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Implementing sustainability in product portfolio development through digitalization and a game-based approach☆

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ABSTRACT

The aim of this research is to explore if and how digitalization and a game-based approach can improve the usability and implementation of sustainable design methods and tools in a product development process. Based on semi-systematic literature review, advantages and limitations of digitalization and game-based approaches in this context were identified. A previously developed method that guides the implementation of a strategic sustainability perspective in product portfolio development, was then selected and elements of digitalization and game-based approaches were incorporated in its four building blocks: double-flow scenario modeling, sustainability assessment, market success assessment, and portfolio development. The resulting prototype of this method was further adapted after feedback gathered through expert interviews and then tested in workshops with industry and academia. It was found that digitalization was especially useful for the scenario simulation, data management, and automatic visualization of results, while the benefits of the game-based approach were enhanced motivation, collaboration, and co-design of results and solutions. At the same time, drawbacks were discovered, for example related to decreased transparency of how results are calculated, overuse of visualization and extrinsic rewards, leading to lack of clarity and trust in the results. In conclusion, there are synergies between digitalization and game-based approaches that can improve the usability of sustainable design methods and tools, but extensive testing is recommended to avoid pitfalls that can lead to opposite effects. Moreover, recommendations were identified for how to include digitalization and a game-based approach, for example, to enable integration with other tools, maintenance and constant update, to explore the benefits of team-based assessments and collaboration, to add diversity and customization, and to link the game to the user's context, application, expectations and requirements.

1. Introduction

Society is facing a systematic increment of manufactured products, which entails increasing sustainability impacts. Manufacturing companies increasingly recognize their role and responsibility in transitioning towards a sustainable society (Vanegas et al., 2018). To live up to this responsibility, previous research identified the need to (i) better understand stakeholders' collaboration; (ii) apply a holistic perspective; (iii) manage the entire value chain; involve both the strategic, tactical, and operational levels; and (iv) develop the knowledge and necessary skills to implement sustainability (McAloone and Pigosso, 2017). Integrating sustainability in the company strategy and the early phases of the product development process, is particularly important as this is where there is more room for creating, adapting, and managing sustainable solutions (Arekrans et al., 2022; Cluzel et al., 2016).

More than 600 sustainable design methods and tools (SDMTs) have been developed (Schäfer and Löwer, 2021), but despite the abundance of existing tools, companies are facing difficulties with implementation

Abbreviations: B2B, Business to business; CE, Circular economy; CEO, Chief executive officer; DS-II, Descriptive study II; DRM, Design Research Methodology; FSSD, Framework for strategic sustainable development; ICT, Information and communications technology; PS, Prescriptive study; RC, research clarification; SCI, Sustainability Compliance Index; SDMTs, Sustainable design methods and tools; SME, Small and medium-sized enterprise; SPD, Sustainable product development; SPs, Sustainability principles; STARDUST, Strategic layered double-flow scenario modeling for sustainability risk and portfolio management.

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and the uptake in industry remains low (Peace et al., 2018; Pigosso et al., 2015). In many cases, the sustainability implementation process is challenging due to the low usability of existing tools (Schäfer and Löwer, 2021). Moreover, many tools lack a system- and strategic perspective, which means that they do not include a long-term planning perspective based on a vision of a socio-ecologically sustainable future. This is however necessary for managing social and environmental aspects in a way that also benefits the own organization (Villamil and Hallstedt, 2020).

Digitalization and game-based approaches were highlighted as potential leverage points to facilitate the improvement of decision-support tools (Guillen Mandujano et al., 2021; Wanick and Bui, 2019). Within the era of Industry 4.0 and the digital transformation (Ha et al., 2022), digitalization is a main driver to enhance product development (Dantas et al., 2021; Nara et al., 2021; Schöggl et al., 2023). Meanwhile, approaches that use game elements can support motivation, training, data collection, management, and the simulation of future scenarios and thereby the development of solutions with a higher sustainability performance (Guillen Mandujano et al., 2021; Valencia et al., 2015). The use of game elements in non-game contexts is called gamification (Werbach and Hunter, 2012), and the use of games in serious environments is known as serious games (Whalen and Kijne, 2019). For this research, the concept of "a game-based approach" is used to summarize the application of gamification and serious games to support a process (Tolks et al., 2020).

Despite extensive research within each of the fields, digitalization and game-based approaches, there is a gap in relation to how these two fields can be combined. Therefore, the aim of this study is to explore if and how digitalization and a game-based approach can support the implementation of decision-support tools in the early phases of the product innovation process. A specific method, the so-called *strategic layered double-flow scenario modeling for sustainability risk and portfolio management* (STARDUST) was selected to study how elements of digitalization and game-based approaches can improve the usability of SDMTs.

The contribution of this study is twofold: firstly, an enhanced method for including a strategic sustainability perspective in product portfolio development is presented. Secondly, recommendations for practitioners and researchers are provided for how to improve the usability of SDMTs by applying digitalization and a game-based approach.

2. Literature review

This study draws on research from the areas of sustainable product development (SPD), portfolio development, digitalization, and game-based approaches. The literature from these areas is reviewed in the following sub-sections.

2.1. Sustainable product development (SPD)

Sustainable development was defined as development that "meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development, 1987). One approach for realizing such development that received wide-spread attention in industry and among policy makers is the Circular Economy (CE). It focuses on achieving closed loops with high efficiency and zero waste (de Oliveira et al., 2021; Pigosso and McAloone, 2021; Velenturf and Purnell, 2021). However, CE is lacking the system view and a strategic perspective, which poses the risk that solutions may contribute to circularity while hindering the development towards full sustainability (Korhonen et al., 2018). Hence, there is a need for creating a vision that can guide the development in the direction of both ecological and social sustainability.

The framework for strategic sustainable development (FSSD) builds on backcasting, where a vision of a sustainable future is created, using basic principles for sustainability as boundary conditions. These so-called sustainability principles (SPs) are: "in a sustainable society, nature is not subject to systematically increasing (1)… concentrations of substances from the Earth's crust, (2)… concentrations of substances produced by society, (3)… degradations by physical means, and, in that society people are not subject to structural obstacles to (4) health, (5) influence, (6) competence, (7) impartiality, and, (8) meaning-making" (Broman and Robèrt, 2017). It is then possible to do backcasting from that vision in order to derive solutions that lead from the current situation towards the vision in a strategic, step-by-step way (Haas et al., 2022). It is crucial that such a strategic sustainability perspective as well as life-cycle thinking are applied in sustainable product development (SPD), especially in the early phases of the product innovation process (Hallstedt and Isaksson, 2017). The design of sustainable products also requires a collaborative and holistic approach, where sustainability is seen as a business opportunity, considering different time horizons (Fernando and Wah, 2017; McAloone and Pigosso, 2017).

Even though hundreds of *sustainable design methods and tools* (SDMTs) have been developed to support the industry in the implementation of sustainability, few are in fact implemented and used in practice (Faludi et al., 2020). Dekoninck et al. (2016) and Peace et al. (2018) identified the following reasons for the low uptake: (i) use of terminology and concepts which are difficult for practitioners to understand; (ii) too time-consuming; (iii) hard to use and containing errors; (iv) lack transparency in how outputs are calculated; (v) require detailed data that is not available in early phases; (vi) difficult transfer of data; and (vii) either too complex and overwhelming or over-simplifying .

Based on these challenges, Faludi et al. (2020) and Schäfer and Löwer (2021) have presented an extensive list of criteria that SDMTs should fulfill to facilitate implementation and use in industry. Among other things, SDMTs should i) be accessible to non-experts; ii) integrate well with existing workflows; iii) be inexpensive and easily available and accessible; iv) integrate environmental, social, and economic dimensions of sustainability; v) enable comparisons between design options; vi) highlight trade-offs and synergies between different metrics; vii) combine forecasting with backcasting; viii) address uncertainty, and ix) suggest not only design decisions, but also business-related decisions.

2.2. Implementation of sustainability in product portfolio development

A portfolio is the compilation of projects and programs, where products and services are managed in projects (Cooper et al., 2001). The product portfolios are linked to the company strategic plan, where the vision, goals and strategy are defined (Figge et al., 2002; Jugend et al., 2017). Companies use evaluation criteria such as profit, legislation, quality, and customer needs, to compare and select the product portfolio components. Portfolios are determined in the product planning phase of the product development process (Ulrich and Eppinger, 2012). The implementation of sustainability in the planning phase is crucial for the development of sustainable solutions as decisions made during this phase set the direction for the following phases of the process (Cluzel et al., 2016; Kohl, 2016). In previous research, it was identified the need to provide a clear definition of the *sustainability product portfolio* concept, which was defined as: "A process to set a company platform of solutions, i.e., a cluster of products, services, technologies, and/or customized options, based on the company strategic plan and assessed by a strategic sustainability perspective" (Villamil and Hallstedt, 2020).

The implementation of the sustainability perspective in the product portfolio may come with challenges, such as limited participation of the involved stakeholders, lack of sustainability awareness at high-level positions, the social dimension being poorly assessed, lack of a strategic sustainability perspective, limited data about the sustainability performance of the product in the early stages, lack of knowledge about sustainability related to the product portfolio, and a lack of tools that guide the sustainability implementation in the product portfolio (Villamil and Hallstedt, 2020). In many cases, the social dimension is

focused on the company workers, omitting other stakeholders that are involved in the different stages of the product life cycle (Mesquita and Missimer, 2021), e.g., communities affected by the extraction of raw materials.

A method to support the integration of a strategic sustainability perspective in the product portfolio is the strategic layered double-flow scenario modeling for sustainability risk and portfolio management (STARDUST) (Villamil et al., 2021). It aims to guide companies to select and locate the portfolio components in the *smart zone,* where the sustainable solutions are neither too passive (facing risks like reputational damage, legislative constrains, or losing competitiveness), nor too proactive (facing risks such as high investment costs, immature supply chains, or insufficient customer demand) (Schulte et al., 2020; Schulte and Knuts, 2022).

The STARDUST method consists of a four-step process, see Fig. 1: Step 1) Time – strategic, layered, double-flow scenario modeling: identify events that might affect the portfolio combining backcasting and forecasting and considering the *macro* (society), *meso* (company) and *micro* (portfolio) levels; Step 2) Sustainability assessment: identify hotspots of sustainability impact over time; 3) Market success: assess the market performance over time by using portfolio evaluation criteria, and 4) Portfolio balance – the Cube: visualize the sustainability and market success performance over time and identify strategies and actions to balance the product portfolio.

The sustainability assessment was supported by the Sustainability Compliance Index (SCI) scale to rank products according to their sustainability performance (Hallstedt, 2017). In previous STARDUST method tests (Villamil et al., 2021), some benefits were identified such as obtaining a strategic sustainability perspective, sustainability awareness, market success reflections, portfolio components comparison and cross-functional collaboration. Challenges such as high dependency of the facilitator, assessment of a high amount of products, large amount of data, field complexity and disconnection of the method steps, were also identified.

2.3. Digitalization to support decision-making

Digitalization has an incremental role in manufacturing companies, and the digital era is transforming operations, collaboration, management, networking, logistics, design and productivity, and updating the industry to *4.0*. Digitalization refers to "the use of digital technology, and digitized information, to create and harvest value in new ways" (Gobble, 2018).

Digitalization and sustainability play a key role in modern product design (Bhamra and Hernandez, 2020), requiring specialized capabilities to develop more innovative and competitive solutions (Hallstedt et al., 2020). Utilization of digitalization provides value for the company in mainly three areas: "1) integration and part of the solutions, 2) understand customer needs and 3) improve collaboration and logistics" (Zhao et al., 2019). Digitalization applied to decision-support tools allows for "faster idea screening and more rapid prototyping" (Farrington and Alizadeh, 2017), scenario planning (Farrington and Alizadeh, 2017), and improved logistics (Kayikci, 2018). Digitalization entails several advantages for companies such as facilitating automatization of operations (Soldatova et al., 2020), data management (Kalakul et al., 2014), cross-functional collaboration (Favi et al., 2012), and decision-making processes (Gkisakis et al., 2020; Nell et al., 2021).

