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A Framework of Hybrid Method for Developing Optimal Sustainable Product Strategies and Sustainable Product Roadmap

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Abstract: The success of sustainable product strategies is widely recognized as pivotal to the successful development of sustainable products. Despite some existing research on sustainable product strategies, there is a notable lack of investigation into the tools necessary for their effective development. To address this gap, our study aims to (1) introduce a methodological framework that systematically shapes sustainable product strategy, incorporating key technologies like a Sustainable Product Strategies Focus Group (SPSFG), Brainstorming, Weighted Decision Matrix (WDM), and Genetic Algorithm (GA); (2) demonstrate the practical application of this framework through the example of 3C products; and (3) contribute theoretically by proposing a tool for creating sustainable product strategies that integrates management principles, providing a practical guide for the development of control systems and tools. This study also maps out implications for the future of sustainable 3C products. The development of optimal sustainable product strategies across various sectors requires a comprehensive hybrid approach. This method combines diverse methodologies to create a robust framework addressing unique challenges in health systems, education, environment, industry, agriculture, energy, and resource management. Leveraging quantitative analysis, qualitative assessment, and systems thinking, the hybrid approach provides a nuanced understanding of interdependencies within these sectors. Integrating data-driven insights and qualitative considerations facilitates sustainable strategies, optimizing resource utilization for long-term environmental, social, and economic benefits. This holistic methodology enables a more effective response to interconnected challenges in health systems, education, environmental preservation, industry, agriculture, energy, and resource management, promoting a more sustainable future.

Keywords: sustainable product; sustainable strategies; 3C products; SDGs; brainstorming; WDM; GA

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1. Introduction

Sustainable products encompass those that offer environmental, social, and economic advantages while safeguarding public health and the environment throughout their entire life cycle, from raw material extraction to final disposal [1]. A sustainable product is characterized by the following: (1) Use of Renewable Resources: Sustainable products are crafted from renewable resources to prevent the depletion of natural resources. (2) Minimal Energy Consumption and Waste Generation: These products require minimal energy and generate minimal waste during their production and distribution. (3) Recycling and Reuse Options: Sustainable products offer options for recycling and reuse, contributing to a circular economy. (4) Adherence to Safe and Socially Responsible Practices: They are manufactured under safe working conditions and follow socially responsible practices [2]. In the face of escalating global sustainability challenges, businesses are confronting heightened expectations. This increased pressure emanates from various sources, including the rising consumer demand for sustainable products, evolving regulations, and the expectations of fellow businesses, financial institutions, and shareholders. Consequently, there is a

growing emphasis on considering and adopting sustainable practices within both product development and overall business operations [3]. When products are designed with sustainability in mind, they contribute to the overall success and longevity of the product itself [4]. The development of sustainable products involves incorporating environmentally friendly practices, considering the product's life cycle, and minimizing negative impacts on the environment [5]. By adopting a sustainable approach, companies can not only meet the demands of the present but also ensure the continued success of their products in the future [6]. Successful sustainable product development goes beyond immediate profitability. It encompasses the responsible use of resources, reduction in waste, and the promotion of eco-friendly manufacturing processes. This holistic approach not only benefits the environment but also enhances the reputation of the product and the company [7]. In conclusion, sustainable product development is a key factor in achieving lasting success. By prioritizing environmental considerations, adopting eco-friendly practices, and focusing on the long-term impact of products, companies can create products that stand the test of time and contribute positively to both their bottom line and the planet [8].

