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ORIGINAL ARTICLE

The CiFoS game: a serious game to redesign food systems for human and planetary health

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Abstract
Food systems are exceeding planetary boundaries and endanger both human and planetary health. Transforming these systems requires stakeholder engagement and constructive dialogue for acknowledging the diversity of views and values from different actors within the food system. Serious games have proven effective in fostering collaboration and exploring social-ecological dynamics, yet a holistic food system game linking planetary and human health remains absent. This paper presents the CiFoS Game, a serious game designed to explore food system transformation strategies, showing both the individual and collective impacts of diets, production choices and circularity principles on environment and human health. Co-designed with university students, food system experts, and game designers, the game was tested in multiple pilot sessions in different contexts. Throughout its development, multiple dynamics were added in a step-by-step process to enhance complexity, while improving and aligning already existing dynamics along the way. Results highlight its potential to facilitate learning and support discussions, connecting dietary and production choices to food sustainability challenges. By engaging stakeholders in interactive explorations of food system transformations, the CiFoS game can serve as a boundary crossing tool to foster dialogue, create common understanding and support collaboration towards sustainable food futures for human and planetary health.

Keywords Food systems · Transformation · Serious game · Dialogue · Game design

Introduction

Today's agri-food system has a significant and wide-ranging impact on the planet's well-being, with six of the nine planetary boundaries already being transgressed, increasing the risk of large-scale, irreversible environmental changes (Rockström et al. 2023). It is responsible for 1/3 of global greenhouse gas emissions (GHGe) (Crippa et al. 2021); it is a major contributor to aquatic and terrestrial pollution (Leip et al. 2023); it uses 45% of habitable land for agriculture, of which 80% is used to grow livestock feed (Ritchie and Roser 2024); and agriculture is simultaneously one of the biggest drivers of biodiversity decline (Benton et al. 2021). These impacts are mainly a consequence of current production practices and consumption patterns (Ritchie et al. 2022; Willett et al. 2019). European agriculture, for example, is largely characterized by industrial and resource-intensive practices, such as the usage of synthetic fertilizers, pesticides, intensive technologies (e.g., heavy machinery), and its dependence on fossil fuels (EEA 2023). When looking at

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current consumption patterns, European diets are relatively high in animal products, sugars, salt, fat, and calories, while low in whole-grain products, fruits, vegetables, legumes, and nuts (European Commission 2020). Producing these diets is not only unsustainable but its consumption is also unhealthy, which contributes to major public health issues, including obesity, cardiovascular diseases and type II diabetes (EEA 2023; WHO 2022). However, if action is taken now, a more livable future for both humans and the planet can still be achieved (Webb et al. 2020; McGreevy et al. 2022; van Zanten et al. 2025). Transforming our food systems is therefore key, and requires a whole of society and governance approach that includes supply- and demand-side, as well as governance measures, due to the strong interlinkages and complexity of the system (Herrero et al. 2021; Rosenzweig et al. 2020; Springmann et al. 2018). An example of a more systemic solution is the transition towards a circular food system (van Zanten et al. 2023), which also forms one of the key European Union sustainable food system strategies (European Commission 2020).

Working towards more sustainable and healthy food systems requires fostering dialogue with multiple stakeholders in the face of polarized future visions and strategies, acknowledging both consensus and frictions (Kalibata and Nabarro 2024; Caron 2025). Serious games have shown great potential for exploring and redesigning social-ecological systems, fostering learning, developing scenarios, linking multiple stakeholders, sharing underlying values, challenging assumptions, and stimulating dialogue (Mangnus et al. 2019; Garcia et al. 2022; McGreevy et al. 2022; Juri et al. 2025). By playing serious games, stakeholders can gain a hands-on understanding of some of the key dynamics of the system, enabling them to explore its complexities and related trade-offs and synergies at varying spatial and temporal scales (Dernat et al. 2025; Foppe and von Wehrden 2025). Several games have been successfully developed to explore transdisciplinary collaboration (Salliou et al. 2021); environmental impacts (Mangnus et al. 2019), change farming systems (Dernat et al. 2023), and to promote sufficient and sustainable diets (Mazac et al. 2025). However, to the best of our knowledge no food system game has been developed yet that holistically combines planetary and human health (Hordijk et al. 2025).

In this paper, we attempt to fill this gap by presenting the design and validation processes of the CiFoS game, highlighting how this game explores food system complexity, facilitates a discussion of circular principles and how it can contribute to more sustainable food systems. For more information about the game and data availability please contact the first author.

Methods

This section describes the CiFoS game and its design process (Figs. 1 and 3). First, a description of the final game is given, including its objectives and an explanation of gameplay. This is followed by the game design process, which took place over the course of one year (2024–2025) in three steps: development of the game concept (step zero), quantification of its main components (step one), and enhancing complexity by adding more dynamics (step two). Throughout this process, multiple prototypes were developed and tested before finalizing the CiFoS game.

The first prototype with the main components was tested on two occasions: during the MSc course "Redesigning global farming and food systems" at Wageningen University, The Netherlands, in March 2024, and at the Global Food Security conference in Leuven, Belgium, in April 2024. This same prototype with the addition of the circularity and dairy-beef dynamic was tested with food systems experts at Wageningen University in April 2024. Pilot sessions with the second prototype where biodiversity was added were conducted on two occasions at Cornell University in Ithaca, USA, in May 2024. The first one was done with food system experts from Food Systems & Global Change at the Department of Global Development. For the second session, we organized a workshop called 'Navigating food systems within planetary boundaries', which served as an open invitation for anyone interested in this topic. Besides the involvement of participants from various backgrounds and disciplines in the pilot sessions, we also consistently collaborated with game designers during the development of the game.

The CiFoS game

The CiFoS game has been finalized in September 2024 (Fig. 1). One game session takes approximately 1.5–2 h, including an introductory explanation (briefing), gameplay and a debriefing. Each game session consists of five rounds, with each round following a structured game loop. It can be played with four to eight people and requires at least two facilitators.