2.4. A game-based approach to support decision-making

A game is any playful activity delimited by rules (Schell, 2008). According to the player expectations and skills, Bartle (1996) identified a player typology that includes: a) explorers, those who like to discover what is around them, b) achievers, those that want to fulfill a mission or challenge, c) killers (or competitors), those that like to compete and earn rewards, and d) socializers, those that are oriented to collaborate and support others. Gamification is known as "the use of game elements and game-design techniques in non-game contexts" (Werbach and Hunter, 2012). Serious games are games framed in serious cases, with the focus to accomplish an objective, where fun is a secondary aspect (Whalen and Kijne, 2019). In education, the concept of game-based learning has been used with the main focus on teaching and training (Gatti et al., 2019).

The term game-based approach is related to the use of game elements to support activities, where gamification and serious games are included (Tolks et al., 2020). Based on this understanding of a game-based approach, it differs from "game-based learning", which mainly focuses on teaching environments with learning objectives (Gatti et al., 2019). Although a game-based approach might include some learning aspects, the main focus of this approach is to be used in many fields with different purposes, enabling motivation and collaboration and facilitating the use of a process or activity (Tolks et al., 2020). In line with this, the Octalysis framework (Chou, 2019) has the potential to create gamification platforms to implement sustainability (Ponce et al., 2020), by using eight drivers: 1) Epic Meaning & Calling, users feel that their actions are meaningful and have a great value to support or help the society, it is the sense of hero, e.g., saving the planet by reducing CO2 emissions; 2) Development & Accomplishment, users are engaged by getting mastery in the process of completing a mission, e.g., collecting points for

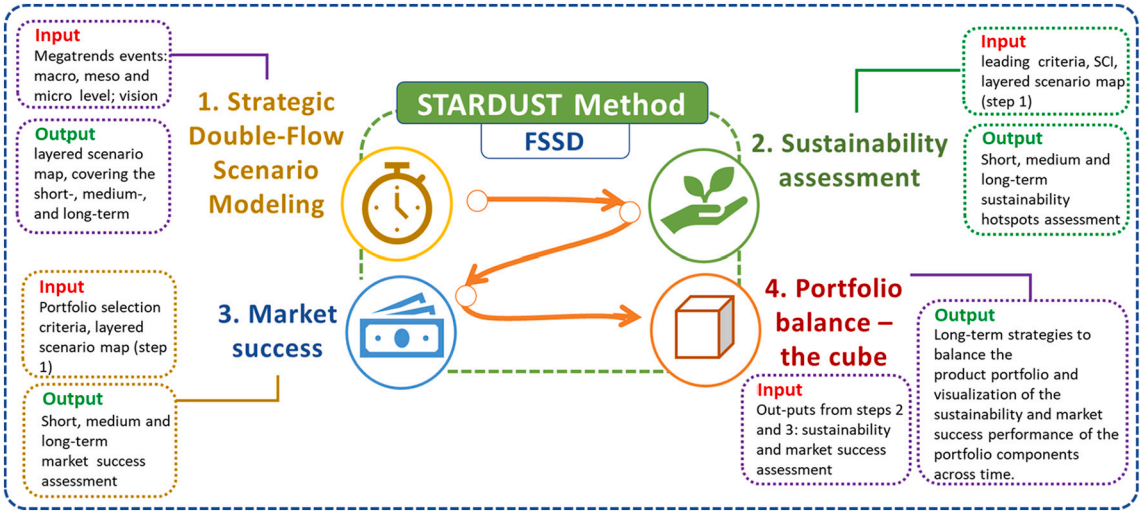

Fig. 1. Inputs and outputs of each step of the STARDUST Method (Villamil et al., 2021).

improving their sustainability skills; 3) Empowerment of Creativity & Feedback, users are motivated when they have the opportunity to create and give value to their creativity, e.g., providing creative ideas to solve sustainability issues in a design challenge contest; 4) Ownership & Possession, users feel that they are in control of the process; 5) Social Influence & Relatedness, users are motivated by collaborating or supporting others, e.g., players can get additional rewards for helping other players; 6) Scarcity & Impatience, users are motivated due to some limitations in the system, such as time constrains e.g., including a design contest that is using only disposal material; 7) Unpredictability & Curiosity, users are engaged by unknown paths or secrets that bring unexpected processes and results, e.g., selecting from different treasures and revel the reward; 8) Loss & Avoidance, users try to avoid losing what they have gained, e.g., losing points by overpassing the amount of allowed energy consumption per day. According to the Octalysis framework, there are several game mechanics that can be used to enforce these drivers, such as the case of leader's boards, which are used to enforce the competition between different players, motivating them to be better than others, this is related to the driver 2: Development & Accomplishment.

One of the purposes to use serious games and gamification is to motivate users (Mekler et al., 2017). Therefore, it is possible to consider the self-determination theory (SDT) (Ryan and Deci, 2000), that mentions that people can be extrinsically or intrinsically motivated. Extrinsic motivation is related to elements outside such as external rewards (money, points, bonuses). Intrinsic motivation is related to the willingness to perform an activity that provides internal satisfaction. In line with this, the SDT mentioned that intrinsic motivation is connected to the human psychological needs (Ryan and Deci, 2000), which are a) autonomy, the feeling to be in control and take own decisions, b) competence, the feeling to be capable of doing something, and c) relatedness, where individuals can connect and share with others.

3. Methods

The Design Research Methodology (DRM) (Blessing and Chakrabarti, 2009) was selected to structure the research approach of the complete study. The DRM allows to include a design perspective in the research by identifying the problem and proposing and testing a solution in a systematic and iterative way. The DRM has four main stages: a) the research clarification (RC) aims to establish an initial understanding of the existing situation and to identify a relevant research focus; b) the descriptive study I (DS-I) creates a more detailed understanding of the existing situation by studying further influencing factors; c) the prescriptive study (PS), where an intervention is conceived, e.g. a model or tool, to change the existing situation into a desired direction; d) the descriptive study II (DS-II) investigates the impact of the intervention and its ability to realize the desired situation.

This study presents the PS and initial DS-II of the DRM, see Fig. 2. For the research clarification (RC), previous literature reviews provided the state of art of the sustainability product portfolio field (Villamil and Hallstedt, 2018). In the DS-I, semi-structured interviews and workshops with industry provided a further understanding of the industry perspective (Villamil and Hallstedt, 2020).

With this background, the STARDUST method was developed in the PS (Schulte et al., 2020; Villamil et al., 2021). In the continuation of the

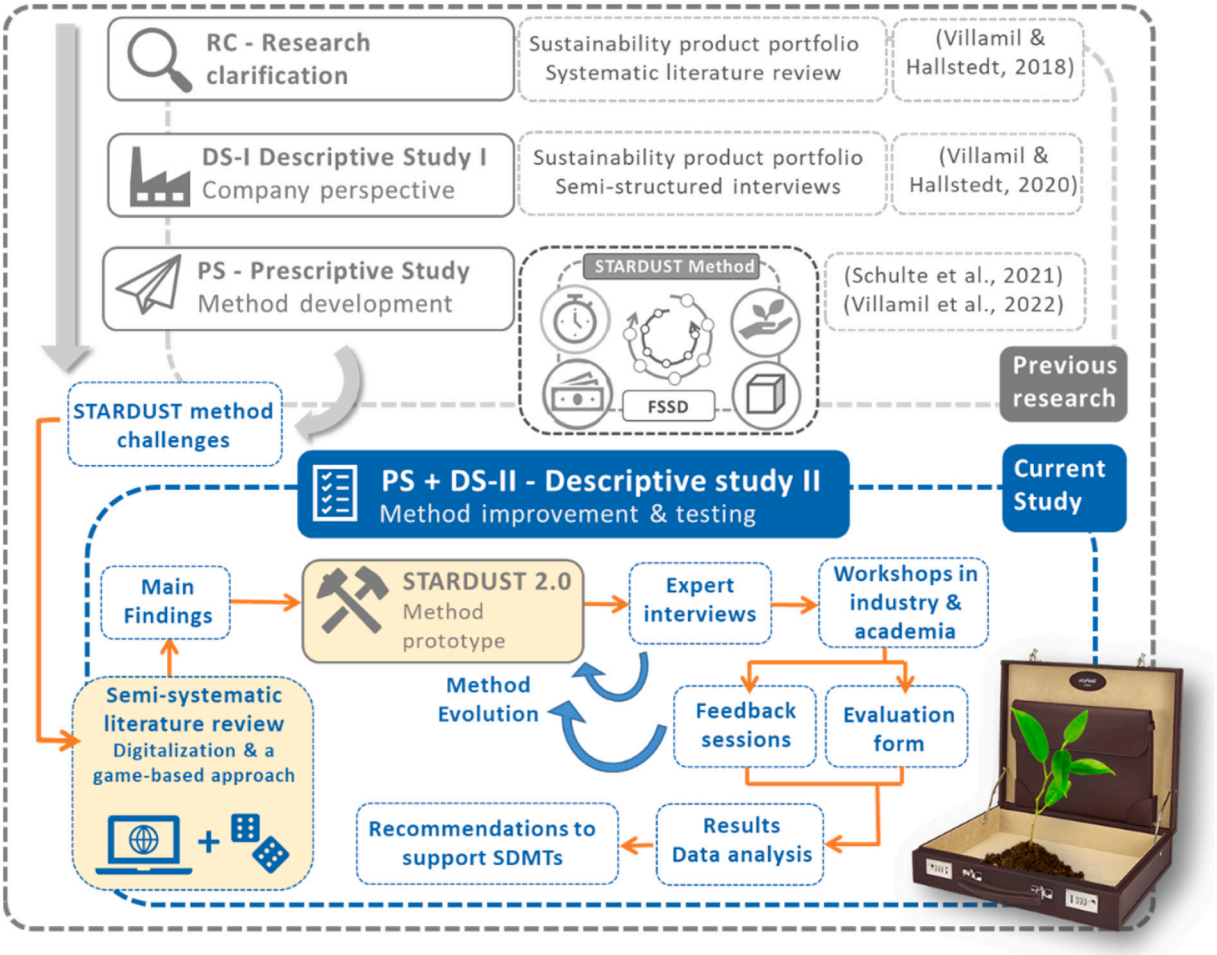

Fig. 2. Research approach used in this study (based on Blessing and Chakrabarti, 2009).

PS and the initial DS-II, presented in this paper, the STARDUST method is improved further by applying digitalization and a game-based approach, called STARDUST 2.0 method. The initial DS-II here focuses on "application evaluation", i.e., on identifying whether the developed support is usable and applicable for its intended task.

The STARDUST method was selected in this research to represent the SDMTs, due to its novelty in supporting the decision-making process of the sustainability product portfolio by applying a strategic sustainability perspective. Furthermore, it guides the implementation of sustainability in the early stages of the innovation process and fosters systems thinking by considering the environmental, social and economic dimensions of sustainability. Moreover, in the initial testing of the STARDUST method, it was noticed that there are similar difficulties in relation to its usability and implementation as with other SDMTs.

To obtain an understanding of the state of art of digitalization and a game-based approach, a semi-systematic literature review (Snyder, 2019) was performed, meaning that a specific amount of literature, partially covering the field, was analyzed in a systematic way. The purpose of a semi-systematic literature review is to collect representative material to obtain a clear understanding of the field. This kind of review allows to consider relevant material for the analysis that is structured and analyzed in a systematic way i.e., by applying the same process in the collected data (Snyder, 2019). In this study, The Web of Science and Scopus databases were used with the research query presented in Fig. 3.

The reviewed material was selected based on the following inclusion criteria: a) connection with the research areas: sustainability, product development, digitalization, and a game-based approach; b) publication: between 2010 and 2022; and c) published in a scientific journal or conference proceeding. The exclusion criteria were sorting out publication that were not: a) relevant to the digitalization and game-based approach field, b) oriented to support SDMTs, c) focused on the implementation of sustainability, d) supported the decision-making process, e) promoted the discussion and critical thinking, f) published in English or Spanish. Furthermore, a snowballing process helped to include key references (Wohlin, 2014). 39 papers were reviewed in full text. The four main areas of analysis were: benefits and limitations, used tools, case studies, and main aspects to improve the STARDUST method.