Creating effective and sustainable product strategies is a crucial and multifaceted process that goes beyond being merely a step in the sustainable product development toward successful sustainable products; rather, it stands as a pivotal factor in their overall success. Sustainable product strategies refer to those strategies for designing and developing sustainable products [9]. To achieve success sustainable product, effective sustainable product strategies are essential [10]. Unlike conventional product strategies that focus on introducing or modifying products for market success, sustainable product strategies specifically center around incorporating environmental and economic considerations into the design and development process. This entails factors such as energy efficiency, the use of renewable materials, and waste reduction [11]. Social aspects, such as adherence to labor standards, poverty alleviation, and assessment of health impacts, are also integral to these strategies [12]. The intricacies of sustainable product development involve not only the integration of eco-friendly materials and production methods but also encompass considerations of market demand, ethical sourcing, and long-term environmental impact [13]. By emphasizing the development of comprehensive and accurate sustainable product strategies, businesses can navigate the complex landscape of sustainable practices, ensuring that their products not only meet the immediate demands of conscious consumers but also contribute to a lasting positive impact on the environment and society [14]. In essence, the sustainable strategic foundation laid during the product development phase becomes the cornerstone upon which the success of sustainable products is built, reinforcing the notion that careful planning and thoughtful execution are integral to achieving genuine and enduring sustainability [15].

3C products, encompassing computers, communication devices, and consumer electronics, constitute an integral part of our modern technological landscape. Defined as items falling within these three categories, 3C products have become indispensable in our daily lives, reflecting their profound impact on human connectivity and convenience. These products include smartphones, laptops, tablets, and various electronic gadgets that play a vital role in communication, work, and entertainment [16–18]. The global annual output value of 3C products has surged exponentially, underscoring their economic significance. However, as the demand for these products continues to grow, there is a pressing need to address sustainability concerns [19,20]. Presently, 3C products lack a comprehensive sustainable product strategy, necessitating the establishment of robust mechanisms for discussion and construction. Recognizing the environmental impact of electronic waste and the depletion of resources, integrating sustainable practices into the production, use, and disposal of 3C products is imperative for a more responsible and eco-friendly technological future.

Developing a robust tool for creating correct sustainable product strategy is crucial for crafting successful products that prioritize sustainability. This tool functions as a guiding compass, directing organizations toward environmentally conscious and socially responsi-

ble practices. Integrating such a tool into the strategic planning process enables businesses to align their objectives with sustainable principles, ensuring that each phase of product development adheres to ethical and ecological considerations. This holistic approach not only promotes environmental stewardship but also enhances long-term viability and profitability [21,22]. The use of an effective sustainable product strategy development tool becomes a cornerstone for companies committed to innovation, meeting current market demands, and anticipating and addressing evolving consumer and stakeholder expectations [23]. This fosters a harmonious balance between business growth and ecological responsibility.

In the realm of sustainable product, a myriad of contemporary research avenues beckon exploration, chief among them being the elucidation of sustainable policy definitions [24] and the construction of framework for sustainable product development [25]. Scholars are delving into the intricacies of what constitutes a sustainable policy, seeking to establish clear parameters that guide conscientious decision making [26,27]. Concurrently, there is a concerted effort to decipher the nuanced process of formulating these policies, which is a task that demands a comprehensive understanding of the intricate balance between environmental, social, and economic factors [28]. Interestingly, the current landscape of research in this domain has yet to fully investigate the methodologies involved in crafting sustainable product strategies. This omission underscores a critical gap in our understanding of how to effectively integrate sustainability principles into tangible product development. Consequently, this article also aims to address this lacuna by focusing on the development of methods tailored specifically for the formulation of sustainable product strategies, thereby contributing to the holistic evolution of sustainable business practices.

