, stakeholders shaped the exploration through situated judgement and action rather than through co-design of the scenario logics, which is why the sessions are treated as a research setting for observing agency and directionality rather than as a stakeholder validation exercise.

Each workshop implemented the tailored SES protocol described in Section 3.1 and lasted approximately three hours. After a short introduction to the exercise and the research aims, participants were allocated roles and completed role sheets specifying guiding values, a long-term vision, and strategic priorities. Participants then explored two contrasting scenarios, and the session concluded with a facilitated debrief. Quantitative data were captured throughout gameplay via the SES evaluation templates completed at each

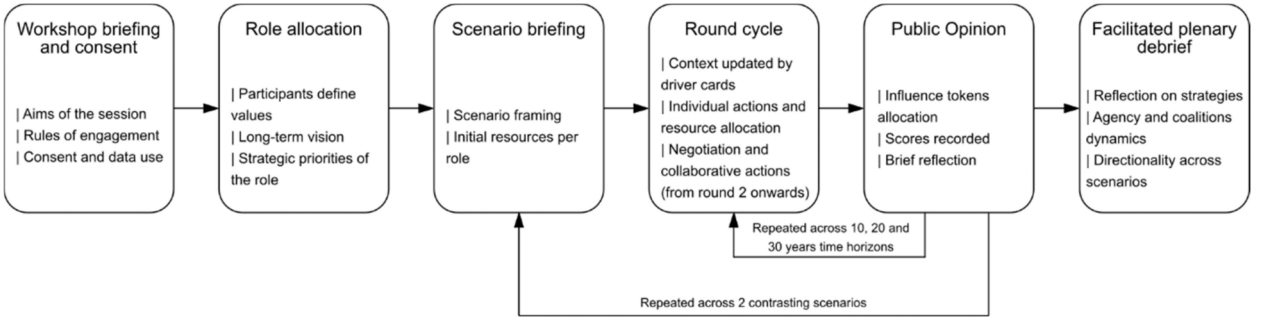


Fig. 1. Gameplay flow of the circular economy-tailored Scenario Exploration System workshops. Participants are briefed and assigned stakeholder roles, then explore two contrasting scenarios. Each scenario is played across three successive time horizons (10, 20, and 30 years) through iterative rounds of action selection, resource allocation, negotiation, and collaboration, followed by Public Opinion evaluation using influence tokens. The session concludes with a facilitated plenary debrief focusing on strategies, coalition dynamics, agency, and directionality across scenarios.

Table 1
Profile of participants.

			Public admin.	Private sector	Research	Civil society	Total
Brussels	Gender	Female	2	2	2	1	7
		Male	1	8	1	3	13
	Age range	$20 < \& \geq 40$	3	5	3	3	14
		$40 < \& \geq 60$	0	5	0	1	6
Pontevedra	Gender	Female	0	3	4	2	9
		Male	1	2	3	3	9
	Age range	$20 < \& \geq 40$	1	4	3	4	12
		$40 < \& \geq 60$	0	1	4	1	6
Total			4	15	10	9	38

time horizon, while qualitative material was generated through structured observation and the debrief discussion.

Quantitative and qualitative data were collected systematically during gameplay. Quantitative data were recorded in the standard SES templates and evaluation sheets. These included the distribution and allocation of each participant's resource tokens, investments in actions proposed by other roles, the influence tokens allocated by Public Opinion, and the resulting scores for actions and roles. These data provide a basis for analysing resource flows, cooperation patterns, and the effects of evaluation on which strategies gained traction under different scenario framings. Qualitative material was collected through structured observation and note-taking by trained observers, focusing on deliberation, negotiation, justification, and contestation during the rounds, as well as on the reflective discussion during debriefing. Where consent was granted, photographs were taken to document the workshop setting and support transparent reporting of the research process (Fig. 2).

Survey data complemented the workshop material by capturing participant characteristics and reflections not fully observable during the sessions. Before each workshop, participants completed an online questionnaire covering socio-demographic information, professional background, familiarity with circular economy concepts, and orientations regarding governance and economic priorities relevant to circular transitions. All participants completed the pre-workshop survey. This information supported role assignment and provided contextual grounding for interpreting strategic positioning during gameplay. After each workshop, participants were invited to complete a follow-up survey capturing their experience of the session, perceptions of scenario plausibility, and reflections on workshop dynamics and learning. In total, 21 participants completed the post-workshop survey: 13 from Brussels and 8 from Pontevedra, corresponding to a response rate slightly above 50 per cent.

3.3. Data analysis

Data were analysed using a mixed methods approach that combined quantitative and qualitative material to develop an interpretive account of how agency and directionality unfolded across scenarios. Overall, qualitative analysis provided the primary analytical lens. Quantitative game traces were used descriptively to map patterns and support the interpretation of mechanisms through triangulation, rather than to support statistical inference or broad generalisation. The intention is therefore transferability through detailed reporting of the context, protocol, and data sources, rather than statistical generalisability.

Quantitative analysis drew on the game traces recorded in the SES templates, including the distribution and allocation of resource and influence tokens and the resulting scores. These data were used to produce descriptive statistics for each actor role across scenarios and to support comparison between governance and growth orientations. Frequency tables indicated how often actor roles appeared as



Fig. 2. Snapshots of the Pontevedra workshop. Introduction to the SES game (right) and scenario exploration (left).

relatively more or less influential across games. Spearman rank correlation tests explored whether these descriptive patterns varied systematically with scenario characteristics, and the Gini coefficient was calculated as an indicator of how unevenly influence accumulated within each scenario. Full details of the statistical procedure are provided in Appendix A. In the main text, quantitative results situate the interpretive account and corroborate the qualitative explanation of observed dynamics.

Qualitative analysis aimed to explain the mechanisms underpinning the quantitative patterns by examining how strategies were articulated, justified, negotiated, and adapted during gameplay. The material consisted primarily of structured observation notes and facilitated debrief discussions, which captured participants' deliberations, coalition formation, contestation, and reasoning about feasibility and legitimacy. The analysis followed a thematic approach oriented to the research questions, with particular attention to how actors enacted agency under scenario constraints and how directional pressures emerged through interaction and evaluation. To enhance analytical depth and consistency, the qualitative analysis was conducted collaboratively. Four co-authors each undertook a review of qualitative material for one scenario across both workshops, identifying recurrent strategic moves, sources of influence, barriers and enabling conditions, and the role of public evaluation in shaping which actions gained traction. The team then held three meetings to compare detected patterns and interpretations. Each meeting lasted approximately two hours and used a shared digital whiteboard to map preliminary patterns, identify convergences and divergences across scenarios, and iteratively agree a common set of explanations. Finally, qualitative explanations were cross-checked against the quantitative traces to triangulate conclusions and ensure that interpretations remained grounded in the combined dataset.