The literature review results guided the improvement of the STARDUST 2.0 method prototype with the support of digitalization and a game-based approach. This method was presented to eleven experts selected based on their contribution and experience in the field of sustainability, product development, product portfolios, digitalization and game-based approaches, see Table 1. The experts were selected following a "purposive sampling technique", where interviewees are chosen based on their knowledge and expertise related with the research (Etikan et al., 2016). In line with this technique, the selected experts have a high contribution in their field, with academic publications, project support and consultancy expertise in industry and academia. Moreover, they are from different countries to obtain diverse contextual and cultural perspectives. The semi-structured interviews with experts

Table 1
List of experts that participated in the semi-structured interviews.

Expert	Expert field	Expertise	Role	Country
A	Gamification and digitalization	Academia	Professor	Sweden
B	Digitalization, data management, gamification	Academia, industry	Engineer	Sweden
C	Project management, sustainability, gamification	Academia, industry	Consultant, teacher	Colombia
D	Design for future scenarios, product design	Academia, industry	Consultant, professor	Colombia
E	Product portfolio and sustainability	Academia	Professor	Brazil
F	Innovation and Gamification	Industry	Consultant	Colombia
G	Product portfolio and sustainability	Industry, government	Consultant	Netherlands
H	SPD, sustainability assessment	Academia, industry	Researcher	Spain
I	Product portfolio and sustainability	Industry	Consultant	Netherlands
J	Sustainable development	Academia	Professor	Finland
K	Gamification, data management and digitalization	Industry	Consultant	Sweden

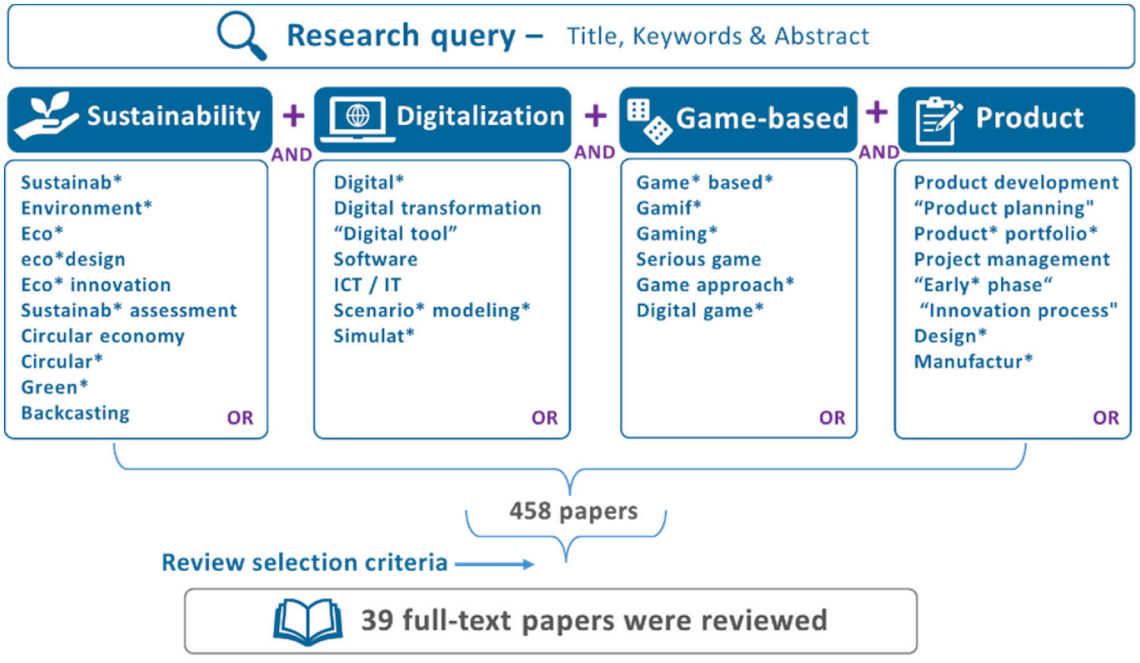

Fig. 3. Research query used to identify key references for the semi-systematic literature review.

had the purpose to gather feedback on the application of digitalization and a game-based approach in the design of decision support tools. The interview questions were focused on finding the advantages, disadvantages, possible improvements and future application of the STARDUST 2.0 prototype. The questions focused on, for example, user interaction, collaboration, data visualization, data organization, game results, and interaction with other tools.

The semi-structured expert interviews followed an interview guideline, see Appendix A.

Four workshops were held with industry and academia to evaluate the STARDUST 2.0 method, using feedback sessions and evaluation forms to collect the opinions of the workshop participants, see Table 2 and Appendix B. The companies that participated in the workshops represented a wide range of businesses: different manufacturing sectors and sizes, located in industrialized countries and emerging economies, global and local participation, and with varying interests for implementing sustainability in their processes. The interviews and workshop results were analyzed based on the coding process by Strauss and Corbin (1990), with the following phases: i) open coding, the data was separated in smaller parts, identifying initial codes; ii) axial coding, defining and connecting the codes to group them into categories; iii) selective coding, the codes are classified according to their contribution. The data analysis was performed using the Atlas.ti 9.0 Software. Appendix C presents the code categories used in the analysis.

4. Results

This section presents the results from the literature study by describing the advantages and limitations of digitalization and a game-based approach when applying them in decision-support tools in general, and in SDMTs in particular. Further on, examples are presented of how the STARDUST method was modified with the aim to improve its usability in industry and academia.

4.1. Advantages and limitations of digitalization and a game-based approach

The results from the literature study indicated that a game-based approach in decision-support tools can allow for improved communication (Nemoto et al., 2014), facilitate the decision-making process (Patricio, 2017), promote collaboration and teamwork (Dewulf, 2010), guide the creative process (Whalen and Kijne, 2019), encourage co-design (Hauge et al., 2016; Leclercq et al., 2017; Loizou et al., 2019), simulate reality (Whalen and Kijne, 2019), motivation and training (Gatti et al., 2019), and simulate negative sustainability effects (Schrier, 2015). Moreover, a game supported by event cards and system thinking helps to adapt the company strategy by following market trends (Nemoto et al., 2014), see Table 3. Furthermore, the literature review indicates that some serious games and gamification can support sustainability implementation in the early phases of the innovation process (Dewulf, 2010), select the most creative ideas (Patricio, 2017), simulate Life Cycle Assessment (LCA) (Duin et al., 2012), increase sustainability competences and critical thinking (Duin and Thoben, 2011), and simulate external trends (Whalen, 2017; Zhang and Zwolinski, 2015). Scurati et al. (2020) identified that board games are effective tools when

Table 3
Advantages of digitalization and game-based approach in enhancing decision-support tools.

Advantages of digitalization in enhancing decision-support tools	References
Enhance flexibility, simultaneous management, and automatization of operations	(Imgrund et al., 2018; Soldatova et al., 2020)
Support data management, provide enough data and manage multiple aspects	(Nell et al., 2021)
Enhance data visualization, recording, organization and sharing	(Zhao et al., 2019)
Support integration with company systems, and data transfer between different platforms	(Favi et al., 2012; Kalakul et al., 2014)
Facilitate communication, cross-functional collaboration, and Networking	(Imgrund et al., 2018; Parida et al., 2019)
Facilitate decision-making	(Nell et al., 2021)
Process optimization: efficiency and facilitate logistics, e.g., quick data analysis; respond to changes	Konys, 2020; Soldatova et al., 2020)
Support for training	(Zhao et al., 2019)
Simulation and Scenario planning and risk identification	(Kayikci, 2018)
Product life-cycle simulation and assessment	(Farrington and Alizadeh, 2017)
Facilitate the implementation of sustainability aspects	(Favi et al., 2018)
Support backcasting perspective, determine a future vision	(Guillen Mandujano et al., 2021)
Advantages of a game-based approach in enhancing decision-support tools	
Support long-term perspective	(Schrier, 2015)
Intrinsic motivation, e.g., activity itself is rewarding	(Wanick and Bui, 2019)
Enhance co-creation	(Perini et al., 2017)
Motivates creativity, gamification as an innovation driver	(Whalen and Kijne, 2019)
Triggers critical thinking holistic view, system thinking, e.g., product life cycle	(Scurati et al., 2022; Stanitsas et al., 2019)
Facilitates training and learning	(Duin et al., 2012)
Facilitates stakeholder and multi-disciplinary collaboration and enhance teamwork	(Tsourma et al., 2019)
Facilitates logistics and risk management	(Wanick and Bui, 2019)
Customization: adapt to user expectations/goals	(Duin and Thoben, 2011)
Link gamification with data management and digitalization, e.g., gather feedback or data	(Lithoxoidou et al., 2020)
Deal with complexity, inherent to sustainability	(Dewulf, 2010)
Support decision-making tool	(Patricio, 2017)
Simulate scenarios e.g., unsustainable hotspots identification, world trends	(Nemoto et al., 2014)
Connect with reality	(Scurati et al., 2020)

Table 2
STARDUST 2.0 method workshops.

	Company A	Company B	Company C	SPD course
Business	B2B	B2B	B2B	
Industry Field	Vehicle	Aerospace	Manufacturing	Cleaning
Company Size	SME – 25	Multinational	Multinational	
Country	Colombia	Sweden	Sweden	Sweden
Industry participants	1	10	9	
Academic participants		4	1	13
Duration (Hours)	2	3,5	5	3
Evaluation form	1	2	5	9
Participant role	CEO	Product managers, portfolio managers, sustainability specialists. SPD researchers.	Product managers, portfolio managers, sustainability specialist. SPD researcher.	Mechanical engineering students

engaging in discussions. In contrast, digital games are specialized in simulating and providing simultaneous feedback.

There are also some limitations in the application of digitalization, concerning data security (Imgrund et al., 2018), resource needs, as well as infrastructure and training (Parida et al., 2019). Furthermore, it is important to consider that "ICT is in constant change and dynamic development" (Konys, 2020), requiring certain capabilities to implement digitalization in business management (Imgrund et al., 2018). In other cases, digitalization might slow down the decision-making process. This can be solved by identifying relevant data (Nell et al., 2021), simulate and manage the complete product life cycle (Farrington and Alizadeh, 2017), and integrate several tools to connect the data (Favi et al., 2018).

Despite the many advantages, some limitations of a game-based approach were also identified in the literature review, for example context dependency (Scurati et al., 2020), lack of evidence of long-term impact (Guillen Mandujano et al., 2021), overuse of extrinsic rewards (Wanick and Bui, 2019), and facilitator dependency (Whalen and Kijne, 2019), see Table 4.

To summarize the review, it was shown that digitalization and game-based approaches complement each other and can be combined to enhance the usability of decision-support tools. Digitalization can be linked with game-based approach to engage collaboration (Lithoxoidou et al., 2020; Tsourma et al., 2019), to simulate scenario creation (Guillen Mandujano et al., 2021), to provide instant feedback (Duin et al., 2012), to facilitate multidisciplinary and cross-functional participation (Perini et al., 2017), and for training support (Wanick and Bui, 2019). Therefore, in order to achieve these advantages, new features and modifications of the STARDUST method were made in line with the findings.

Table 4
Limitations of digitalization and a game-based approach in enhancing decision-support tools.