In this study, our main goal is twofold: firstly, to propose a methodological framework that effectively shapes sustainable product strategy, and secondly, to demonstrate its practical functionality. To achieve these objectives, we followed a systematic approach involving key tasks. (1) Initially, we conducted a thorough literature review to identify relevant technologies suitable for constructing a methodological framework tailored for sustainable product strategy formulation. Notable methodologies considered included SPSFG, Brainstorming, WDM, and GA Technologies. (2) Building upon the principles of Sustainable Development Goals (hereinafter referred to as SDGs) and product strategy formulation processes, we seamlessly integrated these identified technologies to establish a robust methodological framework. This integrated framework serves as a valuable tool for formulating sustainable product strategies. (3) To provide a concrete demonstration of its application, we selected 3C products as a representative example, illustrating how the integrated framework operates in the context of sustainable product strategy formulation. (4) Through the sustainable product strategy for 3C products developed through the framework constructed in this study, this study puts forward suggestions for a sustainable product strategy for the 3C products industry. (5) Finally, through this comprehensive approach, our study aims to contribute not only to the theoretical understanding of sustainable product strategy formulation but also to provide a practical guide for industry practitioners. SPSFG's mission is to formulate sustainable product strategies by employing technologies like Brainstorming, WDM, and GA within a structured framework.

2. Literature Review of Relevant Technologies

2.1. The Tool for Developing Sustainable Product Strategies

A tool for creating product strategy is an instrumental resource designed to guide businesses in formulating a comprehensive and effective plan for the development, marketing, and management of their products [29]. Such a tool serves as a structured framework to help organizations align their product initiatives with overarching business objectives [30]. The components of a tool for creating product strategy typically encompass market analysis, competitive landscape assessment, target audience identification, value proposition definition, and a roadmap for product development and deployment [31]. Different from tools for developing product strategies, a tool for creating a sustainable product strategy serves as a comprehensive framework that organizations can employ to develop and implement prod-

uct plans aligned with ecological, social, and economic sustainability goals [32]. This tool integrates various components to guide decision-makers in crafting strategies that not only meet market demands but also minimize environmental impact, foster social responsibility, and ensure long-term economic viability [33]. Key components of such a tool include robust environmental impact assessments, ethical supply chain considerations, circular economy principles, and stakeholder engagement strategies [34]. The tool operates by systematically analyzing these components, allowing businesses to identify opportunities for sustainable innovation, assess potential risks, and make informed decisions throughout the product life cycle [35]. By providing a structured approach, the tool empowers organizations to weave sustainability into the fabric of their product strategies, contributing to a more responsible and resilient business model in an ever-evolving global landscape. The core concept for constructing the framework for developing sustainable product strategies will be the tool for developing sustainable product strategies.

2.2. The SPSFG

A focus group method, also known as a focus group or discussion group, is a qualitative research method involving group interviews to gather insights on a specific product, service, concept, advertising, or design [36]. The goal is to collect opinions and comments from participants [37]. The selection of focus group members is typically completed by the researcher to ensure that participants can express their views openly [38]. The concept of the focus group originated from an experiment conducted by Robert K. Merton, an expert at Columbia University's Bureau of Applied Social Research, while its fundamental idea was formulated by psychologist and market analyst Ernest Dichter [39]. The focus group method is advantageous in product development for several reasons. (1). Unique and In-Depth Insights: It provides distinctive and thorough insights into the product. (2) Direct Market Feedback: The method allows for a genuine understanding of the market's feedback on the product. (3) Flexible Interviewing: Interview questions can be promptly adjusted based on the ongoing discussion with participants. (4) Behavioral Observation: By observing the behavior of participants, a better understanding of the user situation can be gained. (5) To leverage these advantages in the development process, we will implement the focus group method within the framework to establish the SPSFG [40]. This group will play a crucial role in aiding the development of sustainable product strategies. Different from traditional focus groups, SPSFG is a specialized form of a focus group designed to gather qualitative insights and expertise on sustainability-related topics of product strategies [41]. Comprising individuals with in-depth knowledge and experience in areas such as environmental conservation, social responsibility, and economic sustainability, this focus group aims to explore and analyze sustainable practices, strategies, and initiatives [42]. The components of an SPSFG involve the careful selection of participants who possess diverse and comprehensive expertise in sustainability, sustainable product development and product strategies. These experts engage in group interviews facilitated by a knowledgeable moderator, following a well-designed outline that aligns with the intricacies of sustainability discussions [43]. SPSFG's mission is to formulate sustainable product strategies by employing technologies like Brainstorming, WDM, and GA within our framework.