4. Results

This section reports and interprets the main patterns observed in the SES sessions. It follows the two research questions, first examining how agency was enacted and negotiated under contrasting scenarios, then analysing how directionality emerged through continuous interaction among actors and the contexts of each scenario. Table 2 summarises the main results. The final column links each finding to supporting literature, anchoring the interpretation in wider theory.

4.1. Enacting and negotiating agency across scenario framings

Across the workshops, we identified four main findings regarding how participants enacted and negotiated agency in relation to scenario framings. First, scenarios shaped the distribution of influence in the sessions, widening or narrowing whose actions and which actions could become favourable. In the centralised, growth-oriented scenario, Centralised Circularity Uptake, Policymakers and Established Business tended to occupy more influential positions within the explorations. Policymakers achieved the highest average scores in this scenario, with a mean of 38.25 and a median of 41, and their strategic moves often gained traction because regulatory coordination and central steering were treated as workable and legitimate within the narrative. Established Business also performed strongly, with a mean of 33.0 and a median of 39.5, frequently advancing investment-led proposals that matched the scenario's state–corporate alignment. In contrast, SMEs, Consumer Organisations and NGOs more often faced tighter constraints on how far preferred strategies could gain traction unless they aligned with dominant institutional logics or secured cross-role backing. This

Table 2
Main findings from the sessions.

Concept	Finding	Description	Supporting literature
Agency	Framing redistributes influence	The scenario favours some actions and roles over others. In centralised settings, roles aligned with coordination and large-scale solutions tend to gain traction, whereas decentralised settings open space for a wider range of roles.	Avelino et al. (2016); Avelino and Rotmans (2009)
	Agency as pragmatic adaptation	Most participants begin with actions that are plausible within the scenario, oriented towards maintaining or improving their position. More disruptive moves may emerge later or when the context triggers them.	Emirbayer and Mische (1998); Shove and Walker (2010)
	Alignment over sacrifice	Agency becomes more effective when alliances are formed and benefits are shared across parties. There are few strategies that involve unilateral loss for the common good.	Ostrom, (1990), (2010)
	Structured, not fixed	Although framing structures what is more likely to gain traction, outcomes are not determined. Results vary across games depending on how roles are interpreted, which actions are taken, and what coalitions and shared expectations emerge.	Jessop, (2001), (2016)
Directionality	Scenario channels pathways	The scenario sets an initial direction of travel by shaping shared expectations that favour particular actions. In broad terms, centralisation pushes towards coordination and infrastructure, whereas decentralisation favours local networks, experimentation and alliances.	Borup et al. (2006); Jasanoff and Kim (2009)
	Social acceptance is consequential	Social acceptance conditions how actors frame their expectations, as they seek to increase support. In the sessions, participants try to attract backing and secure more tokens from Public Opinion.	Irwin (2006); Stirling (2024)
	Moral thresholds pivot direction	When scenarios cross perceived moral thresholds, resistance increases and oppositional moves emerge. Directionality is reconfigured through contestation rather than adaptation and compliance.	Boltanski and Thevenot (2006); Thompson (1971)
	Directionality from interaction	Directionality is produced through ongoing interaction between actors and context. Although the scenario provides an initial direction, it evolves through the exploration.	Sovacool et al. (2020); Stirling (2024)

concentration of influence is also reflected in the distribution of scores, which was most uneven in this scenario, with a Gini coefficient of 0.147.

By comparison, decentralised scenarios tended to widen the range of roles able to gain traction. In Decentralised Circularity Uptake, SMEs recorded the highest mean score across the study at 41.67, often positioning themselves as agile innovators able to connect experimentation, emerging markets and local initiatives. In Bottom-up Circular Loops, decentralisation combined with a post-growth orientation and influence was more evenly distributed, with the lowest Gini coefficient at 0.072. In this scenario, NGOs frequently achieved high scores and were closely involved in mobilisation-oriented pathways, while Consumer Organisations often increased their influence by acting as intermediaries for citizen-facing concerns, including access, affordability and everyday practices. Planned Circular Loops combined centralised steering with a post-growth orientation and produced a more mixed pattern. Policymakers remained influential, with a mean and median of 35.0, while Consumer Organisations reached their highest mean score in this scenario at 36.0, suggesting that when constraints and redistribution are normalised, consumption-side institutions can gain traction even under centralised governance.

Second, agency was most often enacted as pragmatic adaptation to the given conditions. Early moves typically aimed to maintain or improve role position while remaining plausible within the scenario logic, with fewer attempts to pursue radical change as an initial step. This pattern was evident across all four scenarios. Participants generally began by identifying what the scenario made actionable for their role, then developed strategies that could reasonably be defended as credible within that context. In the growth-oriented scenarios, for example, Invest and Innovate were selected frequently, accounting for 15.9 per cent and 11.9 per cent of actions, respectively. In the context of the game, *Innovate* was applied broadly, covering technological, process, product and organisational changes. Both Invest and Innovate were repeatedly framed as practical ways to remain influential under uncertainty. In the post-growth scenarios, participants more often justified agency through compliance with constraints, redistribution-oriented measures or locally grounded initiatives, but still tended to proceed through incremental repositioning rather than initiating overtly transformative moves. When participants did attempt more countervailing moves, these were typically triggered by specific scenario developments, for example, when prompts introduced developments perceived as ethically unacceptable during the game.

Third, agency tended to be exercised through collective alignment, rather than through strategies requiring unilateral sacrifice for collective benefit. Across the sessions, participants consistently pursued role-specific goals, and we observed few explicit moves framed as sacrificing role interests for collective outcomes. Where cooperation emerged, it was typically justified as mutually beneficial, as a way to pool scarce resources, or as a route to secure support from other roles and from Public Opinion. This was particularly visible in decentralised scenarios, where Mobilise, Participate and Partner together accounted for a substantial share of actions, especially among SMEs, NGOs and Consumer Organisations. These actions were used to broaden support, pool resources and present initiatives as aligned with community priorities. Yet cooperation was rarely framed as self-sacrifice. Instead, collaboration was often used to translate fragmented initiatives into more coordinated pathways. In centralised scenarios, alignment was also important, but it often manifested as strategic positioning within dominant institutional logics. Roles without structural advantages tended to gain traction when they framed proposals as complementary to central coordination or joined coalitions that could plausibly be implemented under the scenario's governance style. Across scenarios, Public Opinion support provided an additional layer of alignment. Participants routinely framed actions to attract Public Opinion backing, which encouraged coalition formation around initiatives that could be defended as socially acceptable within the session.