Limitations of digitalization in enhancing decision-support tools	References
Digital security risk	(Parida et al., 2019)
Need of additional infrastructure and support	(Imgrund et al., 2018)
Data management requires more resources (time, knowledge, IT development	(Zhao et al., 2019)
Big data slow the decision-making process	(Nell et al., 2021)
Focus on the required data leaving behind creativity	(Nell et al., 2021)
Bias of the data interpretation	(Nell et al., 2021)
Need for additional training	(Soldatova et al., 2020)
High cost of technology e.g., Virtual Reality	(Zhao et al., 2019)
Intellectual properties in R&D, e.g., AI patents	(Farrington and Alizadeh, 2017)
Need more IT support and update of IT infrastructure and capabilities	(Farrington and Alizadeh, 2017)
Limitations of a game-based approach in enhancing decision-support tools	
Lack of effectiveness evaluation	(Nemoto et al., 2014)
Lack of evidence of long-term impact and real sustainability change	(Scurati et al., 2020)
Monetary rewards reduce motivation	(Wanick and Bui, 2019)
Not all gamification strategies work. Particular context, target and goals require a specific gamification strategy	(Guillen Mandujano et al., 2021)
Requires Data protection and regulation	(Wanick and Bui, 2019)
Perceived as "mandatory" fun	(Wanick and Bui, 2019)
Requires more planning and resources: time, money, data, platform and facilitators	(Whalen and Kijne, 2019)
Player's competition brings temporary effects	(Whalen and Kijne, 2019)
Non straightforward process	(Patricio, 2017)
Serious games need of high support of facilitator	(Dewulf, 2010)
Physical tool is limit use e.g., no scalable	(Patricio, 2017)
Use of unrealistic mechanisms	(Whalen et al., 2018)
Gamification has a short-term use, e.g., if it is use for longer time, the user might reject it	(AlMarshedi et al., 2015)
Digital application: lack of interaction and discussion between participants	(Scurati et al., 2020)

4.2. Digitalization and game-based approach in the STARDUST 2.0 method

To improve its usability and to support an implementation of sustainability in the development of a product portfolio, a further development of the STARDUST method was made (Villamil et al., 2021). The aim was to achieve the identified advantages by utilizing digitalization and a game-based adaptation of the STARDUST method. The new version, the STARDUST 2.0 method, includes modifications and changes to reach several advantages presented in Table 3 and is described in more detail below.

The prototype was developed based on the STARDUST 2.0 method, which is an Excel-file, designed similar to a web site, using buttons, links and hyperlinks to create a digitalized and gamified experience. It can be used on-site or on-line simultaneously. Microsoft Excel was selected due to the availability and familiarity in academia and industry, giving the possibility to add more information, organize the data, connect with other tools and data, and create interactive graphics that support the usability of the method. The method supports multiple team usage, including expert knowledge regarding product portfolios, product planning, sustainability, and product development. Prior to the workshop, participants were required to watch a video tutorial to facilitate the application of the method. The STARDUST 2.0 method steps are guided by a mentor (represented as a child), who provides explanations of the process, see Fig. 4.

Moreover, examples and graphics were added to provide a better explanation of each step. Fig. 5 presents a map of the slides used in the method.

The STARDUST 2.0 method is using a game-based approach which is a combination of serious games and gamification. The serious games are used to engage users through: i) timeline trivia-games to support strategic thinking, inspired by the "Timeline game" (Frédéric, 2012); ii) drag-and-drop games to support scenario modeling, iii) event card games to support the critical reflection related to future trends, the game is inspired by the event cards of the "Play forward" game (Dewulf, 2010); iv) brainstorming games to identify strategies and actions, based on the Wakeupbrain game (Solano, 2016, 2022). See example excerpts from the STARDUST 2.0 method in Fig. 6.

Moreover, gamification elements were included to stimulate the users' extrinsic motivation (Werbach and Hunter, 2012), such as end game treasures, providing extra support; *strategic wisdom*, points collected for accomplishing tasks, incrementing the strategic perspective; a progress bar, communicating the process advancement; and leader boards, showing the user accomplishment. To enforce the user's intrinsic motivation, the gamification was complemented with the Octalysis framework drivers (Chou, 2019). These drivers guided the implementation of game mechanics that focused on the psychological needs of the users, which are related to the autonomy, competence and relatedness (Mekler et al., 2017; Ryan and Deci, 2000). Therefore, following the SDT, users might be engaged to collaborate with each other to propose products and services with a higher sustainability performance. The Octalysis drivers (Chou, 2019) were included as following: i) finding actions to reach a sustainable society ("Epic Meaning & Calling"); ii) collecting strategic wisdom to obtain a strategic sustainability perspective ("Development & Accomplishment"); iii) creating more sustainable solutions ("Empowerment of Creativity & Feedback"); iv) applying the best solution ("Ownership & Possession"); v) engaging stakeholder collaboration ("Social Influence & Relatedness"), and vi) encouraging critical thinking to determine how trends can affect the product portfolio over time ("Unpredictability & Curiosity").

The expert feedback from the interviews and workshops supported the update of the STARDUST 2.0 method in an evolutive way. Improvements such as, for example, brainstorming games were included, incrementing the amount of ideas (strategies/actions) and creating a roadmap by linking prioritized actions with key stakeholders in a

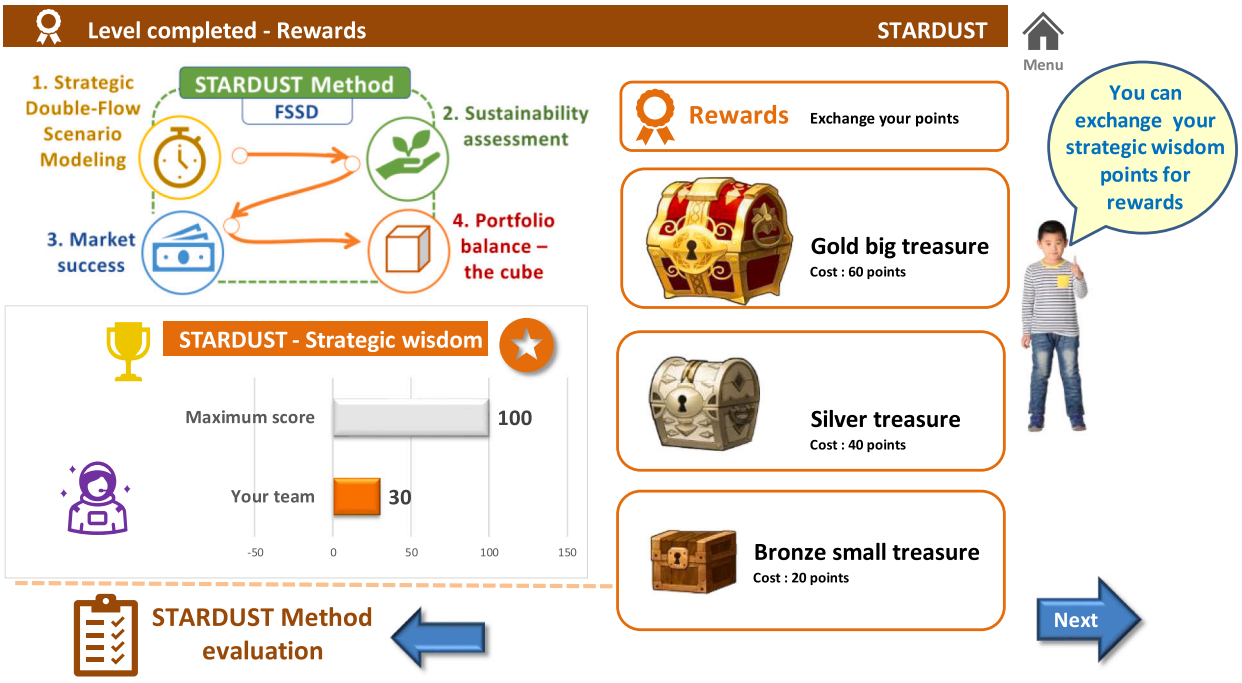

Fig. 4. Example of an interface of the STARDUST 2.0 method applying digitalization and a game-based approach.

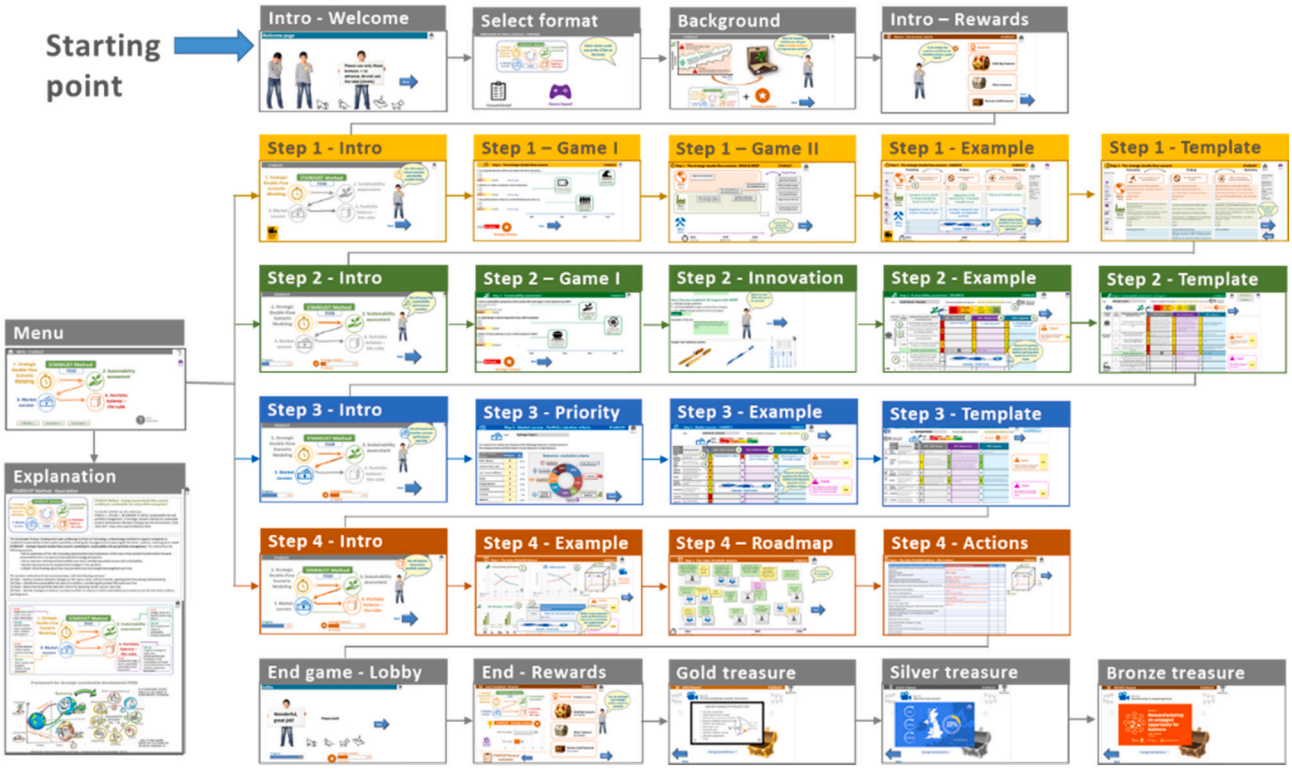

Fig. 5. Platform map: tabs used in the Excel-file.

timeline, see Fig. 7.

The STARDUST 2.0 method steps are supported by digitalization and a game-based approach. In line with this, Table 5 presents the objectives in giving support in decision-making of the STARDUST 2.0 method related to the game-based approach application, the Octalysis drivers and digitalization (graphic visualization). In the following paragraphs each step of the STARDUST 2.0 method is deeply described.