2.3. Brainstorming

Brainstorming is a creative and collaborative process designed to generate a multitude of ideas to address a specific problem or task [44]. It serves as a valuable technique for unlocking the collective creativity of a group, fostering innovation, and exploring diverse perspectives [45]. The components of brainstorming typically involve a group of individuals, a facilitator or leader, an open and non-judgmental environment, and a focus on quantity over quality during the initial idea generation phase. Participants are encouraged to freely express their thoughts without fear of criticism, and the goal is to build upon each other's ideas to create a robust pool of potential solutions [46]. The

process works by leveraging the power of collective thinking, allowing for the exploration of various angles, insights, and innovative concepts [47]. Brainstorming encourages the generation of unconventional ideas that can lead to breakthrough solutions, making it an effective tool for problem solving and fostering a culture of creativity within teams and organizations [48]. Brainstorming offers several advantages that contribute to effective idea generation and decision making. (1) Facilitation of Creativity: In a short timeframe, group members can produce a multitude of creative ideas through the collaborative process of brainstorming. This method allows participants to fully unleash their creativity and facilitates the establishment of a collective decision-making consensus. (2) Stress Reduction: Face-to-face interactive conversations can sometimes introduce stress and tension, which may hinder creative thinking. Brainstorming, however, mitigates these potential barriers by providing a more open and collaborative environment for idea generation. (3) Overcoming Cultural and Social Barriers: Traditional interactions may be influenced by differences in culture and social status, hindering the free flow of ideas. Brainstorming helps to neutralize these influences, creating an atmosphere conducive to uninhibited thinking [49]. Given these advantages, Brainstorming is a valuable tool for developing sustainable product strategies. Leveraging its ability to foster creativity and collaboration, Brainstorming will be employed to shape the initial framework for our sustainable product strategy.

2.4. The WDM

The WDM, also recognized as the "prioritization matrix", "weighted scoring model", "decision-matrix method", "Pugh method", or "Pugh concept selection", stands as a potent quantitative tool originating from the innovative mind of Stuart Pugh [50]. This method serves as a qualitative technique designed to assess and rank options possessing multiple dimensions within a given set. Its versatile application extends to diverse scenarios, ranging from the evaluation of ideas and projects to pivotal decisions involving investments, vendors, or products [51]. The essential components of a WDM encompass a predefined set of criteria and a pool of potential candidate options. Within this matrix, one specific design is chosen as the reference, while the others are systematically compared and ranked against it. Criteria such as "better", "worse", or "same" are employed for comparison, and the outcome highlights the number of times each design is considered superior or inferior, although it lacks a summarized overview [52]. Decision making often involves multifaceted criteria, introducing complexity into the process. Striking a balance between the urgency of decision making and a thorough evaluation of options is paramount. The complexity arises from the varying degrees of importance assigned to different factors, necessitating an objective and quantifiable decision-making approach that prioritizes efficiency. In this intricate landscape, the WDM proves to be an invaluable tool [53]. Its strength lies in facilitating the comparison of diverse options by accounting for the varying significance of different factors. Decision-makers can assign weights to each criterion based on its importance, eliminating guesswork and emotional bias, and fostering an objective analysis. The WDM empowers decision-makers to identify and prioritize their needs, assess, rate, and compare options, ultimately facilitating the selection of the optimal solution. Furthermore, it encourages self-reflection within design teams, reducing bias and enhancing candidate analysis. Sensitivity studies enable an understanding of how much an opinion must change for a lower-ranked alternative to surpass a competing one [54]. The WDM, with its structured approach, emerges as an indispensable tool in navigating the intricate landscape of decision making with precision and objectivity. WDM is a tool that allows SPSFG to evaluate preliminary sustainable product strategies and select appropriate sustainable product strategies within the framework.