The game aims to support dialogue on food system transformation for human and planetary health, involving diverse stakeholders, such as current and future decision makers in multiple contexts, and to jointly explore food system transformation strategies. In the game, participants get to explore both the individual and collective impacts of various diets and agricultural production choices (e.g., type of food and/or feed crops of food and/or feed, usage of byproducts and manure, spatial placement) on land use, GHGe, biodiversity, and on circularity principles, and consider the scarcity

Fig. 1 Components overview of the CiFoS game including the board representing land-use, two side-boxes representing greenhouse gas emissions, red-team tokens (food group tiles, avatars, feed cubes, and mission, environmental impact and health cards, biodiversity tokens, rounds card, hint cards, circularity tokens, and a hourglass)

of resources. It therewith reveals synergies and trade-offs between multiple environmental and health outcomes, highlighting potential challenges and opportunities to food system transformation. The CiFoS game therefore, functions as a dialogue tool, illustrating potential consequences of food system changes, and contributing to a shared understanding necessary forbuilding consensus towards sustainable futures.

CiFoS gameplay

The game session starts with a narrative to set the scene, sharing the overall objective with the participants. Players are thereafter first invited to design their own dietary mission, which is composed of various food groups (Fig. 2). This mission can represent their vision of a sustainable food system, or the changes that they are willing to make in their diet to achieve this. The exact framing can be adjusted based on the aim of the workshop and its participants. Following the explanation of gameplay, players need to produce this diet on the shared but limited arable and grassland present on the gameboard (i.e. production phase). The produced items can be checked off in the mission card (i.e. harvest phase), but their collective production affects biodiversity and results in GHGe, which will accumulate over the course of the game (i.e. environmental impact phase). The actions of the players can also unlock various tokens, such as manure and byproducts, which can be reused in the system and thereby reduce some environmental impacts. This way, players are given different strategies that can be applied to fulfil their dietary mission, while respecting the planetary boundaries. As some of the dynamics are yet unknown to the players, hint cards are used to reveal these throughout the course of the game. The game ends either when everyone has fulfilled their dietary mission and successfully stayed within the planetary boundaries or when the planetary boundaries have been transgressed at the cost of fulfilling the dietary mission. When either one of these events has occurred, the final step is to reflect on the healthiness of the developed diets, based on European food-based

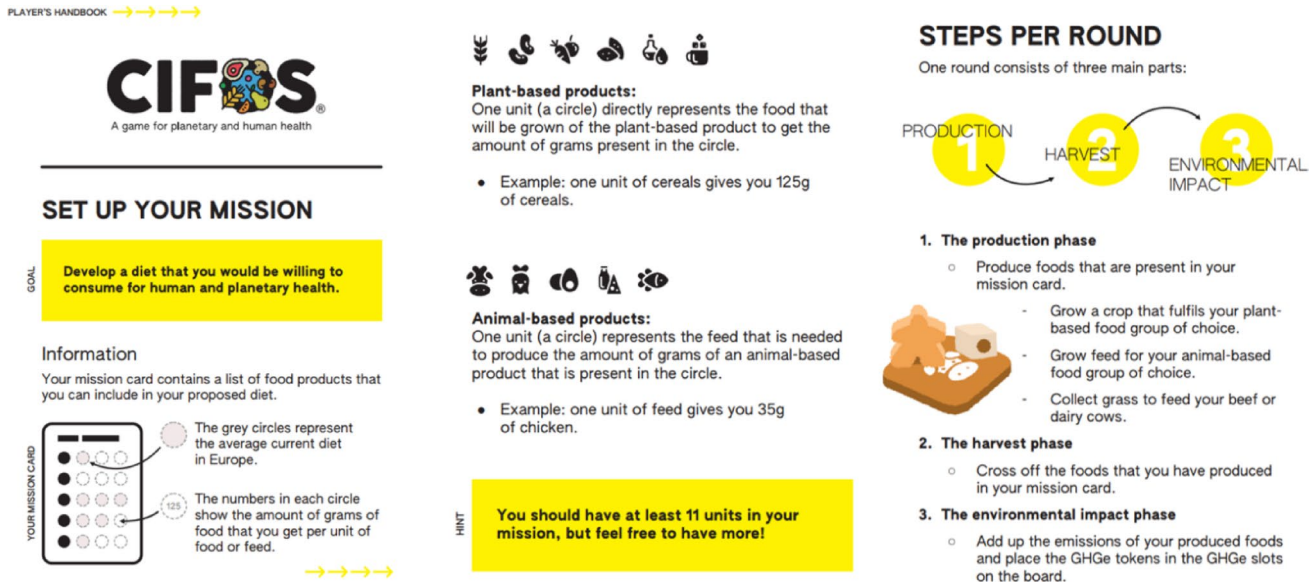

Fig. 2 CiFoS players' handbook indicating how to fill the mission cards and the three steps per game round: production, harvest, and environmental impact

dietary guidelines statements. Gameplay is followed by a debriefing, which has a predetermined format, but could be adjusted based on the preferences and time availability of participants. It starts with a collective reflection on the game session and its outcomes, and is followed by an exercise that dives into other strategies that participants may envision in a future food system beyond the game.

Game design process

Development of the initial game concept (step zero)

An initial game design concept was developed during a three-day workshop in Switzerland with a team of food systems experts from different disciplines (e.g. environmental sciences, human nutrition, agriculture, modelling, and social sciences), including a part of the co-authors. Here, we adapted the Companion Modelling approach (Barreteau et al. 2013), integrating it with elements from the ARDI (Actions, Resources, Dynamics, Interactions) method (Etienne et al. 2011) and the "Thinking with Things" methodology (Lockton et al. 2020), to develop the game. Following up this approach, we co-designed the game in an iterative process, integrating feedback from players, designers, and experts, identifying objectives, system dynamics, game components, and target group. During the workshop, we first determined the game's objectives, target group and system boundaries: to support evidence-based discussions on food system transformation for human and planetary health for current and future decision-makers in the European context. Furthermore, we co-designed a conceptual representation of the food system, capturing key actors, resources, dynamics, trade-offs, and synergies, and translated these into game components and mechanics. During the workshops, the CiFoS model EU27+UK served as a conceptual model (van Zanten et al. 2023) to support game components and mechanics choice and quantification. We focused on the CiFoS model as it is based on a food systems approach and includes sustainable principles such as circularity. These elements were then translated into material elements as board-game tokens, further developing the conceptual model and highlighting the most important components. A key consideration was the level of detail required to ensure the game would be both engaging and practically useful. Given these considerations, the main components to be included in the game were from the production side, the types of food and feed crops, the type of animal systems and fertilisers, and from the consumption side, the food groups and the dietary requirements. For the environmental impact categories, land availability, GHGe, and biodiversity were selected, and circularity was included as an additional strategy to work towards a sustainable food system. As the inclusion of all components simultaneously was rather ambitious and it was yet uncertain how complex the game could be, we followed a step-by-step process during which different prototypes were developed. Besides the companion modelling and systems thinking approaches, we integrated the principles of food system dialogue into the design and implementation of the game. As highlighted by Kalibata and Nabarro (2024), food systems dialogue is understood as an inclusive and deliberative process based on open exchange, the exploration of options, debate around