4.2.1. Step 1 - time: strategic, layered, double-flow scenario modeling

In step one, the events that might affect the portfolio in the short (forecasting), medium and long term (backcasting) are identified, in three levels, such as a) macro, or global level, e.g., the population increment, b) meso, or company level, e.g., customers demand zero emissions in production, and c) micro, or product level, e.g., customers demand more products, requiring more material, which can result in

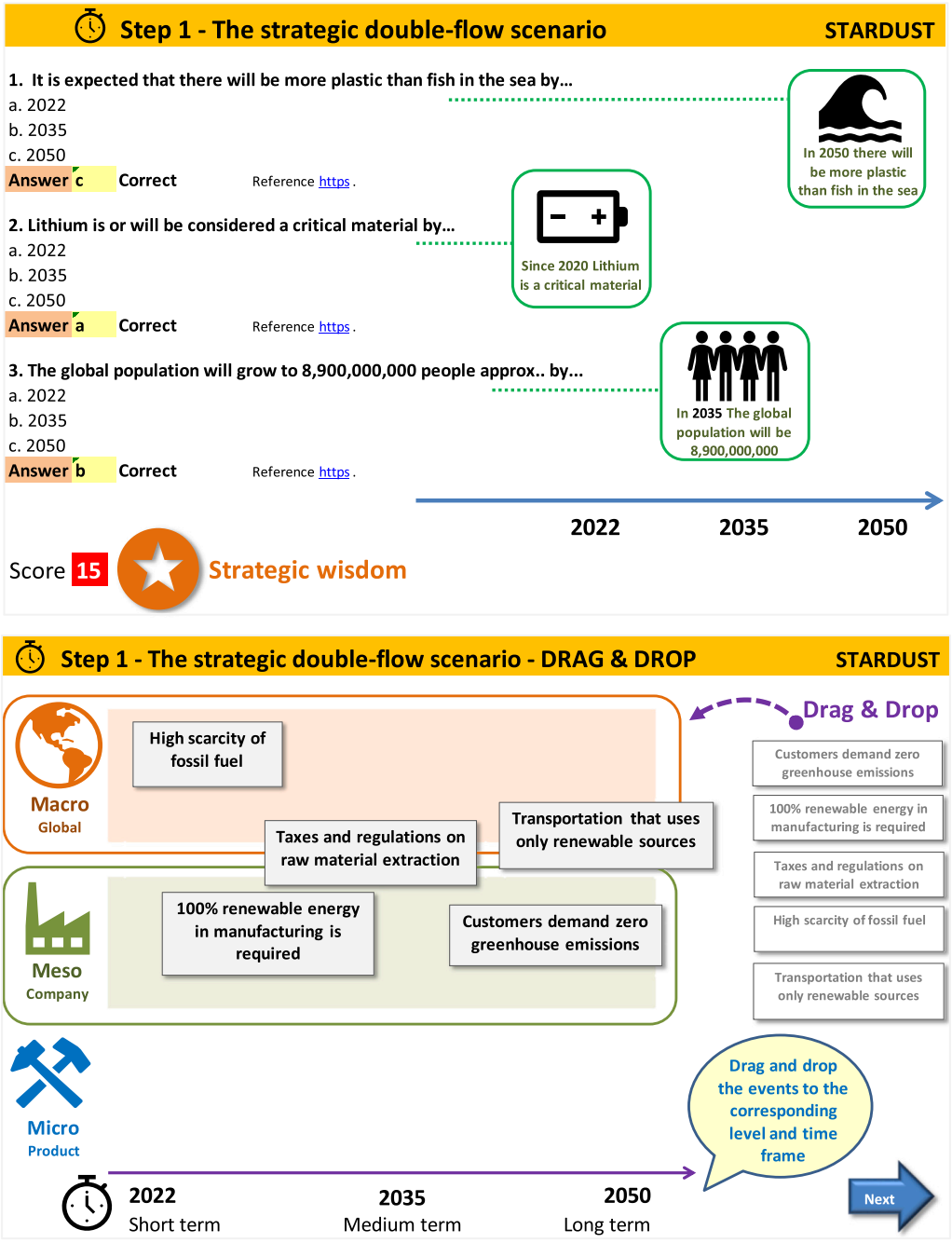

Fig. 6. Examples of some of the serious games used in the STARDUST 2.0 method, the timeline trivia (up), and the drag and drop (down) games.

raw material scarcity. To support this process two serious games are included to warm-up the strategic thinking and reflection, the first one is a trivia game with questions to reflect on the events that might occur in the macro and *meso* level, e.g., it is expected that there will be more plastic than fish in the sea by, a)2022, b)2035, c)2050. The second one, is a drag and drop game, where users locate events in the macro or meso levels, for the short, medium or long term, e.g., "100% renewable energy in manufacturing is required", which has been located in the medium-term, and between the macro and meso level, because it affects globally, likewise the company might change its infrastructure and operations to achieve this requirement. With these games and an example, users are able to fill up the template and identify the events that might affect their product portfolio overtime, see Figs. 6 and 8.

4.2.2. *Step 2 - sustainability assessment*

With a strategic perspective obtained from step 1, the users can continue with the sustainability assessment, where the life-cycle stages are assessed in the short, medium and long-term. Therefore, a serious game based on trivia questions motivates the critical thinking of the assessment, e.g., "from a sustainability perspective which product life cycle stage is more important by 2035?, a) raw material extraction; b) production; c) all the product life cycle stages. In addition, it is required to define if the product will have radical, incremental or no changes in the long term. These reflections are useful to support the use of the template, which has guiding questions for each product life cycle, these questions are based on the SPs, e.g., Use phase - SP2 "Does the design of the product contain or use any restricted substances or materials, such as lead?". Each question is assessed using and interactive SCI scale, from one to nine, which is supported visually by colors that change

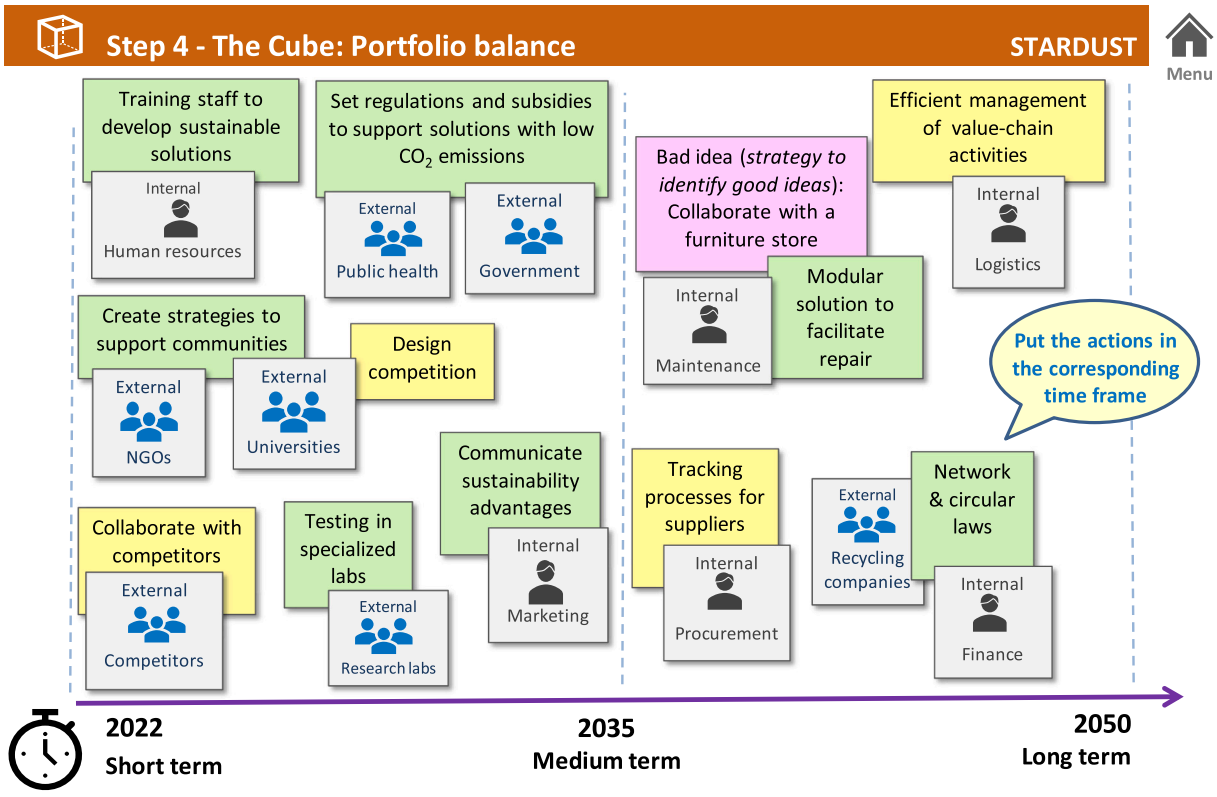

Fig. 7. Interactive interface of the roadmap of prioritized actions, step 4, these actions were identified using brainstorming serious games.

interactively, where 1 SCI is a low sustainability performance (red), 3 SCI is low but acceptable (orange), 6 SCI is moving to excellent (yellow) and 9 SCI is excellent (green), see Fig. 9. Therefore, an average number appears in each life-cycle phase and at the end of the assessment of the sustainability performance of the three periods of time. These results are visually presented in interactive graphics, see Appendix D. Moreover, the discussion is triggered by a serious game based on events cards, using the events that were identified in step 1, e.g., when might the company adapt to 100 % renewable or recycled materials? a) 2022, b) 2035, c) 2050".

4.2.3. *Step 3 - market success assessment*

In the market success assessment, the portfolio selection criteria, such as profit, customer needs/requirements, legislation, among other criteria are assessed overtime. This step starts with the prioritization of each criterion in a scale of one (low relevance) to five (high relevance). This prioritization differs according to the context, field, focus and purpose of the company. For example, an IT company might give higher priority to the innovation criterion, meanwhile a dairy company might focus on quality and legislation. This process is facilitated by an interactive graph, that shows the results of the prioritization, see Appendix D. The step 3 template has guiding questions to support the assessment of each portfolio selection criterion for the short, medium and long-term. The Market Success (MS) scale is used to assess each portfolio criteria with an interactive template that change the color of the assessment, from 1 (very low-red) to 9 (excellent-green), see Fig. 10. At the end, an average number provides a result of the market success performance, which is visualized in interactive graphs, see Appendix D. Similar as step 2, a serious game using the events from step 1 appears to guide the discussion, e.g., "if 100% circularity is included, i.e., the company requires new infrastructure and logistics, then when might the product be profitable? a) 2022, b) 2035, c) 2050".

4.2.4. *Step 4 - portfolio balance—cube*

In this step, it is possible to visualize in graphs the sustainability and market success performance overtime, see Appendix D. Therefore, the participants are encouraged to identify some actions and strategies that help to balance the portfolio in the short, medium and long-term, i.e., the sustainable solutions might be in the smart zone, where they are not too early in the market requiring a higher investment, or too late being behind the competitors (Broman and Robèrt, 2017). Brainstorming serious games are used to identify actions, such as i) "analogies brainstorming", where a random image might trigger an idea, e.g., the image of a team might inspire the idea "to create channels of collaboration with internal and external stakeholders to achieve circularity". ii) "bad ideas brainstorming" is used to identify bad situations, which are linked to the identification of events in step 1, afterwards, to turn them into innovative opportunities, e.g., the bad idea "global legislations ban the use of fossil fuel for manufacturing and transportation" might trigger a positive idea such as "produce locally using renewable energy and ensuring the reduction of environmental and social impacts". iii) "internal or external stakeholders brainstorming" to enhance the creation of ideas using stakeholders, e.g., University (external stakeholder) inspires the idea of "creating academic projects to develop more sustainable and efficient materials". iv) the ideas generated in stage i, ii and iii are collected, analyzed and selected. v) the selected ideas in stage iv, are located in a timeline. As a result, a road map helps to visualize the prioritized actions, linked with some stakeholders and located in a specific time frame, see Fig. 7.

4.3. *Results of the STARDUST 2.0 method interviews and testing*

Based on the semi-structured interviews and the workshops, it was possible to adapt and evaluate the STARDUST 2.0 method. The results, presented in this section, are based on empirical data provided from feedback sessions, evaluation forms, and interview transcripts.

Table 5
The objectives in giving support in decision-making of the STARDUST 2.0 method, which are related to the game-based approach application, the Octalysis drivers and digitalization (graphic visualization).