Although framings influenced which roles and actions were more likely to gain traction, outcomes were not determined by the scenario. No single role dominated across all scenarios, and the same roles within the same scenario performed differently across sessions. The quantitative record also shows that influence remained sensitive to strategic action. Variability within roles, visible in score ranges across scenarios and groups, suggests that the same role could be marginal in one session and consequential in another, depending on how participants framed their mandate, sequenced actions, and mobilised collaboration and Public Opinion support. The data did not indicate predetermined winners across scenarios, reinforcing that outcomes remained open to redirection through strategic action. The sessions therefore suggest a view of agency that is both structured and negotiable. Scenario framings shaped the landscape of plausibility and the distribution of influence, yet participants still shaped that landscape through individual and collective action.

4.2. Directionality as an emergent outcome

Across the sessions, we observed four principal results regarding directionality. First, scenario framings channelled which types of pathways appeared more realistic. Centralised scenarios consistently oriented discussion towards coordination, large-scale infrastructures, and technocratic steering, as these pathways matched the narrative assumptions about where capacity and authority reside. In Centralised Circularity Uptake, for example, regulatory coordination and large-scale investment were repeatedly treated as credible levers, and strategies aligned with central planning or state–corporate infrastructure development were easier to justify as workable. In Planned Circular Loops, the presence of explicit limits to growth and binding constraints channelled directionality towards planned restrictions, redistribution-oriented measures, and system-wide redesign of ownership and consumption. In decentralised scenarios, by contrast, pathways framed around local initiatives, experimentation, and coalition-building were treated as more realistic. In Decentralised Circularity Uptake, participants repeatedly oriented directionality towards scaling local innovations and connecting dispersed initiatives, while Bottom-up Circular Loops channelled directionality towards sufficiency-oriented practices, shorter value chains, and community-based provisioning. Across all cases, scenario framings did not determine participants' actions but shaped what could be credibly proposed and defended, thereby narrowing or widening the field of pathways treated as plausible.

Second, directionality was mediated in real time by the evolution of collective expectations and subsequent social acceptance and

reward, which in turn were negotiated by interaction among actions and by the support of Public Opinion at the end of each round. Because influence tokens allocated by Public Opinion weighted the in-game impact of actions, support and opposition were not merely discussed but became materially consequential within the exploration. Participants treated social acceptance and Public Opinion as crucial elements whose support needed to be cultivated. Strategies were frequently framed to attract Public Opinion backing, whether by emphasising fairness, feasibility, protection of livelihoods, or everyday acceptability. This dynamic also interacted with coalition-building. Participants often built alliances not only to pool resources but to increase the perceived legitimacy of a pathway by demonstrating cross-role support. The quantitative traces reinforce this pattern within the game setting. Public Opinion tokens have the strongest association with final scores, with a coefficient of 3.34; collaboration from others also shows a strong association, with a coefficient of 2.10, and collaboration to others showed a coefficient of 1.95. Within the boundaries of the SES scoring structure, this indicates that directionality in the sessions was closely tied to how actors combined coalition dynamics with the ability to secure Public Opinion support and then adapt their strategies in response. Actions that failed to attract support could be dampened even when resourced, whereas actions framed as publicly acceptable could gain traction and shape subsequent strategic choices.

Third, directionality could pivot when scenario developments were perceived to cross moral thresholds. When scenario prompts implied ethically contentious conditions, such as severe restrictions on personal autonomy or large-scale unemployment, participants were more likely to move from adaptation to explicit resistance. In these moments, challenging and countervailing moves became more salient, and participants attempted to redirect trajectories rather than comply. This suggests that, within the exploration, directionality was shaped not only by what seemed feasible or efficient but also by what participants judged to be intolerable. Moral thresholds therefore operated as potential turning points, triggering shifts in strategy and opening space for contestation over initial directionality. Importantly, this does not imply that ethical controversy automatically generates transformation, but it does show that acceptability can be withdrawn and that such withdrawals can change what participants treat as viable pathways within the session.

Fourth, taking all the above into account, directionality arose from the ongoing interaction between actors and their context. Participants did not simply react to an imagined future as if it were a fixed environment. They actively constructed a direction of travel by proposing actions, responding to others' proposals, revising strategies over different time horizons, and building coalitions capable of advancing a pathway. Directionality thus emerged from the accumulation of action sequences and the ways participants justified continuity or change across rounds. In centralised scenarios, directionality was often shaped by attempts to set agendas, align with dominant institutional logics, and secure endorsements that made particular sequences appear feasible. In decentralised scenarios, directionality more often depended on coalition dynamics, as pathways had to be sustained across fragmented initiatives and the risk of dispersion was repeatedly raised. In both settings, counter-actions were frequent when participants perceived that a proposed pathway would marginalise their role, undermine core values, or create unacceptable trade-offs, demonstrating that directionality was continually contested rather than simply adopted.

5. Discussion

The results presented above contribute to the literature on circular futures, foresight research, and serious games in various forms. Overall, the SES sessions enabled exploration of how agency and directionality emerge and interact in different scenarios, reframing these scenarios as strategic landscapes dialectically constructed through interactions among actors and their context. While circular futures research has distinguished between futures typologies (e.g. centrally steered, growth-oriented variants versus more decentralised and sufficiency-oriented pathways) and described which actors and R-cycles (e.g. reusing, repairing, remanufacturing, and recycling) might be prominent in each case (Bauwens et al., 2020; Calisto Friant et al., 2020), our sessions show that, although some patterns are visible (e.g. policymakers and established businesses tend to be favoured in centralised growth framings), framings do not fully determine outcomes. This echoes accounts of sustainability transitions as politically contested and institutionally structured processes (Avelino et al., 2016, 2024; Avelino & Rotmans, 2009). The fact that the same role could be marginal in one session and consequential in another also cautions against rigid mappings between a future and a single dominant practice. Institutional contexts matter, but they do not eliminate agency.