priorities, and the examination of trade-offs, with the intention that all stakeholders can contribute to shaping future food systems. These principles are embedded in the game mechanics and components through diverse perspectives, structured interactions, and decision points that require negotiation and collective reflection.

Development of the first game dynamics (step one)

The (quantified) dynamics for the CiFoS game were developed between January and August 2024 (Fig. 3), initially informed by the CiFoS model and further validated by literature. The pilot sessions served as an additional validation moment, aiming to obtain feedback on the accuracies of the (newly added) dynamics and (changed) game components, while also gaining insights on the game's design and its overall gameplay. The feedback was collected via guided discussions that followed after gameplay, recordings of the pilot sessions, and photographs of game results.

Prototype 1: Food, feed, land use and greenhouse gas emissions In the first prototype, we developed the baseline for the game by quantifying the food groups in four different diets, as well as the GHGe and land use impacts of the production of crops and animals corresponding to these food groups. The development of each of these components is described in detail below. Although they are mentioned separately, they were developed simultaneously due to their strong interlinkages.

Consumption: food groups The four diets that were developed in the game are the average current European diet, the EAT-Lancet diet, a vegetarian diet and a vegan diet.

For each daily diet, a mission card was developed (Fig. 4), in which eleven (aggregated) food groups were included: red meat, chicken, fish, dairy, eggs, oil & fat, legumes & nuts, fruits & vegetables, tubers, cereals, and sugar & beverages. We aimed to include as many food groups as possible to enable dietary diversity and proper representation of diets, without overcomplicating the game. The current average European diet was developed as initial baseline to illustrate what the environmental impacts are of producing food in line with current consumption practices. The other diets were developed to further calibrate game data (e.g., food group units and environmental impact categories), while also serving as dietary examples in line with healthy recommendations that could simultaneously benefit the environment. For the current European diet, the quantities were based on the baseline diet used in the CiFoS EU27+UK model (van Zanten et al. 2023). The quantities

Fig. 3 CiFoS game development process showcasing prototype 1 (development main components: food, feed, GHGe, land use, circularity and dairy-beef mechanics and tokens), prototype 2 (addition of biodiversity mechanics and changed mission cards), and the final game (addition of human health component and hint cards)

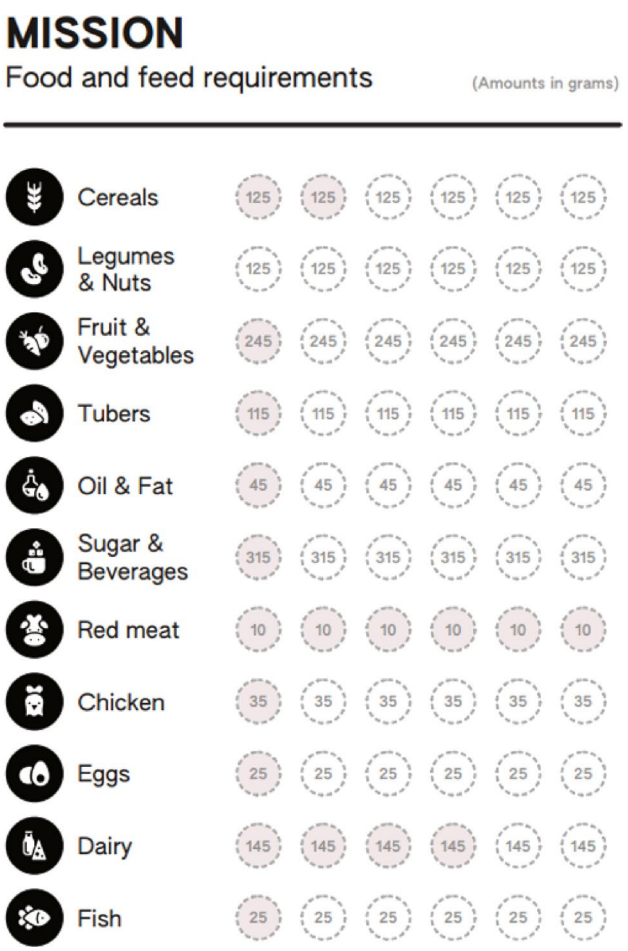

Fig. 4 CiFoS game dietary mission card, showing the different food groups used in the game and an indication of daily intake in grams within the circle; red circle indicates the current diet

of the EAT-Lancet diet were directly derived from the set recommendations (Willett et al. 2019). For the vegetarian and vegan diet we started with their approximate composition to get an initial idea (Springmann et al. 2021), but final diets in the game were aligned to the EAT-Lancet diet, while adhering to their inherent requirements (i.e., no meat and fish for the vegetarian diet, and only plant-based products for the vegan diet). The mission cards were developed in such a way that the number of units per food group represented the consumed amounts per diet, while simultaneously resulting in their respective environmental impacts.

These dietary mission cards were only actively used in the first prototype. In the second prototype and the final game, we created empty mission cards, meaning that participants could develop their own diet and see how this would play out in terms of environmental impacts (Fig. 3). This change shifted the game's dynamics from players passively trying to produce preset diets to actively challenging themselves to produce bespoke diets that will not transgress planetary boundaries. It resolved a core challenge in our main gameplay loop, moving the experience away from a linear simulation and towards a more dynamic, unpredictable process where players' choices mattered more.