Stardust Step	Objectives in giving support in decision-making	Serious Game / gamification	Octalysis driver	Digitalization – graphic visualization
1	Support the understanding of future events linked with macro, *meso* and micro levels	Timeline Trivia game, drag and drop game	Development & Accomplishment	Time-line with events
1	Identify short-, medium- and long-term events that might affect the product portfolio	Fill up	Unpredictability & Curiosity	Interactive Template and example
2	Guide the understanding of the sustainability assessment overtime	Timeline Trivia game	Development & Accomplishment	Interactive Template, example.
2	Link sustainability assessment with future events	Event cards game	Unpredictability & Curiosity	Icons – visual, step 1 data.
2	Guide the sustainability assessment by using the sustainability principles	Fill up	Development & Accomplishment	Interactive Template, bar graphics
3	Prioritize the portfolio evaluation criteria	Percentage donut	Development & Accomplishment	Interactive Template: donut graphic
3	Guide the market success assessment by using the portfolio evaluation criteria	Fill up	Development & Accomplishment	Interactive Template, example.
3	Link the market success assessment with future events	Event cards game	Unpredictability & Curiosity	Icons – visual, step 1 data
4	Identify actions to improve the sustainability and market success performance overtime	Brain storming games	Empowerment of Creativity & Feedback	Interactive Template, bar and 3D graphics
4	Link key stakeholders with prioritized actions in a time frame	Road map	Epic Meaning & Calling, Ownership & Possession	Timeline, stakeholders' icons
all	Encourage the discussion and collaboration in the team	Compete as a team	Social Influence & Relatedness	Interactive Template and graphics
all	Reward to accomplish the challenge	Points. Leader board, Progress bar, final treasures	Development & Accomplishment, Unpredictability & Curiosity	Interactive template, Icons and mentor (child)
all	Develop the critical thinking	Trivia games, scenario modeling, event card games, road map.	Ownership & Possession	Examples, tutorials, Interactive Template and graphics

4.3.1. General usability aspects

The experts and workshop participants noticed the benefits of using the method. It was mentioned that "I think it creates a lot of good discussions in a small amount of time" (SPD course student). In the evaluation form, most of the workshop participants would like to use and apply the method in the future. Some experts and workshop participants highlighted the possibility to use the STARDUST 2.0 method to train and discuss about sustainability. They mentioned that "this would teach the companies that are at the beginning of their sustainability journey quite a lot" (Expert J), and "It brings colleagues together to define and discuss sustainability in a business context" (workshop participant from company C). In product development, it is crucial to explore other ways to innovate and determine what is needed. It was suggested that "rather than thinking about the specific product concept, we should move towards functional innovation and think about what kind of need we are meeting, what kind of core competencies we have" (Expert J). Moreover, the workshops triggered reflections about the sustainability performance in the long term and how to deal with future trends. It was mentioned that "what is acceptable today, might not be acceptable tomorrow… in the future, the legislation will be tougher, what is required today will be different tomorrow" (workshop participant from company B). Some experts and workshop participants noticed the link between the four steps of the method and how they support each other with comments such as "You've linked everything together. I haven't seen that in many tools" (Expert G).

Further on, in the workshops, the games used in one of the STARDUST 2.0 method steps proved to be useful when trying to understand the relevance of different time perspectives and different system levels, such as macro events related to the trends that occur worldwide and how the portfolio is affected by those, for example the population rise. Expert D mentioned that it is possible that the company define its own future and design *future proof solutions*, i.e., solutions prepared for future changes, making necessary changes to the company operations, and educate and train high-level positions. Moreover, applying different brainstorming serious games helped to be more creative and develop a roadmap. Reflections mentioned that "It was interesting to make good ideas out of bad ideas… and see them in a timeline", and "it's quite early, so we haven't established all the stakeholders, so it's a good exercise" (workshop participants from Company B). Most of workshop participants found the two-dimensional graphs useful, in opposition to the three-dimensional graphics which were challenging to understand.

4.3.2. Usability aspects in relation to digitalization of the STARDUST 2.0 method

Some of the experts mentioned that Microsoft Excel was a good option to facilitate the use of the method, highlighting the possibility to connect with other tools and data sources, collaborate on-line, easy to use, one single file, and no extra training. Some commented: "Excel is used everywhere… it's shareable, extendable and editable by everybody" (Expert B). In contrast, to obtain a better visualization of the process and the results, some participants preferred analog material,

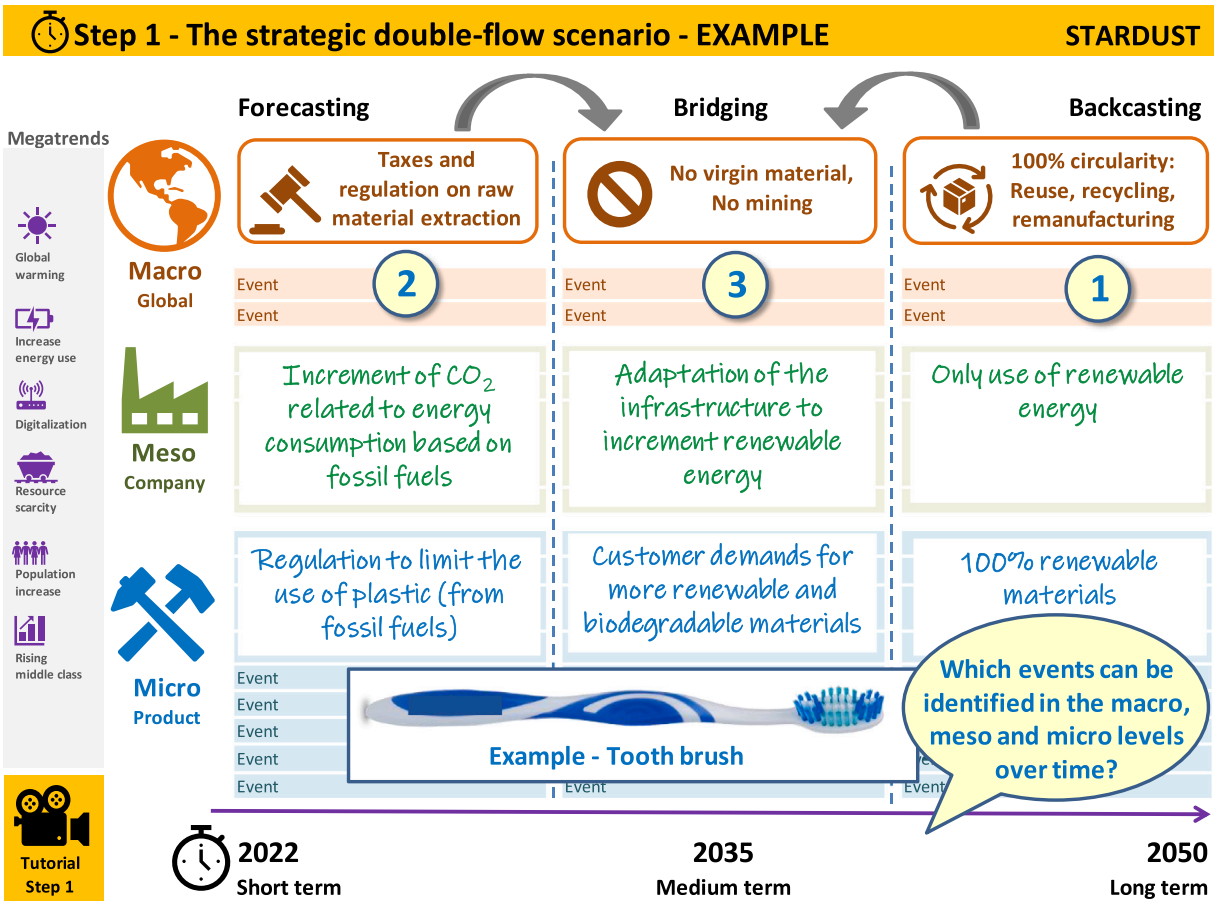

Fig. 8. Interactive interface of the strategic double-flow scenario modeling, step 1. Toothbrush case.

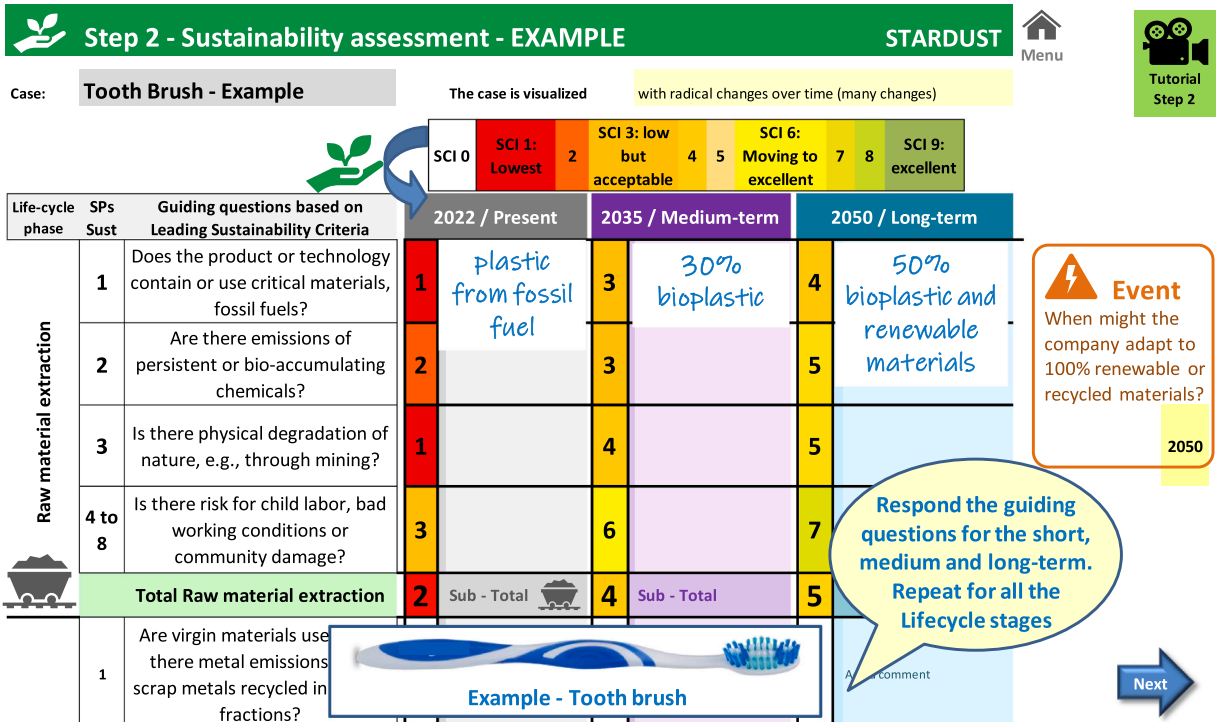

Fig. 9. Interactive interface of the sustainability assessment, step 2, including event card games and questions based on SPs and SCI scale. Toothbrush example.

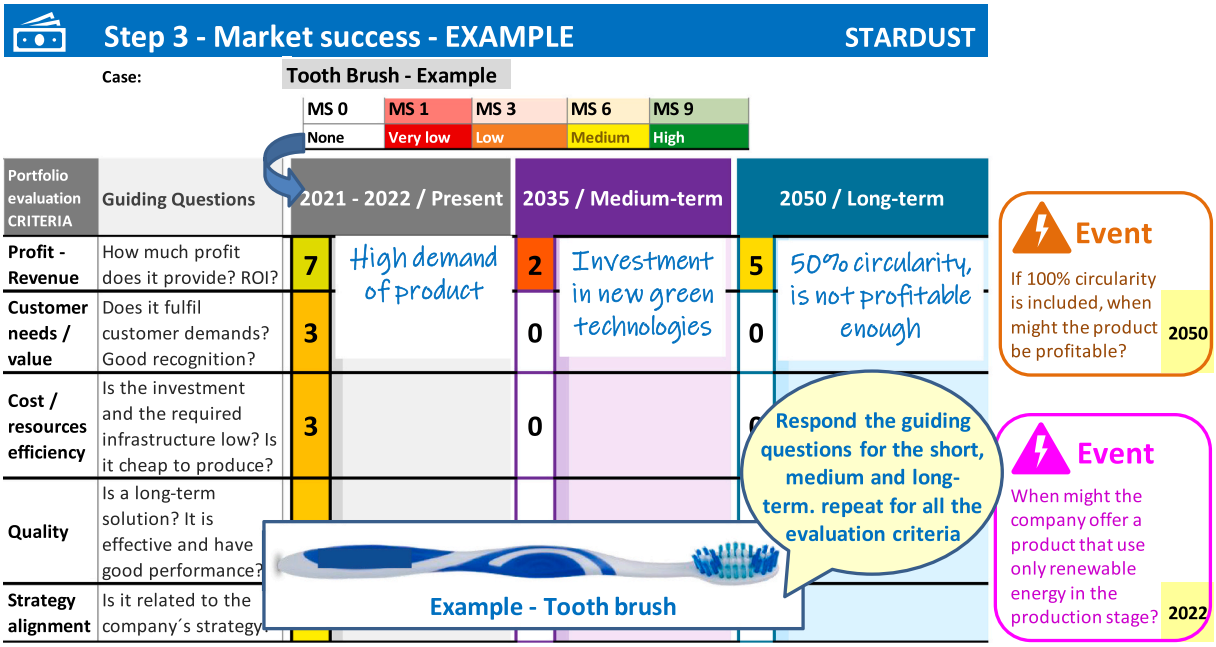

Fig. 10. Interactive interface of the market success assessment, step 3, including event card games and questions based on portfolio evaluation criteria and MS scale. Toothbrush example.

such as posters. Some experts noticed the need to include extra data in the process to support the assessment and the decision-making process. One expert mentioned that "I like the method structure, but at the end it is necessary to include how much this will cost for the company" (Expert H). Some workshop participants mentioned that it was positive to watch the video tutorial before the workshop, it helped them to form a better understanding of the complete method. Most of the method users experienced that it was necessary to re-do the assessment to obtain a useful outcome, and the digital templates facilitate this process in a systematic way. In the workshop with the students, they continued and finalized the assessment, they adapted the graphics according to their needs. Digitalization allowed to visualize the data using graphs. Most of the users liked the graphs, colors, and images. In contrast it was mentioned that "this method describes complex problems with simple charts, this may be a good way to communicate… For problem solving it is less clear to me" (workshop participant from company B). The method users also noticed that the assessment requires active participation of the team members with the constant support of a trained facilitator to guide the complete process. Some experts suggested that the method could be linked and supported by other tools to improve its usability.