Furthermore, the paper informs circular futures research on how agency manifests across scenarios in practice. Agency during the sessions was linked to pragmatism, legitimacy, justice, and coalition-building. Participants generally began with pragmatic, plausible moves that protected their role position and made sense within the scenario logic, and actions were mostly selected strategically to gain legitimacy and public acceptance. Participants invested effort in framing proposals to attract support from public opinion and avoided moves likely to be rejected. This relates to how politics can become stabilised through everyday practices and shared notions of what is feasible and acceptable, rather than only through explicit confrontation (Hobson & Lynch, 2016; Shove & Walker, 2010). More oppositional or disruptive strategies appeared less frequently, and resistance intensified when scenario prompts crossed perceived moral thresholds, such as severe restrictions on autonomy or large-scale unemployment. This highlights the importance of acceptability and legitimacy in sustainability pathways, and how support can be withdrawn when futures are framed as unjustifiable (Boltanski & Thevenot, 2006; Thompson, 1971). Additionally, coalition-building was pursued as a central strategy to mobilise agency and shape outcomes. This aligns with work highlighting the role of alliances and institutional work in sustainability transitions, where actors build and sustain supportive arrangements through coordination, negotiation, and the creation of shared rules and expectations (Lawrence & Suddaby, 2006; Smith et al., 2005).

This also relates to how directionality is constructed. Circular futures research often differentiates futures by tacit assumptions, yet the sessions show how directionality is reshaped through ongoing interaction among actors and their context. Although scenarios presented an initial narrative, participants could eventually follow or challenge it. In the explorations, directionality was sometimes reinforced by actors' actions and interactions, and at other times challenged and reshaped. Across sessions, individual expectations

maintained a constant conversation with collective expectations, which simultaneously interacted with assumptions within each scenario, modifying or qualifying them and altering the directionality of the scenario. This complements work that treats directionality as contested and political, involving struggles over which pathways are promoted or marginalised (Schot & Kanger, 2018; Sovacool et al., 2020; Stirling, 2024), and it shifts circular futures analysis from asking howfutures look like to examining how pathways are carried, blocked, stabilised, or redirected through ongoing negotiation in practice.

Methodologically, the study contributes to foresight research by demonstrating the benefits of treating scenarios as environments for structured decision-making. Scenario planning is widely valued for moving beyond prediction, broadening plausibility, and supporting strategic reflection under uncertainty (Amer et al., 2013; Börjeson et al., 2006; Durance & Godet, 2010). The SES builds on this tradition, producing practical insights in an explicitly hypothetical but policy-relevant setting by tracing sequences of decisions and negotiations – actions selected, resources invested, collaborations formed, and public evaluations – that can be systematically analysed rather than merely summarised in a final narrative. This connects to Candy and Dunagan (2017) notion of an "experiential turn", where learning arises from encountering futures through interaction and immersion. In particular, this occurs through collaborative exploration within a bounded set-up, generating situated knowledge via participants' judgements about feasibility, legitimacy, and strategy under contrasting framings.

Furthermore, the sessions demonstrate how game mechanics influence what becomes significant within the sessions. In this case, the combination of resource scarcity, a predefined set of actions, and token-based Public Opinion feedback shaped the development of the game and, consequently, the outcomes observed. The game architecture was essential for interpreting action patterns during the sessions. For example, the prominence of *Innovate* and "Invest" in the centralised, growth-oriented scenario reflects not only participant preference but also how those action cards operate across scenario contexts as broadly defensible ways to assert relevance. Rather than viewing this as a limitation, we treat it as a boundary condition that must be made explicit when interpreting the findings, since the game mediates what participants perceive as strategically worthwhile. Even under constrained conditions, we found that agency and directionality follow relational logics, as they are continually constructed and reconstructed through interaction among actors and their context. This shifts the focus from scenario building alone to how circular futures are enacted through negotiation, coalition-building, and contestation in practice.

6. Conclusions

Recent circular futures scholarship has made significant progress in unpacking the plurality of circular economies, mapping and describing contrasting imaginaries and endpoint scenarios that range from growth-oriented, techno-optimist circularity to post-growth and sufficiency-led variants. This study advances this branch of literature by showing how agency is enacted and negotiated, and how directionality is produced, stabilised, or contested through interaction in diverse scenarios. We achieved this by applying a circular economy adaptation of the Scenario Exploration System (SES), a serious game that operationalises scenarios as structured decision environments and makes evaluation observable in real time. By inhabiting these explicit hypothetical scenarios, participants test their strategies and experience living within those scenarios. The game thus operates as a social technology mediating human interaction, establishing explicit rules and constraints for participants. This provides evidence of how serious games operate in practice and how they can be applied in the context of foresight.

The scope of our analysis entails certain limitations in using SES to understand agency and directionality in Circular Economy Futures. First, SES simplify reality through predefined roles, action repertoires, and scoring rules; these preconditions limit possible outcomes. Furthermore, workshop outcomes depend on the quality of facilitation and group composition. In this context, the workshops represent an invited, role-based form of participation that may reproduce selection and power biases. In the real world, public opinion typically operates through more mediated and diffuse channels – such as elections, consumption, protest, and media – whereas in the SES it is intentionally personified to make legitimacy effects analytically observable. Despite these limitations, the article presents a clear central message: even under strongly framed and resource-constrained conditions, circular futures are actively assembled through contestable processes of agency and directionality. Across scenarios, framings redistributed influence by shaping which actions were considered feasible and legitimate; participants typically exercised agency through pragmatic adaptation rather than immediate transformation; and cooperation tended to rely on alignment and coalition-building rather than self-sacrifice for collective benefit. Importantly, agency was structured but not fixed: it evolved over time through interaction among actors, resources, and public evaluation. Directionality likewise emerged relationally. Scenarios initially channelled plausible pathways, but trajectories were continually reshaped through negotiation and legitimacy-seeking; when perceived moral thresholds were crossed, resistance and contestation could alter the direction of travel. Overall, while most circular futures literature has conceptualised endpoint future scenarios and identified which actors and R-cycles might be prominent, this article argues for shifting the focus from scenario building alone to how circular futures are enacted through negotiation.

In this context, future research may proceed along at least three main lines. First, it may test new games or adaptations of the SES to further explore circular futures, examining in greater detail how design relates to game outcomes. This would contribute to the serious games literature. Second, the SES may be used to assess new aspects of how circular futures are negotiated. Current research still lacks insights into how the same actors may vary across scenarios and how these changes are linked to institutional logics created within each scenario. This would contribute to the serious games literature and foresight research with new evidence, and to circular futures research with new insights into how to guide particular trajectories. In this context, the third line of future research is the assessment of agency and directionality in circular futures from a sustainability transitions perspective, focusing on elements such as collective learning, network building, expectations mobilisation, and institutionalisation of trajectories.