2.5. The GA

GA Technologies represent a sophisticated approach to problem solving and optimization inspired by the principles of natural selection and genetics [55]. At its core, a GA is a computational technique designed to mimic the process of natural evolution to

find optimal solutions to complex problems [56]. The components of GA Technologies include a population of potential solutions, a fitness function to evaluate the quality of these solutions, genetic operators such as crossover and mutation to simulate natural genetic processes, and a selection mechanism to choose individuals for the next generation [57]. These components collectively work in tandem to iteratively refine and improve candidate solutions over multiple generations [58]. The process begins with an initial population of potential solutions, which undergoes successive generations of evolution through the application of genetic operators, ultimately converging toward an optimal or near-optimal solution [59]. The adaptability and versatility of GA Technologies make them applicable across various domains, from engineering and optimization problems to machine learning and artificial intelligence [60]. The GA serves as an introduction to heuristic algorithms with the primary goal of approximating the best solution. It offers several advantages, including the following. (1) Customizable Solution Encoding: Each solution is typically encoded based on the specific context, facilitating the development of mutation functions and fitness functions (Fitness Function). (2) Flexibility in Solution Coding: Solutions are generally coded according to the real-world scenario, aiding in the creation of both mutation functions and fitness functions (Fitness Function). (3) Efficient Exploration of Solution Spaces: Genetic algorithms exhibit the capability to rapidly identify high-quality solutions, even within intricate solution spaces. (4) Parameter Adjustability: The genetic algorithm's performance in addressing a specific optimization problem can be enhanced by adjusting parameters such as the number of individuals, crossover rate, and mutation rate [61]. Optimizing these parameters contributes to improved and faster convergence. Given the Genetic Algorithm's proficiency in finding optimal solutions, we intend to leverage it within the framework to assist in determining the most effective combination of sustainable product strategies for WDM.

2.6. The Sustainable Product Roadmap

The Sustainable Product Roadmap serves as a dynamic guide in the product development journey, which is akin to a meticulously planned travel itinerary. It is a communicative tool that outlines the route for the team, stakeholders, and customers, answering critical questions such as the path for product development, the steps to achieve ambitious goals, and the strategies to proceed [62]. Similar to a navigation system, a product roadmap provides a clear direction for development. The main components of a product roadmap include the product vision, which aligns with the organizational mission; business objectives, tying product development to broader corporate goals; timeframes for deliverables; and themes, focusing on outcome-oriented problem-solving rather than just functions [63]. Constructing a Sustainable Product Roadmap involves strategic planning, aligning organizational plans with the product vision and concentrating on delivering value to customers [64]. The emphasis is on problem solving, gathering feedback from users, and incorporating learning into the product development process. Prioritization and organizational cohesion are crucial, which are achieved through constant communication with team members to ensure everyone understands the product roadmap's direction [65]. Importantly, the roadmap is a tool not just for internal guidance but also for engaging customers and eliciting excitement about the future product direction, making it a lightweight method for verifying requirements and ensuring alignment with user expectations [66]. The workflow steps of a Sustainable Product Roadmap involve careful planning, customer-focused problem solving, continuous learning, organizational cohesion, and maintaining customer enthusiasm for the product direction [67]. This study intends to use the form of the Sustainable Product Roadmap to collect optimal sustainable product strategies using GA so that product designers can better understand optimal sustainable product strategies and thereby design successful sustainable products.

3. The Framework of Hybrid Method Derived from SPSFG, Brainstorming, WDM, and GA Technologies for Creating Sustainable Product Strategies and Sustainable Roadmap