Production: food & feed The crops and animal systems that could be produced in the game directly correspond to the food groups, with one exception: for red meat, the animal system that needed to be produced was beef. Their production is required to fulfil the food group units in the dietary mission card. There are however differences in the way plant- and animal-based products are obtained in the game. Plant-based foods could be obtained by directly producing their corresponding crop. For example, when one wants to receive a unit of cereals, a cereal token is placed on an empty plot of land to indicate its production, and this directly results in the cereal food group that can be crossed off in the mission card. Animal-based production requires first producing the respective animal feed. For example, to produce a unit of chicken, a feed token needs to be placed on an empty plot of land together with a chicken token. This allows the game to simulate the substantial share of land use that is required for feed production (EuroStat 2023; Ritchie and Roser 2024).

The initial feed options that could be selected in the game are grass, cereals, and legumes. The amount of grass tokens on the board is based on current European grassland (Eurostat 2023) and can be claimed by players to feed ruminant animals. While grass is a shared resource among players and finite, cereals and legumes are provided to players individually and could be used unlimitedly.

Environmental impact: Land use The total land use plots in the game were visualized on the game board based on the total land needed to produce the current diet, while also illustrating the division of agricultural land in Europe: 157.4 million ha is used for agricultural production, of which 98.1 million ha is used for arable land, 48.0 million ha for permanent grassland and 11.1 million ha for permanent crops (Eurostat 2023). Therefore, approximately 1/3 of the total land plots are assigned to grassland (Schils et al. 2022). To determine land use of the different diets, we used the results of the CiFoS model, which were further verified with evidence from the literature. For the average current European diet, approximately 2/3 of its land use is related to the production of animal foods (Clark et al. 2019; Kyttä et al. 2023; Mertens et al. 2019; Poore and Nemecek 2018), which is roughly in line with the share of animal-based products in the diet (FAOSTAT 2024). For the EAT-Lancet, the vegetarian, and the vegan diet, we explored to what extent land use approximately could be reduced when transitioning from the current to any of these diets (Aleksandrowicz et al. 2016; Fresán and Sabaté, 2019; Hallström et al. 2015; Kesse-Guyot et al. 2021; Laine et al. 2021; Springmann et al. 2020). The land use per diet is in the game also directly

related to the number of food group units in the dietary mission cards, as the production of one unit of a food group is done via the production of its corresponding crop or animal system on one plot of land. Additionally, land use differs highly between the types of foods produced. In general, plant-based products are less land-intensive than animal products, and there can be substantial differences in land-use efficiency across different animal production systems. The CiFoS game captures some of this heterogeneity by making a distinction per food group regarding the amount of product that is obtained per plot of land. Recognizing for example that ruminant (beef) production is less efficient (i.e. required more feed to produce) than poultry production, the amount of grams that is obtained per unit of land for the diet is less for red meat compared to chicken.

Environmental impact: Greenhouse gas emissions The GHGe were visualised in two ways in the game: The emissions per food group unit were presented in the environmental impact card (Fig. 5), while the accumulated impacts of production and consumption choices were shown on the game board. The numbers in the environmental impact card

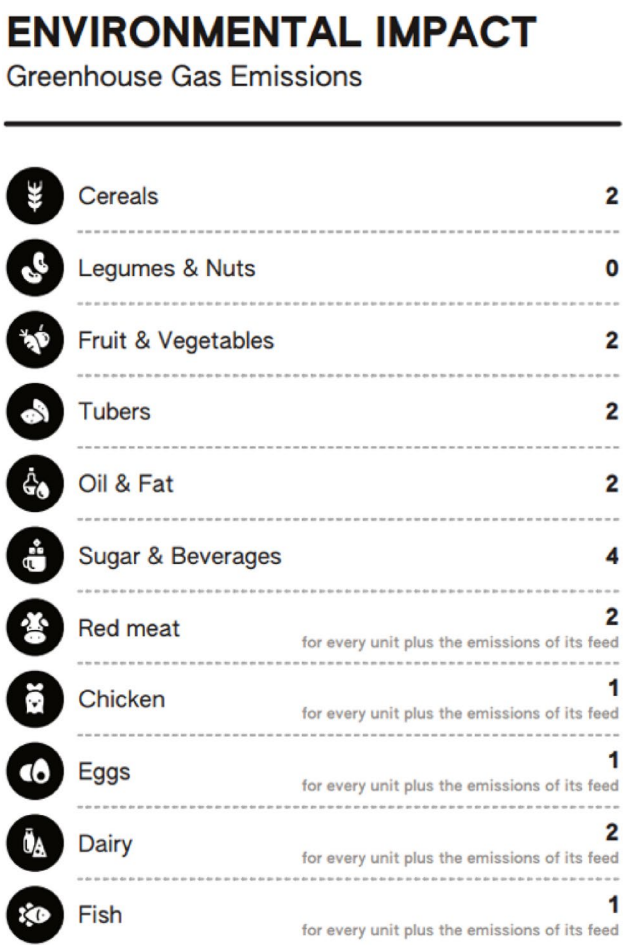

Fig. 5 CiFoS game environmental impact card, highlighting the environmental impact of each food group, measured in GHGe tokens

were developed in such a way that the differences in impacts within and between animal- and plant-based food products were clearly shown (Poore and Nemecek 2018), while also being simple enough for gameplay. In general, this resulted in most plant-based food groups having similar GHGe, with two exceptions. The emissions of the legumes & nuts group were lower due to their ability to fixate nitrogen, and the sugar & beverages group had higher emissions due to the large number of items that is covered in this category and the inclusion of some high-impact products (e.g., coffee, tea, chocolate). Although there are still some distinctions in GHGe arising from plant-based products, this nuance could not be fully captured due to simplification of results for gameplay. When considering the animal systems, their total emissions consisted of two components: The GHGe that arise from feed production, and the emissions that result from other aspects related to animal production, such as manure management and in case of ruminant livestock enteric fermentation. Given the relatively large share of enteric fermentation in total GHGe (Poore and Nemecek 2018), the environmental impact card has higher additional emissions for ruminant livestock. Differences between food groups were also indirectly visualised by providing lower quantities per food group unit for higher impact foods, therewith also resulting in higher net impacts from their consumption.