Others suggested that STARDUST 2.0 method might be applied as a consultancy tool with other organizations, because its coherent structure, guiding the assessment step-by-step with engaging visualizations.

4.3.3. Usability aspects in relation to a game-based approach in the STARDUST 2.0 method

A game-based approach was used to improve the STARDUST 2.0 method. Workshop participants and experts agree that this approach engaged them to have a better understanding of the assessment. Some of them said: "making a hard and boring task, pretty fun and enjoyable!" (SPD course student), and "a gamified way is more fun and engaging… presenting this as a game is much nicer than presenting it in a dry way" (Expert J). Few of the workshop participant found that the use of games makes the activity childish, removing the required seriousness. It was mentioned that "I liked the questions and the visualizations, but it could give an unserious image of the results" (workshop participant from company B). To solve this issue, one expert suggested that "One strategy to make the participants encouraged and feel that it is a serious and relevant activity, is to avoid saying that it is a game" (Expert F). Most of the method users were satisfied with the brainstorming games included in step 4 as shown in their remarks. It was said: "It was interesting to have the bad ideas… it can be easy to focus on what is wrong today… and find ideas to solve that problem" (workshop participant from company B). Moreover, it was mentioned that the *Strategic wisdom* as an award element, engaged users to acquire more wisdom related to a strategic sustainability perspective. In opposite side, it was mentioned that "I like the questions, but I don't think it's necessary, the point system at the end" (workshop participant from company B).

5. Discussion

Based on the results from the literature review, interviews with experts, and learnings from applying the STARDUST 2.0 method in practice, recommendations for how to utilize digitalization and a game-based approach to improve the usability of decision-support tools in general, and for SDMTs in particular, were identified, see Table 6. These recommendations can help to facilitate the application of such tools and improve their uptake and implementation in both industry and academia.

It is important to reflect on the fact that "digitalization is not about turning existing processes into digital versions, but rethinking current operations from new perspectives enabled by digital technology" (Parviainen et al., 2017). The digitalization of the STARDUST 2.0 method enabled to keep the assessment organized, manage the process complexity, and to visualize the results. In addition, the game-based approach is also recognized for increasing motivation, creativity, and stakeholder participation. In decision-making and sustainability assessment, gamification is more than points, badges and leader boards. It makes it possible to engage users by applying the gamification drivers such as *Empowerment of Creativity & Feedback*, where creativity is a rewarding activity by itself (Chou, 2019).

Faludi et al. (2020) recommended that SDMTs should be general enough to be used in different contexts and fields, but also that SDMTs should be easy to adjust to specific company needs and requirements. With digitalization it is possible to offer both of these criteria. In the case of the STARDUST 2.0 method, it provided general support, applicable in different industry sectors, as well as in academic settings. At the same time, facilitators were able to adapt some parts of the method to make

Table 6
Recommendations to apply digitalization and a game-based approach in sustainable design methods and tools (SDMTs).

Recommendations to apply digitalization and a game-based approach in SDMTs.
Digitalization
From the literature
Include a digitalization strategy, linking the company resources, logistics and management (Imgrund et al., 2018)
Determine what kind of data that is relevant (Nell et al., 2021)
Understand the limitations of digitalization (Nell et al., 2021; Niehoff, 2022)
Create digital awareness and training in selecting, managing and using the data (Parida et al., 2019)
Provide a variety for different expectations and needs (Nell et al., 2021)
Determine the digital tool goal related to the use and expected results (Denner et al., 2018)
Facilitate collaboration between different stakeholders (Favi et al., 2018)
Enable maintenance and update (Kalakul et al., 2014)
Add reality to the simulation (Schrier, 2015)
Guarantee privacy and data security (Parida et al., 2019)
Enable integration with other tools (Favi et al., 2012)
From experts and workshop participants
Provide enough flexibility to assess products, services, and business models
Include interactive examples that guide through the tool step by step
Provide clear guidance for how to use the tool, e.g., tutorials
Avoid cognitive load, minimizing the information amount, e.g., pop-up windows
Include example banks from different industry fields
Make templates flexible, allowing for adaptation according to the assessment and context
Visualize the complete assessment, e.g., using several screens
Game-based approach
From the literature
Track long-term effects and results of the process (Guillen Mandujano et al., 2021)
Explore de benefits to use team-based and collaboration in the process (Tsourma et al., 2019)
Add diversity and customization, e.g., different levels, awards, challenges (Lithoxoidou et al., 2020)
Support with conceptual background and focus on the target audience (Whalen et al., 2018)
Enable adjustment of difficulty (levels) based on the mastery, experience and skills of the team (Tsourma et al., 2019)
Include different challenges, difficult achievements, and fun (Dewulf, 2010)
Provide immediate feedback (Perini et al., 2017)
Work with real cases and data (Duin and Thoben, 2011)
Provide reward by the game itself (AlMarshedi et al., 2015)
Link the game to the user's context, application, expectations and requirements (Scurati et al., 2020)
Make it clear that participation is a voluntary action (AlMarshedi et al., 2015)
Ensure learning and reflecting in a short period of time (Dewulf, 2010)
From Experts and workshop participants
Make the serious games customizable, according to the company field and context
Encourage collaboration avoiding competition
Use reverse treasures, i.e., guiding those teams with lower amount of points
Increase uncertainty in the game, e.g., randomness
Provide valuable rewards to the users, e.g., extra support

them fit specific companies. In line with this, it was recommended that a digitalization strategy be developed in order to connect the company resources, logistics, and management (Imgrund et al., 2018), as well as to make templates flexible, allowing for adaptation according to the assessment and context (workshop participants and experts). It is also important to recognize that users and companies have different skills, expectations, and needs. For that reason, it is recommended that the digitalized platform provides enough diversity and flexibility to adjust to the company requirements (Lithoxoidou et al., 2020) and the players' taxonomy (Bartle, 1996). As a contrast, it was also found that the use of a game-based approach can cause the opposite effect. Increased tool complexity tends to make it more difficult for practitioners to adjust the tools themselves, since a deeper understanding of the game mechanics and balancing of game difficulty now is required.

According to Peace et al. (2018), decision-support tools need to take the user into account and facilitate usability and interaction with the tool. Thus, they recommended to increase collaboration between users, facilitators, and tool developers. The testing of the STARDUST 2.0 method showed that digitalization and a game-based approach can be beneficial in this regard, both as tutorials that can guide the user step-by-step, and via examples, interactive graphics, and pop-up windows that can elevate usability and interaction.

In SDMTs, clear and transparent visualization of the assessment process and results are required (Faludi et al., 2020; Bianchini et al., 2019). In the STARDUST 2.0 method, digital visualizations of the process were included with the intention of facilitating the discussion and the assessment of the sustainability performance of the product portfolio. Surprisingly, the method testing showed that some of the digital graphics were not supporting the assessment, but instead requiring further guidance from the facilitators. It was recommended by users to visualize the complete process using other screens, and to support the discussions using analog activities. Some recommendations are related to the fact that digitalization has limitations, and not all the processes might be suitable for or facilitated by digitalization (Nell et al., 2021). Also, the use of a game-based approach often increases complexity and decreases transparency, which can lead to the tool being perceived as a black box, making its results less trustworthy by users.

Most digital games are lacking the nonverbal communication, social proximity, and concurrent communication (Almås et al., 2021). But, game participants need social interaction and make decisions about sustainability implementation as a team, which is why Scurati et al. (2020) recommend using analog serious games to encourage the discussion and reflection of the industry participants. Even though digital games are limited in some respects, they do offer both the benefit and possibility for users to meet physically with social interaction and to engage in the game remotely from different locations.

In the literature review, it was identified that games themselves are rewarding (AlMarshedi et al., 2015) and that non-monetary rewards in gamification can engage teams to have a better performance (Wanick and Bui, 2019). In line with this, it is necessary to develop strategies to

increment the intrinsic motivation, this might be applied using the SDT and the users´ psychological needs: autonomy, competence and relatedness (Mekler et al., 2017; Ryan and Deci, 2000). In addition to this, some experts in this study recommended the use of *reverse treasures,* i.e., providing extra activities or material to teams with lower scores to boost such teams' knowledge and reflections with incentives. This recommendation was however not included in the reviewed literature.

With digitalization and a game-based approach it is possible to collect data, share it, and continue working with it. However, the amount of data can be overwhelming, and it is recommended to carefully consider what kind of data that is relevant, avoiding cognitive overload (Nell et al., 2021).

When using a game-based approach to support SDMTs, it is essential to consider that this kind of approach is still lacking evidence of its effectiveness in the long term (Nemoto et al., 2014). The application of gamification has a temporary use, i.e., when it is overused, users might reject it (AlMarshedi et al., 2015). Therefore, constant updates according to the users´ needs, is recommended (Kalakul et al., 2014), as well as adding of different elements, challenges, and achievements (Dewulf, 2010). However, this is a resource intensive activity and requires a person with the necessary knowledge and responsibility to maintain and update the tool.

The case of the STARDUST 2.0 method indicates that digitalization and a game-based approach have the potential to improve the usability of a SDMT, but also pointed out that careful consideration is necessary to avoid pitfalls. Based on the results of the testing, the STARDUST 2.0 method might be useful for sustainability training in academia and industry. By leveraging on the strengths of digitalization and game-based approaches to improve the usability of SDMTs the method might guide companies to increase their sustainability awareness, implement a strategic sustainability perspective in the company strategy, include high-level positions in the discussions, reflect on the company responsibility, and develop more sustainable solutions, which can be a path for a transition to a more sustainable society.

6. Conclusions

Decision-makers at product development companies urgently need to increase their capabilities for including strategic sustainability thinking in their processes. This is imperative both for company success on increasingly sustainability-driven markets and for ensuring the well-being of human and other life forms on this planet. The integration of a sustainability perspective in product development requires a holistic view that includes the environmental and social dimensions, as well as economic implications, while at the same time considering the complete product life cycle, all stakeholders involved, and uncertainty around future developments. The implementation of SDMTs in an industrial setting is challenging, largely because of low usability of SDMTs.

In light of these needs and challenges, the contribution of this study is twofold. Firstly, specific recommendations, derived from literature review, expert interviews, and testing, were proposed for how digitalization and a game-based approach can complement each other to increase usability and implementation of SDMTs. Through literature review, expert interviews, and the development and testing of the STARDUST 2.0 method, it was found that digitalization is especially helpful to facilitate data management, scenario simulation, operation automatization, data visualization, and integration with other company systems and tools. In parallel, a game-based approach can support and increase collaboration, motivation, co-design, and data collection. At the same time, it is necessary to consider the limitations for a successful implementation, such as data security, and overuse of extrinsic rewards. The proposed recommendations can be used by researchers and practitioners, who either develop new SDMTs or aim to improve usability and implementation of existing ones.