Figure 1 offers a comprehensive approach to develop product strategies aligned with ecological, social, and economic sustainability goals. At its core is a specialized tool that integrates environmental impact assessments, ethical supply chain considerations, circular economy principles, and stakeholder engagement strategies. This tool provides a structured framework, enabling organizations to systematically incorporate sustainability into their product strategies. The framework operates through several phases: (1) Preliminary Sustainable Product Strategies Development, (2) Evaluation of Preliminary Sustainable Product Strategies, (3) Generation of the Best Sustainable Product Strategies Portfolio, and (4) Building Roadmap of the Best Sustainable Product Strategies Portfolio. In the initial stage of developing sustainable product strategies, we will acquire preliminary sustainable product strategies. During the evaluation stage of these preliminary strategies, we will identify the best sustainable product strategies. In the stage of generating the optimal sustainable product strategies portfolio, we will compile the best strategies into a comprehensive portfolio. Finally, in the stage of building the roadmap for the best sustainable product strategies portfolio, we will create a detailed plan outlining the steps and milestones for implementing these strategies. The information flow of the framework of the hybrid method is also illustrated in Figure 2.

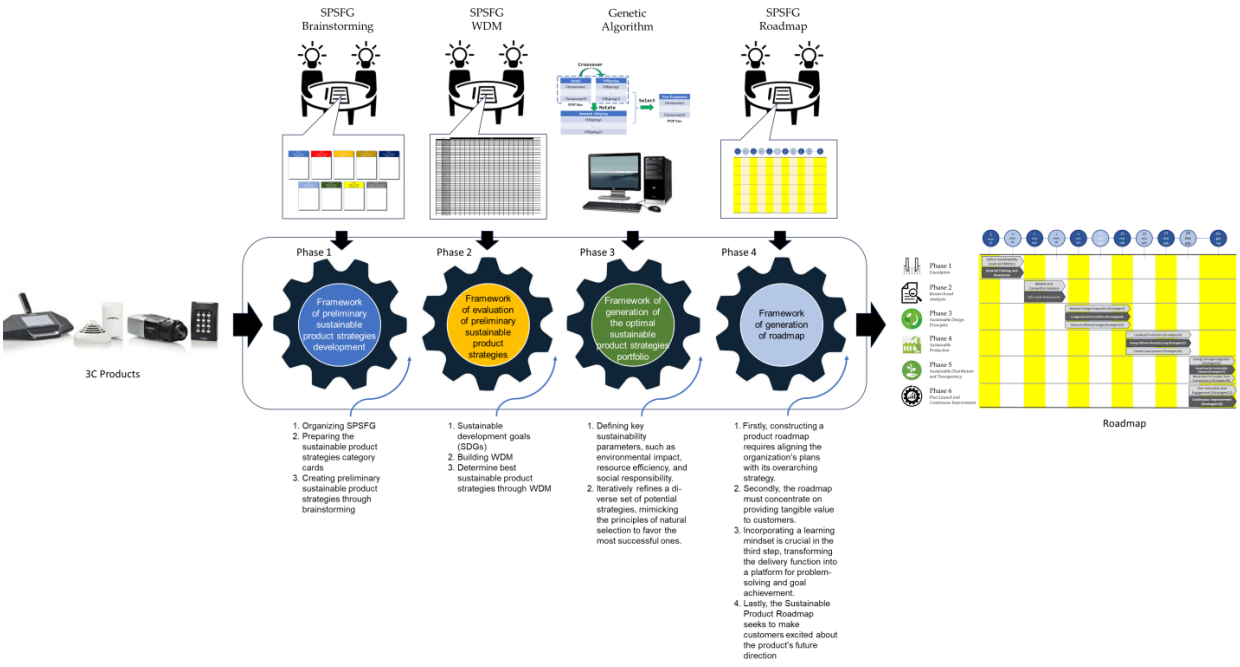


Figure 1. Framework of hybrid method derived from SPSFG, Brainstorming, WDM, and GA Technologies for creating sustainable product strategies.

1. Preliminary Sustainable Product Strategies Development

The SPSFG, consisting of experts in environmental conservation, social responsibility, and economic sustainability, conducts group interviews to gather qualitative insights on sustainability-related topics. Brainstorming within the SPSFG generates creative and innovative preliminary sustainable product strategies. This collaborative process fosters a culture of creativity within the focus group. At this stage, preliminary information on "sustainable product strategies" will be generated during the brainstorming step of creating initial sustainable product strategies.