When accumulating the GHGe for all food group units present in the dietary mission cards, the total GHGe that arise per diet should be in line with what is being found in literature when optimally using feed tokens. For the current European diet, this meant that animal-sourced foods should have a share of about 2/3 in total GHGe (Clark et al. 2019; Kyttä et al. 2023; Mertens et al. 2019; Poore & Nemecek 2018). For the other diets, we aimed to have the total GHGe 40–55% lower for the EAT-Lancet diet, 35–30% lower for the vegetarian diet, and 40–50% lower for the vegan diet compared to the current European diet (Aleksandrowicz et al. 2016; Fresán and Sabaté, 2019; Hallström et al. 2015; Kesse-Guyot et al. 2021; Laine et al. 2021; Springmann et al. 2020; Sun et al. 2022). The boundary for GHGe in the game is set based on the EAT-Lancet diet, which diet is considered to respect the planetary boundaries while being nutritionally adequate (Willett et al. 2019).

Adding complexity by including more dynamics

Prototype 1: Circularity and dairy-beef interaction To enhance complexity, two new dynamics were included in the game: Circularity principles and dairy-associated beef production.In a circular food system, waste is minimized and if produced, reused in the most optimal way (Muscat et al. 2021; van Zanten et al. 2023). Examples include the reusage

of byproducts, manure and human excreta as fertilizer, and the elimination of food waste and overconsumption. Some of these circularity principles have been included if it was possible to align them with the food system components present in the game. This holds true for reusage of byproducts and manure, though consumption changes are also covered in the dietary mission cards. Byproducts are unlocked in the game after the production of plant-based units for human consumption, whereas manure is unlocked after the production of ruminant livestock units. The number of circularity tokens that could be obtained was calibrated based on the four example diets described above. This means that the current European diet had the highest number of manure tokens due to the large consumption of red meat and dairy. The EAT-lancet diet and the vegetarian diet still had some manure as well, and the byproduct tokens obtained were higher compared to the current diet due to higher consumption of plant-based products. The vegan diet received the highest amount of byproducts as the diet is solely composed of products derived from non-animal origin. These tokens could be reused as feed and/or fertilizer to reduce GHGe, where the usage of byproducts as feed could additionally save up land.

Another dynamic that was introduced together with circularity was the dairy-beef mechanic. This aimed to illustrate that dairy consumption simultaneously results in the production of red meat, despite it potentially not being incorporated in the diet. This mechanic was calibrated based on the number of dairy units in the four example diets, making a distinction in the number of calves that were received based on the total quantity of dairy that is produced. A calf token could be reused in the game to fulfil red meat requirements if present.

Based on the number of tokens obtained in the four example diets, a matrix was created that was used to count the number of circularity and calf tokens that could be obtained per player when playing with the empty mission cards.

Prototype 2: Biodiversity When we concluded that the circularity and dairy-beef dynamics functioned accordingly, we included a new dynamic: Biodiversity. This dynamic was initially based on literature (Benton et al. 2021) and later on further developed based on expert opinion. Inclusion of biodiversity is highly important given the fact that the food system is a major driver of biodiversity loss. Exact quantification of this dynamic was however rather challenging due to the uncertainty in the magnitude of biodiversity effects as a consequence of specific actions or events. Therefore, emphasis was more on illustrating the overall impacts, i.e., whether some practices or conditions that are present in the game could improve biodiversity or lead to its decline. This led us to include monocultures and climate change (i.e., GHGe threshold) as elements that reduce biodiversity, while the usage of circularity tokens or the conversion of agricultural land to nature increases biodiversity. In future adaptations or extensions of the game, more biodiversity components could be included or the existing ones could be adjusted, depending on how the game is altered.

Final game: Human health & debriefing For the final game, one last mechanism was added to reflect the healthiness of the diets developed by the players: the human health dynamic. It consisted of a health card with ten empty slots, representing the number of points that could be collected. These points could be obtained when adhering to health statements developed based on overall recommendations of country-specific food-based dietary guidelines in Europe (European Commission 2024). An example of such a statement is to include at least two units of fruits and vegetables in the diet. For some statements, there were also different conditions that determined whether a point was received based on the diet that was chosen. For example, when including fish and meat in the diet, legumes can be lower than when having a vegetarian or a vegan diet, with the latter having higher requirements than the vegetarian diet.

Finally, as an essential part of conducting a serious game session is to have a debriefing following gameplay (Crookall 2014; Daré et al. 2020), we developed a debriefing which is guided by a facilitator and first reflects on the overall game session by addressing the following questions:

- How do the participants feel about the outcomes of the game session? This first question explores participants' initial emotional responses, such as satisfaction or frustration, focusing on their feelings rather than immediately diving into the strategies they adopted.
- What were the key dynamics and mechanics observed during the session? This second question invites participants to reflect on the trade-offs and synergies of the game, including the game mechanics and system dynamics they experienced.
- What are the key takeaways, and how can they inform future actions or adaptations? The final question focuses on potential lessons learned, follow-up activities, and how the session's outcomes might inform future sessions or lead to adaptations or improvements of the game.

The second part focuses on additional strategies that participants deem to be important for a sustainable food future, therewith supporting a holistic dialogue on food system transformation. Participants can liberate their imagination and are given the opportunity to create their ideal food system, while not only being limited by the strategies covered in the game. The debriefing could however also be adjusted based on preferences and time availability of participants,

for example by including a backcasting exercise (Andreotti et al. 2020; Juri et al. 2025) for the development of transition pathways based on the outcomes of the game.

Results

This section describes one of the first sessions held with the final version of the CiFoS game at FiBL (Research Institute of Organic Agriculture) in October 2024 in Switzerland, illustrating the decisions that were made and the potential results that can be obtained by its application. The research participants gave their informed consent to participate in this study before data collection. The game was played with seven food system experts, who approached the game with a strong sustainability focus. Throughout the session, the players redesigned the food system based on plant-based diets principles, with an emphasis on biodiversity preservation (Fig. 6).