CRediT authorship contribution statement

Sánchez Juárez Victor José: Writing – review & editing, Validation, Methodology, Formal analysis, Data curation, Conceptualization. **Vázquez Silva Iria:** Writing – review & editing, Methodology, Formal analysis, Data curation, Conceptualization. **Breogán Riobóo Lois:** Writing – review & editing, Validation, Methodology, Formal analysis, Data curation, Conceptualization. **Brais Suárez-Eiroa:** Writing – review & editing, Writing – original draft, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **García Quintana Ana:** Writing – review & editing, Validation, Methodology, Formal analysis, Data curation, Conceptualization. **Alonso-Rodríguez Aitor:** Writing – review & editing, Validation, Methodology, Formal analysis, Data curation, Conceptualization.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author(s) used ChatGPT, CoPilot and Gemini tools to assist with language editing —improving clarity, grammar, and concision— and to refine the readability. After using these tools, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the published article. No AI-generated content was accepted without human verification, in line with Elsevier's journal policy.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

All authors acknowledge the European Union's Horizon Europe research and innovation programme under the Marie Skłodowska-Curie Actions Staff Exchanges project ExPliCit – Exploring Plausible Circular futures [grant agreement No. 101086465]. Brais Suárez Eiroa acknowledges the support of the Postdoctoral Program Xunta de Galicia under grant ED481B-2023-011, funded by the Consellería de Cultura, Educación, Formación Profesional e Universidades. Ana García Quintana acknowledges the support of the Predoctoral Program Xunta de Galicia under grant ED481A2024-076 – Grant co-financed by the European Union under the FSE+ Galicia 2021-2027. Aitor Alonso Rodríguez acknowledges the support of the Predoctoral Program Xunta de Galicia under grant ED481A2024-190 – Grant co-financed by the European Union under the FSE+ Galicia 2021-2027. Víctor José Sánchez Juárez acknowledges the support of the University of Vigo's Predoctoral Program under grant PREUVIGO-23. Funding for open access charge: Universidade de Vigo/CISUG.

Appendix A. – Statistical analysis

A1. Mean, median, min and max

This analysis presents the descriptive statistics (mean, median, minimum and maximum) for each actor in the different scenarios. These metrics provide insight into the central tendency and variability of each actor's performance under different governance structures and economic orientations. Table A1 summarises the results.

Table A1
Mean, min and max values by actor in each scenario

Actor	Scenario	Mean	Median	Min	Max
Consumer Organisation	BCL	27.33	27	26	29
	CCU	31.33	33	22	39
	DCU	29.5	29.5	26	33
	PCL	36	36	31	41
Established Business	BCL	31.25	31.5	24	38
	CCU	33	39.5	11	42
	DCU	32.33	32	29	36
	PCL	34.66	38	24	42
NGO	BCL	31.33	30	30	34
	CCU	21.33	20	18	26
	DCU	31	35	22	36
	PCL	30.67	31	26	35
Policymaker	BCL	32.75	32	27	40
	CCU	38.25	41	19	52
	DCU	35	35	35	35
	PCL	35	35	32	38

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Table A1 (*continued*)

Actor	Scenario	Mean	Median	Min	Max
SME	BCL	36.25	30.5	28	56
	CCU	35.75	37.5	23	45
	DCU	41.67	37	35	53
	PCL	29	30	26	31

The SME actor showed remarkably high averages in the BCL and DCU scenarios with mean scores of 36.25 and 41.67 respectively, indicating particularly strong performance in decentralised scenarios. Policymakers, on the other hand, showed their highest average performance in the CCU scenario (mean = 38.25, median = 41), underlining their relative strength in centralised government contexts. Established Business scored relatively consistently in all scenarios, with the lowest mean score in BCL (31.25) and the highest in CCU (33). Consumer Organisations and NGOs showed fluctuations in their performance, which was particularly evident in the large discrepancy between their minimum and maximum scores within the scenarios, suggesting that their effectiveness is highly dependent on contextual conditions.

A2. Frequency table

The frequency analysis examines how often each actor emerged as a winner (highest score) or loser (lowest score) in each scenario, reflecting the relative effectiveness and vulnerability in different governance contexts. Table A2 summarises these frequencies.

Table A2
Frequency table of winners and losers (win/lose)

Actor	BCL	CCU	DCU	PCL
Consumer Organisation	0/2	0/1	0/1	1/0
Established Business	1/1	2/1	0/1	2/1
NGO	2/1	0/1	1/1	0/1
Policymaker	0/0	2/1	0/0	0/0
SME	1/0	0/0	2/0	0/1

Established Business performed particularly well in the CCU and PCL scenarios, winning twice in each, indicating clear strength in conditions likely to favour large-scale and centralised business strategies. SMEs performed best under decentralised conditions (DCU) with two wins, but also suffered fewer losses overall. Policymakers showed their strongest relative performance in CCU, winning two games. The Consumer Organisation in particular struggled with two losses in the BCL scenario.

Additionally, we estimated the frequency of actions in each round and scenario. Table A3 summarises these frequencies.