2. Evaluation of Preliminary Sustainable Product Strategies

The WDM serves as a quantitative tool, facilitating the assessment and ranking of options for preliminary sustainable product strategies. The structured approach of the

WDM, involving predefined criteria and assigned weights, allows decision-makers to objectively analyze and compare diverse options, aiding in the selection of optimal solutions. At this stage, information on Sustainable Development Goals (SDGs) will be provided. The "number of Weighted Decision Matrix (WDM) weights for sustainable product strategies" information will be generated in the "Building WDM" step. The information on the "best sustainable product strategies" will be generated in the "Determine Best Sustainable Product Strategies through WDM" step.

3. Generation of the Best Sustainable Product Strategies Portfolio

GA Technology, inspired by natural evolution, is employed to generate optimal combinations for sustainable product strategies over successive generations. The GA technology refines and improves candidate solutions, and the optimal combinations are translated into a roadmap of sustainable product strategies. At this stage, information on the "value of sustainability parameters" will be generated during the step of defining key sustainability parameters. The "best sustainable product strategies portfolio" information is produced through steps that iteratively refine a diverse set of potential strategies.

4. Building Roadmap of the Best Sustainable Product Strategies Portfolio

The workflow steps of a Sustainable Product Roadmap entail careful planning, customer-focused problem solving, continuous learning, organizational cohesion, and maintaining customer enthusiasm for the product direction. This study aims to leverage the Sustainable Product Roadmap format to compile an optimal sustainable product strategies portfolio, which is sorted through GA. The objective is to provide product designers with insights into the most effective sustainable product strategies, enabling them to design successful sustainable products. At this stage, the "Sustainable Product Roadmap" is in the process of being developed. Constructing a product roadmap involves aligning the organization's plans, and various steps are being generated to achieve this.

In summary, this hybrid framework integrates tools and methodologies from various domains, including SPSFG, brainstorming, WDM, and GA. In doing so, it empowers organizations to develop sustainable product strategies that not only meet market demands but also contribute to environmental, social, and economic sustainability goals.

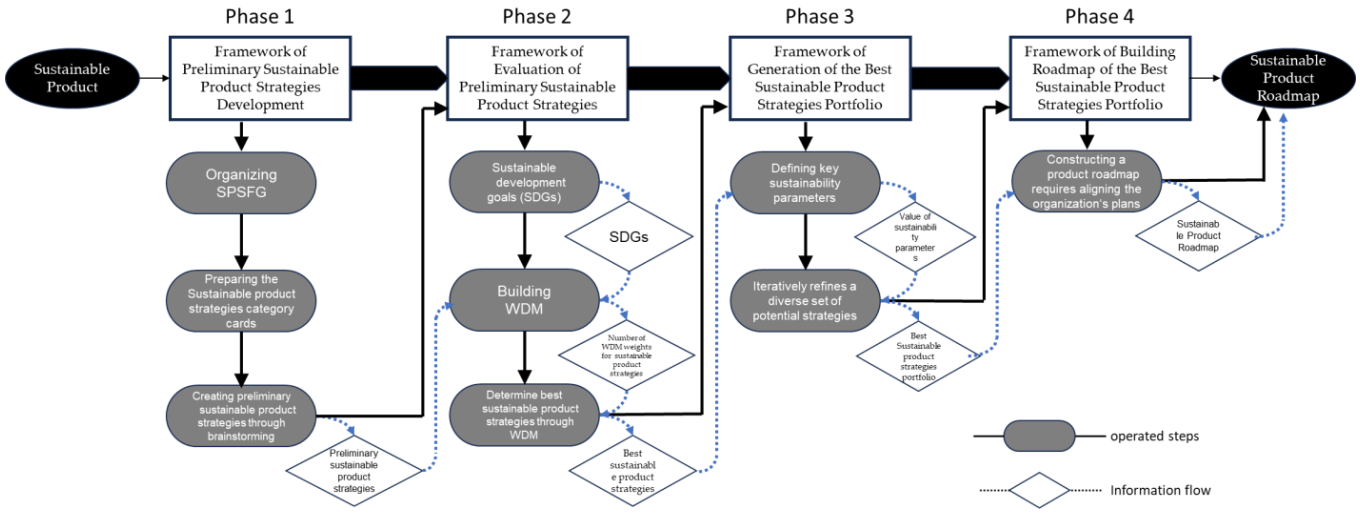


Figure 2. The information flow of framework of hybrid method.