Outcomes gameplay

At the end of the game session, the game board allows to visualize the final food system redesign, showing the total GHGe, land use plots, and biodiversity tokens, as well as the production choices that are made (such as the use of circularity tokens and types of feed). Final dietary choices are shown in the mission card. Results of the session are composed of both quantitative and qualitive data, where the quantitative aspects of both the board and mission cards are presented in visualizations that are designed to be accompanied with the game (Figs. 7 and 8). These visualizations can be adapted and reused for presentation of future game session outcomes (in the appendix we provide an example print play version of the board for representing the spatial configuration and players strategies).

As complementary to these visualizations, we invite future users of the CiFoS game to conduct thematic analysis on the dialogue happening before, during and after the game session, comparing different strategies or reflections within one session or comparing multiple sessions. Thematic

Fig. 6 Game session with the final version of the CiFoS game at FiBL, Switzerland on 24/10/24

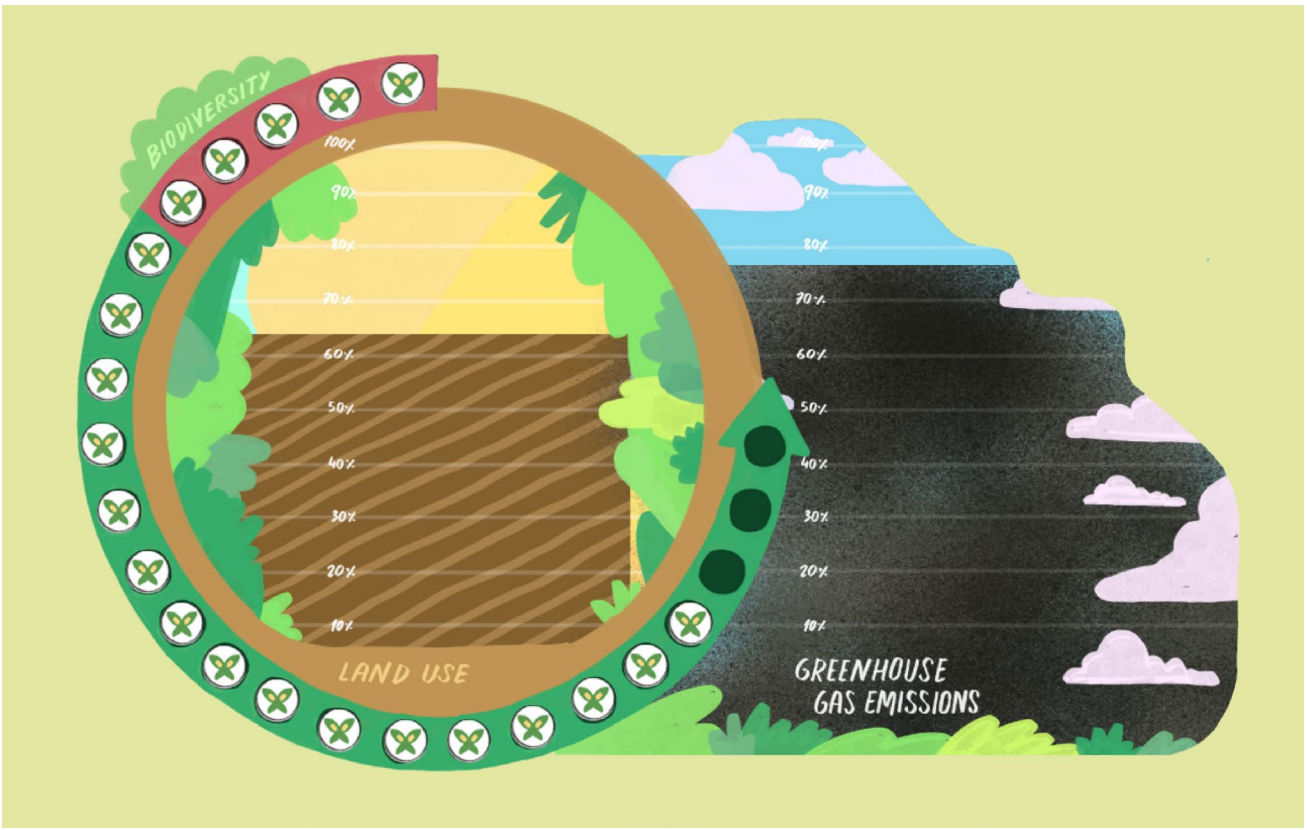

Fig. 7 Illustration of the outcomes from the final board configuration highlighting biodiversity (Total number of biodiversity tokens collected), land use (%) and GHGe (%)