Table A3
Frequency table of actions by scenario and round

Action	BCL	CCU	DCU	PCL	R1 Action	R2 Action	R3 Action	Total
Campaign	2 (66.7%; 4.1%)	0 (0.0%; 0.0%)	0 (0.0%; 0.0%)	1 (33.3%; 2.6%)	0 (0.0%; 0.0%)	3 (100.0%; 4.8%)	0 (0.0%; 0.0%)	3 (100%; 1.7%)
Challenge	2 (13.3%; 4.1%)	5 (33.3%; 10.2%)	4 (26.7%; 10.3%)	4 (26.7%; 10.3%)	6 (40.0%; 9.7%)	4 (26.7%; 6.5%)	5 (33.3%; 9.6%)	15 (100%; 8.5%)
Change	0 (0.0%; 0.0%)	0 (0.0%; 0.0%)	1 (50.0%; 2.6%)	1 (50.0%; 2.6%)	1 (50.0%; 1.6%)	1 (50.0%; 1.6%)	0 (0.0%; 0.0%)	2 (100%; 1.1%)
Communicate	0 (0.0%; 0.0%)	0 (0.0%; 0.0%)	1 (33.3%; 2.6%)	2 (66.7%; 5.1%)	2 (66.7%; 3.2%)	1 (33.3%; 1.6%)	0 (0.0%; 0.0%)	3 (100%; 1.7%)
Consult	0 (0.0%; 0.0%)	4 (57.1%; 8.2%)	2 (28.6%; 5.1%)	1 (14.3%; 2.6%)	5 (71.4%; 8.1%)	2 (28.6%; 3.2%)	0 (0.0%; 0.0%)	7 (100%; 4.0%)
Corruption allegation	0 (0.0%; 0.0%)	1 (100.0%; 2.0%)	0 (0.0%; 0.0%)	0 (0.0%; 0.0%)	0 (0.0%; 0.0%)	0 (0.0%; 0.0%)	1 (100.0%; 1.9%)	1 (100%; 0.6%)
Disrupt	0 (0.0%; 0.0%)	0 (0.0%; 0.0%)	1 (100.0%; 2.6%)	0 (0.0%; 0.0%)	0 (0.0%; 0.0%)	0 (0.0%; 0.0%)	1 (100.0%; 1.9%)	1 (100%; 0.6%)
Enjoy	1 (100.0%; 2.0%)	0 (0.0%; 0.0%)	0 (0.0%; 0.0%)	0 (0.0%; 0.0%)	0 (0.0%; 0.0%)	0 (0.0%; 0.0%)	1 (100.0%; 1.9%)	1 (100%; 0.6%)
Exclude	0 (0.0%; 0.0%)	1 (100.0%; 2.0%)	0 (0.0%; 0.0%)	0 (0.0%; 0.0%)	0 (0.0%; 0.0%)	0 (0.0%; 0.0%)	1 (100.0%; 1.9%)	1 (100%; 0.6%)
Improve	1 (25.0%; 2.0%)	1 (25.0%; 2.0%)	0 (0.0%; 0.0%)	2 (50.0%; 5.1%)	0 (0.0%; 0.0%)	1 (25.0%; 1.6%)	3 (75.0%; 5.8%)	4 (100%; 2.3%)
Innovate	7 (33.3%; 14.3%)	3 (14.3%; 6.1%)	6 (28.6%; 15.4%)	5 (23.8%; 12.8%)	13 (61.9%; 21.0%)	4 (19.0%; 6.5%)	4 (19.0%; 7.7%)	21 (100%; 11.9%)
Invest	8 (28.6%; 16.3%)	7 (25.0%; 14.3%)	6 (21.4%; 15.4%)	7 (25.0%; 17.9%)	8 (28.6%; 12.9%)	11 (39.3%; 17.7%)	9 (32.1%; 17.3%)	**28 (100%; 15.9%)**

(*continued on next page*)

Table A3 (*continued*)

Action	BCL	CCU	DCU	PCL	R1 Action	R2 Action	R3 Action	Total
Lead	7 (24.1%; 14.3%)	11 (37.9%; 22.4%)	7 (24.1%; 17.9%)	4 (13.8%; 10.3%)	8 (27.6%; 12.9%)	10 (34.5%; 16.1%)	11 (37.9%; 21.2%)	**29 (100%; 16.5%)**
Legislate	0 (0.0%; 0.0%)	1 (100.0%; 2.0%)	0 (0.0%; 0.0%)	0 (0.0%; 0.0%)	0 (0.0%; 0.0%)	1 (100.0%; 1.6%)	0 (0.0%; 0.0%)	1 (100%; 0.6%)
Mobilise	4 (40.0%; 8.2%)	2 (20.0%; 4.1%)	3 (30.0%; 7.7%)	1 (10.0%; 2.6%)	6 (60.0%; 9.7%)	4 (40.0%; 6.5%)	0 (0.0%; 0.0%)	10 (100%; 5.7%)
Participate	2 (33.3%; 4.1%)	1 (16.7%; 2.0%)	1 (16.7%; 2.6%)	2 (33.3%; 5.1%)	2 (33.3%; 3.2%)	1 (16.7%; 1.6%)	3 (50.0%; 5.8%)	6 (100%; 3.4%)
Partner	6 (40.0%; 12.2%)	5 (33.3%; 10.2%)	2 (13.3%; 5.1%)	2 (13.3%; 5.1%)	3 (20.0%; 4.8%)	6 (40.0%; 9.7%)	6 (40.0%; 11.5%)	**15 (100%; 8.5%)**
Raise awareness	1 (100.0%; 2.0%)	0 (0.0%; 0.0%)	0 (0.0%; 0.0%)	0 (0.0%; 0.0%)	0 (0.0%; 0.0%)	1 (100.0%; 1.6%)	0 (0.0%; 0.0%)	1 (100%; 0.6%)
Reconfigure	2 (28.6%; 4.1%)	3 (42.9%; 6.1%)	1 (14.3%; 2.6%)	1 (14.3%; 2.6%)	1 (14.3%; 1.6%)	3 (42.9%; 4.8%)	3 (42.9%; 5.8%)	7 (100%; 4.0%)
Regionalise	1 (100.0%; 2.0%)	0 (0.0%; 0.0%)	0 (0.0%; 0.0%)	0 (0.0%; 0.0%)	0 (0.0%; 0.0%)	1 (100.0%; 1.6%)	0 (0.0%; 0.0%)	1 (100%; 0.6%)
Regulate	1 (33.3%; 2.0%)	1 (33.3%; 2.0%)	0 (0.0%; 0.0%)	1 (33.3%; 2.6%)	1 (33.3%; 1.6%)	2 (66.7%; 3.2%)	0 (0.0%; 0.0%)	3 (100%; 1.7%)
Scandalise	0 (0.0%; 0.0%)	0 (0.0%; 0.0%)	0 (0.0%; 0.0%)	1 (100.0%; 2.6%)	0 (0.0%; 0.0%)	0 (0.0%; 0.0%)	1 (100.0%; 1.9%)	1 (100%; 0.6%)
Smart lending	1 (100.0%; 2.0%)	0 (0.0%; 0.0%)	0 (0.0%; 0.0%)	0 (0.0%; 0.0%)	1 (100.0%; 1.6%)	0 (0.0%; 0.0%)	0 (0.0%; 0.0%)	1 (100%; 0.6%)
Stabilise	2 (20.0%; 4.1%)	2 (20.0%; 4.1%)	3 (30.0%; 7.7%)	3 (30.0%; 7.7%)	5 (50.0%; 8.1%)	3 (30.0%; 4.8%)	2 (20.0%; 3.8%)	10 (100%; 5.7%)
Transform	1 (25.0%; 2.0%)	1 (25.0%; 2.0%)	1 (25.0%; 2.6%)	1 (25.0%; 2.6%)	0 (0.0%; 0.0%)	3 (75.0%; 4.8%)	1 (25.0%; 1.9%)	4 (100%; 2.3%)
Total	49 (27.8%; 100.0%)	49 (27.8%; 100.0%)	39 (22.2%; 100.0%)	39 (22.2%; 100.0%)	62 (35.2%; 100.0%)	62 (35.2%; 100.0%)	52 (29.5%; 100.0%)	176 (100%; 100.0%)