Secondly, this study contributes to the area of product portfolio development by providing a method, STARDUST 2.0, that can guide decision-makers in the early phases of the product innovation process in implementing a strategic sustainability perspective. Based on the needs and challenges identified in research and practice, the method was designed to facilitate i) adopting a strategic perspective; ii) modeling various scenarios to identify the sustainability impacts throughout the entire product life cycle; iii) determining clear portfolio evaluation criteria for selecting the portfolio components; iv) guiding the process to create strategies to balance the portfolio over time; and v) facilitating the communication and participation of key stakeholders in the decision-making process. The STARDUST 2.0 method has evolved according to the experts' and workshop participants' feedback. Brainstorming serious games were, for example, included to guide the identification of actions and in the creation of a roadmap. While in general the application of digitalization and a game-based approach helped in overcoming some of the known difficulties with the implementation of SDMTs, new challenges were also discovered. For example, the digitalization made it more difficult to get an overview of the complete assessment process and the game-based approach did not motivate all participants as expected. The assessments were also perceived as less transparent, which negatively affects the trustworthiness of the results. This further points towards the importance of providing recommendations in order to leverage on the strengths of combining digitalization and a game-based approach while avoiding unintended negative effects.

Given the purpose and scope of the study and the methodological choices that were made accordingly, there are also limitations in relation to the validity of the findings. The review of the literature was semi-systematic, which implies that there might be additional research that was omitted. However, an inclusive search query in combination with snowballing was applied to cover the most important work in the field. The STARDUST 2.0 method prototype was tested in a limited number of cases and additional tests are necessary to gain further insights on its applicability and usefulness in other contexts. Finally, the STARDUST method was used as a specific method to study if and how digitalization and game-based approaches can support the usability of SDMTs. While this research design yielded hands-on and in-depth insights, future research should also study other methods, as it is likely that there are differences in how digitalization and a game-based approach should be used to best advance different kinds of SDMTs. Future work will also include a deeper exploration of the possibilities that digitalization and a game-based approach provide to expand SDMTs' usability, such as to: i) use all the gamification drivers proposed in the Octalysis framework; ii) design according to the different user typologies and skills, e.g. increase difficulty when players acquire mastery in the process; iii) explore a hybrid between analog and digital interventions; iv) link, integrate, and support with other tools and data, v) deeper social sustainability assessment,; vi) co-create with the companies to develop SDMTs that are adapted to the company needs and context.

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.

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Appendix A. Semi-structured interview guideline

Table A1
Semi-structured interview guideline.

#	Semi-structured interview guideline (used with field experts)	SPD	Portfolio	Digitalization	Game-based
1	What do you think about the STARDUST 2.0 method?	X	X	X	X
2	What do you like about the STARDUST 2.0 method?	X	X	X	X
3	What do you think about turning the STARDUST 2.0 method as a digital tool?	X	X	X	X
4	What do you think about using a game-based approach in the method?	X	X	X	X
5	What is needed to have a successful application of this method in industry?	X	X	X	X
6	From your field, what can be improved?	X	X	X	X
7	What do you think about the graphics and visual elements used in the method?	X	X	X	X
8	Would you use the STARDUST 2.0 method in the portfolio selection process?	X	X		
9	What is your opinion about modeling the future scenarios for the assessment (step1)?	X	X		
10	What is your opinion about the step 2: sustainability assessment? How can it be improved?	X	X		
11	What is your opinion about the step 3: market success assessment? might it achieve the company expectations? How can it be improved?		X		
12	What is your opinion about the step 4 - the cube: portfolio balance? Does the step 4 provide enough elements to balance the product portfolio?		X		
13	How can the user interaction be improved?			X	X
14	Which platform can be used to improve the use, experience and results of the method?			X	X
15	Which game elements can be included or removed for a better interaction with the method?				X

Appendix B. STARDUST 2.0 method workshop: evaluation form

Table B1
Semi-structured interview guideline.

STARDUST 2.0 Method Workshop - Evaluation form 2022						
1	What is your role/title at the company?					
2	Please describe how this method/tool benefited you					
3	What did you like the most about this method/tool?					
4	Did you notice any limitations while using this method/tool? If yes, what?					
5	Do you think any of your colleagues would benefit from this method/tool in the future? If yes, how and why?					
6	To what degree do you think the method could… (where 5 is most likely and 1 is not likely) a. …guide the understanding of the macro to micro level to determine some threats and opportunities? b. …help to compare concepts in a strategic way? c. …provide guidance to improve the solutions of the product portfolio? d. ...guide the reflection and the planning for future scenarios?	1	2	3	4	5
7	What parts or aspects of the tool do you like? Scale: 1 (Not at all) 3 (To some degree) 5 (Very much) a. Scenario modeling - identifying events and risks in the short, medium and long term b. Sustainability assessment - Use the SPs to evaluate the life-cycle phases c. Market success assessment - using portfolio evaluation criteria d. Cube - balancing the portfolio and finding strategies to improve the solutions	1	2	3	4	5
8	To what degree do you perceive the following aspects to be barriers for use and implementation of this method? Scale: 1 (low barrier) to 5 (high barrier) a. Time intensiveness b. It requires data we don't have c. It requires expert knowledge we don't have d. It needs a deeper explanation	1	2	3	4	5
9	To what degree would you be interested to implement this method in the future? Scale: 1 (not interested at all) to 5 (highly interested)	1	2	3	4	5
10	To what degree did the graphs and the visual elements help you to understand the assessment? (1 not helpful, 5 highly helpful)	1	2	3	4	5
11	What do you think about the game-based approach?					
12	What do you think of the usability of the method, such as flow, steps integration, use of a single Excel-file?					
13	How can this method be improved?					
14	Is there anything else you would like to add?					

Appendix C. Data analysis

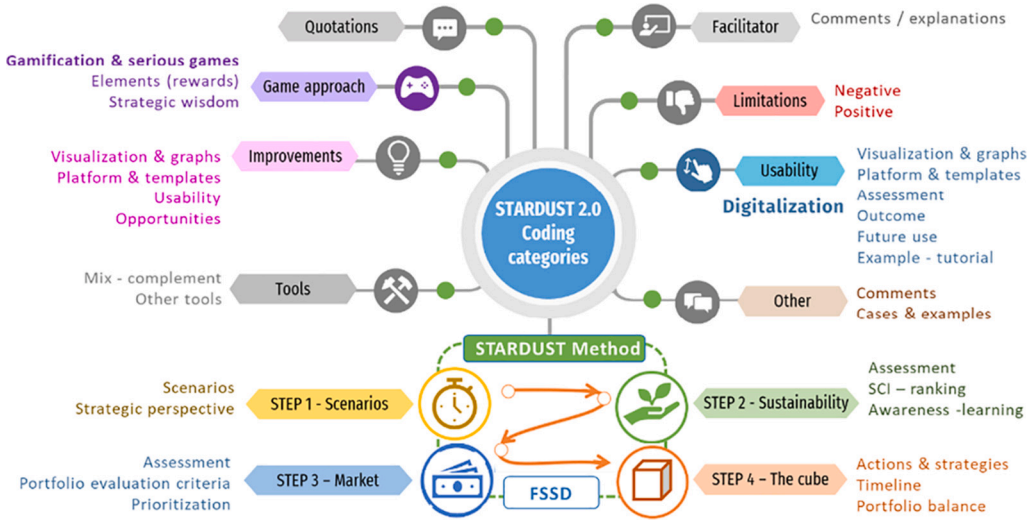

Fig. C1. Code categories used in the data analysis.

Appendix D. Detailed example Excerpts of the STARDUST 2.0 method

Portfolio evaluation CRITERIA	Relevance	%
Profit - Revenue	5	20 %
Customer needs / value	4	16 %
Cost / resources efficiency	2	8 %
Quality	4	16 %
Strategy alignment	3	12 %
Competitive	3	12 %
Innovative	1	4 %
Legislation	3	12 %

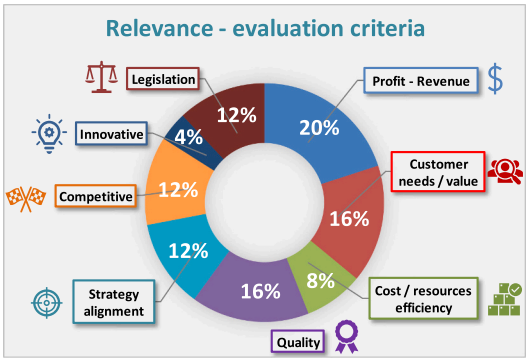

Fig. D1. Interactive interface of the step 3, prioritization of the portfolio evaluation criteria.

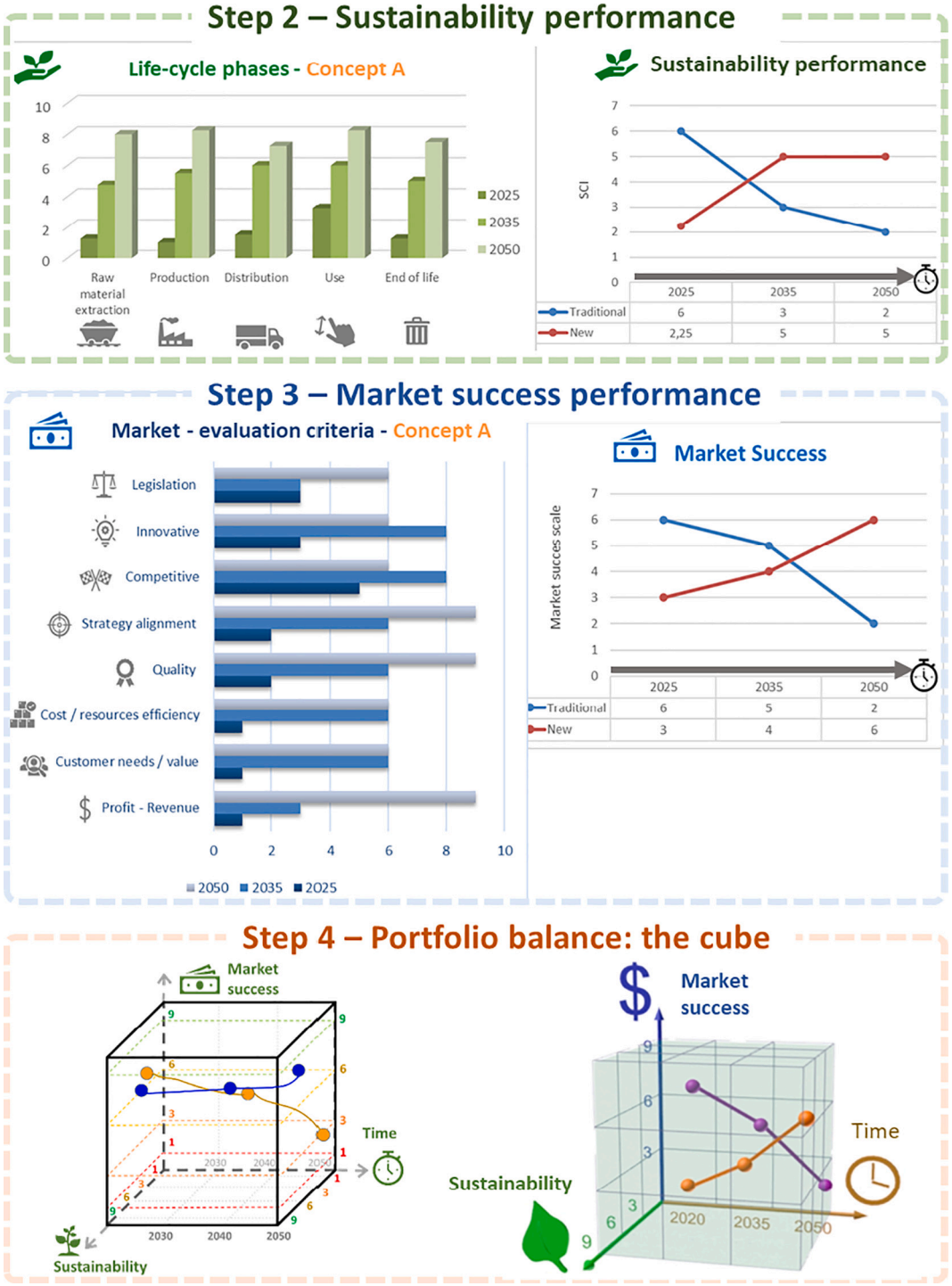

Fig. D2. In the Step 4, Portfolio balance: the cube, the sustainability and the market success performance over time are visualized.

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