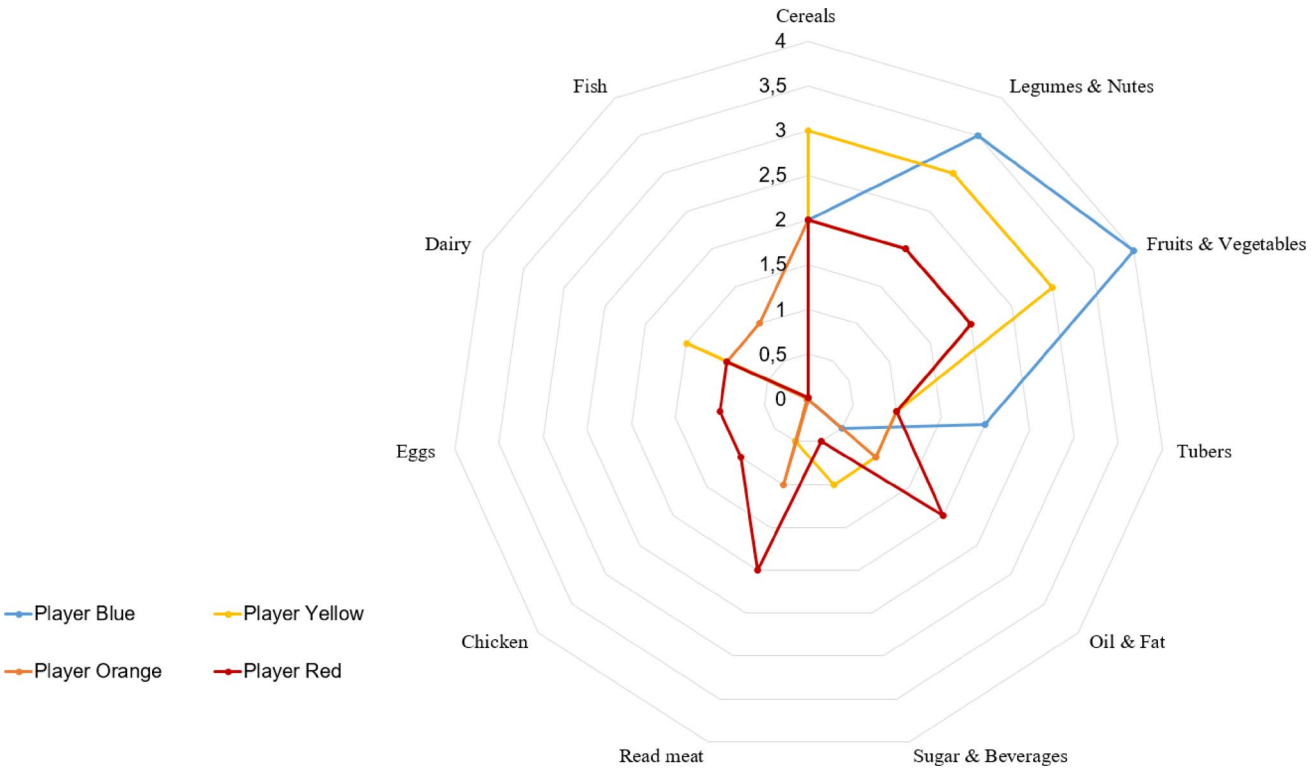

Fig. 8 Radar diagram showing the outcomes from the mission cards indicating each player's food choices

analysis can follow frameworks such as food system components or, learning frameworks, such as food system literacy or boundary-crossing learning. Besides conducting a thematic analysis, other suggestions include the usage of pre- and post-surveys to assess the effects of the game, potentially in line with existing frameworks as mentioned before.

In the game session at FiBL, participants highly increased biodiversity, obtaining 21 biodiversity tokens compared to the starting point of five; used only 49 out of the total 76 plots representing land-use; and managed to stay within the planetary boundary of GHGe, having a total of 75 out of a maximum of 96 emissions tokens (Fig. 7). These outcomes were possible, as participants made limited use of monocultures and actively introduced natural areas, enhancing biodiversity. Circularity tokens were fully utilized, with teams favoring more sustainable feed contributing to the positive environmental outcomes. Planetary health was amongst others achieved due to their choice for diverse sustainable diets, in which the consumption of meat was limited as much as possible. The reduction of red meat also helped in making the diet beneficial for human health, besides the increase in fruits and vegetables, legumes, and reduction of sugar and beverages compared to current consumption practices (Fig. 8).

Outcomes debriefing

After gameplay, we facilitated a debriefing discussing the outcomes of the game exploring individual and collective feelings, strategies and take-home messages. The participants were enthusiastic about the session, found the game inspiring and engaging, appreciating its depth, and the level of complexity, which felt appropriate for exploring real-world food system challenges. For instance:

> *"The game was designed and facilitated in a way that made it easy to follow, especially when having previous knowledge on the food system."* (Player Red).

> *"I really enjoyed the way we played the game, and the facilitation was very good. I felt well guided in a game in which the participants need to understand how the system works. It was looking complex at first, but actually it was easy to understand step by step."* (Player Yellow).

> *"It was very fun to play. Through the game we figure out the strategy of the team, sometimes it worked, sometimes not."* (Player Blue).

Furthermore, we asked participants about their food group preferences and how these relate to both individual and collective strategies. During the discussion, participants identified an opportunity to question their own preferences and values by examining the real impact of each type of food. For example:

> *"When you think of a realistic diet for everybody the game becomes difficult. It is nice to see for me that depending on my choices I can implement biodiversity. It's nice to see the direct impact of the dietary preferences."* (Player Yellow).

> *"We should drink less coffee I think, the food group 'Sugar and beverages' got a high negative impact on our system, but it's realistic! I would definitely miss the coffee in a more sustainable diet"* (Player Blue).

In addition to these results, the debriefing and the post-game survey revealed new opportunities to further develop the game as a way to explore sustainability transformations. Participants highlighted the need to explore more dynamics as ways to mitigate emissions, suggesting the introduction of alternative production systems, such as organic agriculture and agroforestry, to investigate nutrients cycling, and to implement a trade component as well as renewable energy production. Regarding agroforestry, multiple options and game elements to implement were suggested:

> *"At the moment the game only allows for grassland-use as animal feed. This would change when allowing to grow fruit and nuts trees on grassland"* (Player Red).

Participants suggested that the game could be played with a broader range of stakeholders and decision makers, including people who have diverse perspectives on food system transformation. Specifically, they recommended further improving the game by adding game components and mechanics that display ongoing and/or potential future policy measures, involving policy makers as players providing their expert opinion.

Discussion

In this article, we present the game development process and final version of our CiFoS game, designed to engage players in food system transformation. Throughout its development, multiple prototypes were created where new dynamics were added and already existing dynamics were refined if needed. Early findings highlight the game's value

as a tool for learning and as a discussion support tool for exploring food system futures. The game's visual outputs, facilitation, and debriefing protocol offer opportunities for analysis of game outcomes and integrate both quantitative and qualitative data. As a dialogue tool, our game could potentially support inter-transdisciplinary collaboration on food system transformation, where future adaptations could broaden the game's relevance for decision-makers, policy-makers, and practitioners.

The development of the CiFoS game followed a step-by-step process, first including key food system linkages and environmental impacts, such as the effects of dietary choices on land use and greenhouse gas emissions, before integrating sustainability practices like dietary diversification and circularity. Our approach does not primarily focus on defining a specific game type (Rodela et al. 2019; Chen 2025) but rather positions the CiFoS game as an evidence-based discussion tool that can be applied in diverse contexts, including education to foster social learning (Den Haan and Van der Voort 2018), research as for inter- and transdisciplinary collaboration (Salliou et al. 2021; CUCo 2024), and intervention as to support science-policy interface (Turnhout et al. 2021).