Table A3 provides additional information on the specific strategies chosen by the players in each scenario and round, and shows important patterns in their strategic choices. It can be observed that certain actions such as 'Invest' and 'Lead' were predominant, illustrating the widespread preference for control and leadership orientated strategies. In contrast, more specific actions such as 'Corruption allegation' or 'Regionalise' were much rarer, suggesting that these particular strategic approaches were only used in very specific contexts. This analysis strengthens the understanding of how different governance configurations and contextual conditions clearly influence the strategies chosen by actors and demonstrates adaptability and strategic decision-making in the face of different scenarios.

A3. χ^2 test

The chi-square test for independence is used to determine whether there is a statistically significant relationship between two categorical variables. In this case, the variables are:

- Actor (Policymakers, SME, Established Business, etc.).
- Scenario (CCU, DCU, PCL, BCL).

The hypothesis of the test is as follows:

- Null hypothesis (H0): Actors' gains are independent of the scenario (i.e. actors gain equally or randomly in each scenario).
- Alternative hypothesis (H1): Gains are scenario-dependent (there are certain actors who tend to gain more in certain scenarios)

Table A4 summarises the results.

Table A4
Chi Square test

Chi^2 statistic	Degrees of freedom	p-value
18.511	12	0.101

The Chi^2 statistic (18.511) measures the difference between the observed frequencies (the generated table of gains) and the expected frequencies if there were no relationship between actor and scenario. A higher value indicates a greater difference (more dependence). The degrees of freedom (12) refer to the number of categories analysed and determine how we interpret the Chi^2 value. The p-value = 0.101 indicates the probability with which these data (or more extreme data) are observed if the null hypothesis (independence) is true. Although there are visible differences in the performance of the actors in the different scenarios, the Chi^2 test shows that we cannot conclude from the current data that these differences are statistically significant ($p = 0.101$). This could indicate

a trend that could be confirmed with a larger sample or a more robust complementary analysis.

A4. Kruskal-Wallis test

The Kruskal-Wallis test is a non-parametric statistical alternative to the traditional analysis of variance. It is used to determine whether there are statistically significant differences in the medians between three or more independent groups (in our case the CCU, DCU, PCL and BCL scenarios).

In contrast to the traditional analysis of variance, which assumes that the data is normally distributed and the variances are homogeneous, the Kruskal-Wallis test is more flexible and is mainly used when these conditions are not met or when the sample size is limited.

The test compares the median scores of the individual actors in different scenarios and thus answers the question: Do the scores achieved by the individual actors depend significantly on the type of scenario? In other words, it assesses whether the scenario significantly influences an actor's performance. Table A5 summarises the results.

Table A5
Kruskal-Wallis test

Actor	Kruskal-Wallis statistic	p-value
Established Business	1.508	0.6805
Policymakers	1.389	0.708
SME	3.184	0.3641
Consumer Organisation	2.393	0.495
NGO	5.144	0.1616

The Kruskal-Wallis statistic measures the extent to which the medians differ between the scenarios; a high value indicates greater differences. The p-value, on the other hand, represents the probability of obtaining such an extreme (or higher) value of the statistic when there are no real differences between the groups. If we take into account that $p \geq 0.05$, we cannot claim that the actors' performance varies according to the scenario (although visual differences can be detected).

A5. Gini coefficient

Analysing the Gini coefficient measures the degree of inequality or concentration of scores between actors within each scenario. A Gini coefficient ranges from 0 to 1, where:

- 0 represents perfect equality, i.e. all actors have the same score.
- 1 stands for maximum inequality, i.e. one actor has all the points and the others have none.

This analysis helps us to understand whether certain scenarios lead to more or less equitable outcomes among the participating actors, reflecting the differences in power dynamics and resource distribution in these contexts. The results are summarised in Table A6.

Table A6
Gini coefficient values for each scenario

Scenario	Mean Gini	Std Gini	Min Gini	Max Gini
BCL	0.0715	0.043278	0.029	0.131
CCU	0.1465	0.070449	0.045	0.204
DCU	0.085333	0.068966	0.026	0.161
PCL	0.088333	0.015308	0.071	0.1

These results indicate that the CCU scenarios produced the greatest inequality between actors, reflecting the centralisation and concentration of power or resources, while the BCL scenarios led to the most balanced outcomes. The DCU and PCL scenarios produced a medium level of inequality, suggesting that these structures allow for some differentiation between actors but are still relatively equitable. These results reinforce the idea that governance structures have a significant impact on equity and the distribution of actors' agency.

A6. Spearman correlation

This analysis examines the relationship between the frequency of the actions performed by the actors and their average final score. The Spearman correlation coefficient (Spearman's rho, ρ) evaluates how strongly certain actions correlate with success, measured by the average scores of the actors. A positive and significant Spearman's rho indicates that more frequent use of an action is associated with a higher final score, while a negative value indicates that frequent use of the action is associated with a lower score. Table A7

summarises these correlations clearly.

Table A7
correlation analysis (Spearman) between the frequency of each action and the final average scores obtained by the actors

Action	Spearman Rho	p-value
Campaign	-0.354	0.5594
Challenge	-0.158	0.7995
Change	-0.354	0.5594
Communicate	-0.707	0.1817
Consult	-0.894	0.0405
Corruption allegation	-0.707	0.1817
Disrupt	-0.354	0.5594
Enjoy	-0.354	0.5594
Exclude	0	1
Improve	0	1
Innovate	0.9	0.0374
Invest	0.9	0.0374
Lead	-0.2	0.7471
Legislate	0.354	0.5594
Mobilise	-0.527	0.3615
Participate	-0.354	0.5594
Partner	0.474	0.4195
Raise awareness	-0.707	0.1817
Reconfigure	0	1
Regionalise	-0.354	0.5594
Regulate	0.354	0.5594
Scandalise	-0.707	0.1817
Smart lending	0	1
Stabilise	0.289	0.6376
Transform	0.707	0.1817

Based on these results, we find clearly significant correlations for the actions "Innovate" ($\rho = 0.900$, $p = 0.0374$) and "Invest" ($\rho = 0.900$, $p = 0.0374$), indicating a strong positive correlation with higher scores. This suggests that actors who frequently chose to innovate or invest generally achieved better results, highlighting these actions as effective success strategies. Conversely, the action "Consult" shows a significant negative correlation ($\rho = -0.894$, $p = 0.0405$), suggesting that the frequent use of consultation as a strategy may have been less effective in achieving higher scores.

Most other actions did not show significant correlations, meaning that their frequency alone did not have a clear or statistically significant impact on the final performance of the actors. This result suggests a more nuanced interpretation, where the effectiveness of many actions may depend on specific contextual conditions or combinations with other strategies, rather than their mere frequency of use.

A7. Hierarchical clustering analysis

Hierarchical clustering is a statistical method used to group observations based on their similarity. In this study, we performed hierarchical cluster analysis in two different ways to gain deeper insights into the strategic behaviour of actors and their success in different scenarios. Results are summarised in Fig. A1.

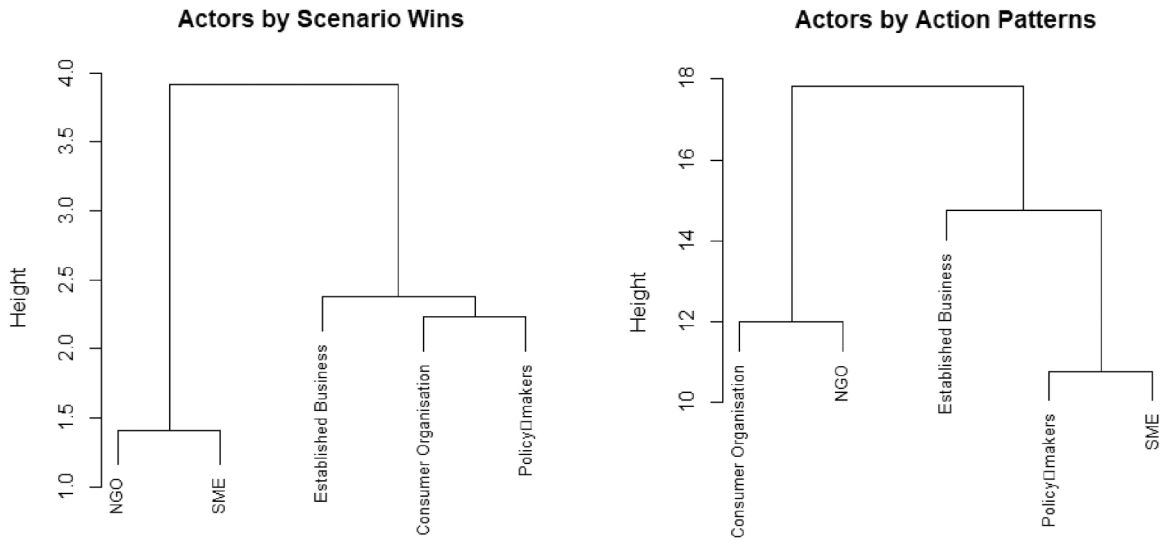


Fig. A1. Hierarchical clustering of actors according to (left) scenario wins and (right) patterns of action

First, we analysed the actors based on their scenario wins (frequency with which they achieved the highest score in different scenarios). Results clearly show this analysis and reveals two main clusters. One cluster includes SMEs and NGOs, indicating a similar pattern of wins across scenarios and possibly reflecting a common strength in certain contexts. The second cluster includes Established Business, Consumer Organisation, and Policymaker, suggesting that these actors have more comparable profit patterns in the scenarios analysed.

Secondly, we clustered the actors according to their patterns of behaviour during the rounds. This analysis revealed different clusters compared to the clustering based on wins. Consumer Organisation and NGO formed a separate cluster, indicating very similar strategic approaches in their choice of actions, possibly focusing on advocacy, awareness-raising or campaigning. Established Business formed a separate cluster, reflecting a unique pattern of action, probably centred on traditional or market-oriented strategies. Policymaker and SMEs formed the third cluster, suggesting similarities in their strategic actions, possibly centred on investment, innovation or partnerships.

The results of the clustering clearly show that the actors pursue different strategic profiles, which differ depending on the context (scenario wins) and decisions to act. This emphasises the complexity of strategy formulation in circular economy scenarios and indicates that actors adapt their approaches to contextual conditions and objectives.

A8. Multidimensional correlation analysis

A multidimensional correlation analysis was conducted using a multiple linear regression model to determine the specific contributions of the key factors to the actors' final scores. The analysis included four explanatory variables: the resources invested by the actors themselves, the collaboration received from other actors, the resources given to others as part of the collaboration and the support received from Public Opinion. This analysis enabled a nuanced understanding of the relative importance and influence of each component in shaping the final outcomes.

Table A9 summarises the results clearly. The coefficients represent the estimated change in final outcomes for each additional unit of the corresponding factor, holding all other variables constant. The associated p-values and confidence intervals indicate the statistical significance and reliability of each estimate.

Table A9
Multidimensional correlation analysis

	Coefficient	Std Error	t	p-value	CI Lower 95%	CI Upper 95%
Constant	-11.1954	7.131716	-1.56981	0.121995	-25.4764	3.085588
Own resources	1.24978	0.630081	1.983522	0.052133	-0.01194	2.511496
Collaboration from others	2.096433	0.317768	6.597359	1.49E-08	1.460112	2.732753
Collaboration to others	1.94694	0.663635	2.933752	0.004817	0.618034	3.275845
Public Opinion	3.33853	0.287627	11.60714	1.21E-16	2.762566	3.914494

The analysis shows that support from Public Opinion has the clearest and highly significant positive effect on actors' final scores, with each additional unit of support from Public Opinion associated with an average increase of approximately 3.34 points ($p < 0.001$). Collaboration received from others also shows a clearly significant and positive contribution, increasing the final score by approximately 2.10 points per additional resource received ($p < 0.001$). Resources provided to others as part of the collaboration also

have a significant positive effect, contributing around 1.95 additional points per resource ($p < 0.01$).

In contrast, resources invested by the actors themselves have a positive but only marginally significant effect ($p = 0.0521$), indicating a possible but less clear contribution to the final score compared to the other factors. The constant term was not statistically significant, which means that the initial value cannot be meaningfully interpreted without taking into account the use of resources and support.

Data availability

Data will be made available on request.

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