As highlighted by Kalibata and Nabarro (2024), there is an urgent need for tools to foster dialogue and navigate dilemmas in food systems by revealing all their components and embracing complexity. This requires inclusive explorations of food system transformations that go beyond predefined scenarios, allowing for novel dynamics (McGreevy et al. 2022). We introduced game mechanics that translate circularity from modeling into a playable form, therewith fostering such innovative principles. Through engagement with participants, we explored the potential of using the game to further debate alternative dynamics and futures, embracing complexity as a means to rethink and redesign food systems. This process also challenges the assumptions embedded in both the game and the underlying models, encouraging critical reflection and innovation in food system transformation (Voinov et al. 2018; Rodela and Speelman 2023). Furthermore, the current CiFoS game is developed for Europe, meaning that for instance, diets and land-use (e.g. grassland) are based on European datasets and preferences. Further research would explore the potential of this game to be adapted to different contexts at national and global levels.

Addressing these challenges required an iterative co-design approach involving both food system experts and game designers. Expert validation ensured that newly introduced sustainability mechanisms, such as circularity and biodiversity trade-offs, aligned with real-world food system dynamics while also assessing whether the game effectively conveyed its intended outcomes. Collaboration with game designers was crucial in refining mechanisms to enhance playability, ensuring an engaging balance between complexity, fun, and realism while maintaining the flow of the game. A central challenge throughout this process was balancing scientific accuracy with an engaging and intuitive gameplay experience. Two key design challenges emerged: simplifying a complex system while preserving the realism and accuracy of its dynamics; and maintaining sufficient complexity to encourage meaningful decision-making without overwhelming players (Dernat et al. 2025; Hordijk et al. 2025). Though the game covers many components, given the design challenges and the complexity of the food system, it was impossible to cover all elements. This holds amongst others true for the economic and political dimensions. Nevertheless, elaboration on these could be covered in the debriefing by serving as discussion points on how economic or political factors could limit or promote the redesigned food system as developed in the game. Furthermore, economic and political dimensions could be further implemented in our game, taking inspiration from existing environmental board games as *Daybreak*, in which these dimensions are developed into the game mechanics, for instance using "social crisis" cards. These cards act as event cards, presenting economic and/or political scenarios that impact both collective and individual strategies for reaching or challenging a sustainable outcome (Dunlop et al. 2025).

Our game currently integrates numerous components of food systems in relation to sustainability outcomes, especially when compared to existing food system games, which are either stronger in connecting multiple food system components to one sustainability dimension or in exploring synergies and trade-offs of sustainability outcomes for only one food system component (Hordijk et al. 2025). Although this indicates that the game is novel in connecting multiple food system components to both human and planetary health while stimulating dialogue on these matters, there remain opportunities to enrich our approach by linking it with complementary playful interventions and methodologies. By creating synergies between various interventions, we could envision diverse workshop formats that integrate different game-based activities, such as the *Planetary Plate Puzzle* (Mazac et al. 2025). Furthermore, our food system approach could be further linked to other frameworks, exploring participants' values in relation to sustainability and nature, such as the Nature Futures Framework (Pereira et al. 2020; Raymond et al. 2025), dialogue dimensions (Cayer 2005), ethical–political dimensions (West and Schill 2022), boundary crossing learning (Akkerman and Bakker 2011) and food system literacy (Martin et al. 2024; FAO, 2025). Additionally, by zooming out and scaling to Earth systems, this integration could further expand the research towards multiple planetary boundaries (Richardson et al. 2023). Though the

CiFoS game allows for redesigning the food system, this is to some extent limited by the options that are included in the game, as it does not directly allow the incorporation of all (un)known alternatives. An example of a game that does this is the FPC simulator, which stimulates the imagination of alternative food system practices in a food policy council format (Mangnus et al. 2019). Nevertheless, our game does show in contrast many synergies and trade-offs of the included strategies to both environmental and health indicators, and the debriefing is furthermore designed to foster discussions around strategies and dynamics not fully captured in the game. Facilitation and debriefing could be further implemented, ensuring playability also without a facilitator, providing a potential opportunity to open up for the general public. For instance, this could be supported by implementing more detailed rules and counting booklet; and/or integrating a conversational AI-based serious games element to facilitate the session and the debriefing (Sabir et al. 2024).

The question posed by Garcia et al. (2022) "Who gets to play?" remains open. We position the CiFoS game within a just and inclusive food system transformation process, where all voices could be represented as pointed out by Turnhout et al. (2021). Beyond its current design, we support the adaptation of the tool to different contexts and challenges, integrating it with other participatory methods to enhance its relevance for diverse users (Ahmadov et al. 2025). For instance, ad hoc workshops could serve as debriefing or collaborative visioning sessions (Andreotti et al. 2020), enabling participants to harvest and validate co-created results for further integration into models, scenarios, or policy discussions (Voinov et al. 2018).

There is potential for integrating the game into long-term, inter- and transdisciplinary iterative projects, where each session not only engages participants but also contributes to further developing game mechanics, supporting food systems dialogue, and fostering collaboration for food system transformation. Scaling the CiFoS game for broader use requires not only contributing to sustainability discussions but also ensuring that game insights translate into real-world decision-making processes (Garcia et al. 2022; Hordijk et al. 2025). Through ongoing iterative play and adaptation, the CiFoS game has the potential to function as an interactive educational tool for multi-stakeholder platforms, therewith facilitating dialogue toward the sustainable transformation of food systems for human and planetary health.

Conclusions

The CiFoS game provides an example of how designing and playing serious games can foster dialogue, interdisciplinary learning, and collaboration for food system transformation. By integrating health and environmental dimensions, including multiple food system components, the game could bridge individual and collective perspectives on redesigning the food system for human and planetary health. Its design and pilot testing highlight the potential of playful approaches to capture the complexity of food systems and their real impacts. To further implement its transformative potential, the game can be expanded in different contexts, or with other participatory tools, frameworks, and interventions, further promoting participation across diverse stakeholder groups including change-makers.

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