4. Methods

4.1. Preliminary Sustainable Product Strategies Development

- Organizing SPSFG

Organizing an SPSFG involves bringing together a diverse group of stakeholders to collaboratively explore, discuss, and refine strategies for developing and promoting

environmentally and socially responsible products. The process typically begins with defining the objectives and scope of the focus group as well as identifying key participants such as consumers, industry experts, and internal stakeholders. Once the group is formed, moderators facilitate discussions around sustainable product concepts, market trends, and potential challenges. The steps include preparing discussion materials, selecting a suitable venue or virtual platform, and establishing ground rules for constructive dialogue. During the focus group sessions, participants share insights, preferences, and concerns related to sustainable products. These discussions help organizations gain valuable feedback to inform product development, marketing strategies, and overall sustainability initiatives. After the SPSFG, organizers analyze the collected data, extract key insights, and use them to refine and shape sustainable product strategies. Effective communication and collaboration are crucial throughout the process to ensure a comprehensive understanding of sustainable practices and to foster innovation in creating products that align with both consumer expectations and environmental considerations. In this instance, we assembled a group called SPSFG, comprising a total of six experts (Table 1). This diverse panel consists of two designers specializing in 3C products, two experts well versed in sustainability strategy, and two consumers of 3C products.

Table 1. Members of SPSFG.

No1.	Identity	Background
Member 1	3C product designer	52 years old, 26 years of 3C product design experience
Member 2	3C product designer	55 years old, 33 years of 3C product design experience
Member 3	Sustainability strategy expert	45 years old, 18 years of experience in sustainable strategy research
Member 4	Sustainability strategy expert	47 years old, 19 years of experience in sustainable strategy research
Member 5	3C product consumer	33 years old, 10 years of 3C product purchasing experience
Member 6	3C product consumer	31 years old, 13 years of 3C product purchasing experience

- Preparing the sustainable product strategies category cards

The sustainable product strategies category cards (Figure 3) serve as a pivotal tool within the SPSFG, facilitating the development of sustainable product strategies. During SPSFG meetings, these cards are employed as a recording mechanism, which are guided by the moderator who prompts group members to jot down their ideas generated during the brainstorming session. These cards are categorized into distinct types, each aligning with a specific aspect of sustainable product development. The categories encompass cards for energy-efficiency strategies, cards focusing on the use of renewable materials, cards dedicated to waste reduction strategies, cards addressing labor standards, cards centered around poverty alleviation strategies, cards designed for assessing health impacts, cards considering market demand, cards for ethical sourcing, and cards dedicated to evaluating long-term environmental impacts. This structured approach ensures a comprehensive exploration of various dimensions within the realm of sustainable product strategies.

- Creating preliminary sustainable product strategies through brainstorming

Creating a sustainable product strategy for 3C (computers, consumer electronics, and communication devices) products through the brainstorming method requires a systematic approach (Figure 4). The process begins with brainstorming sessions aimed at generating ideas related to environmentally friendly materials, energy-efficient technologies, and eco-conscious design principles. This collaborative process involves cross-functional teams, fostering diverse perspectives. After the ideation phase, the stir-up method is employed to encourage creative solutions by challenging conventional norms. This includes questioning existing practices and exploring innovative alternatives, such as integrating recycled materials, minimizing energy consumption during manufacturing, and enhancing product lifespan through modular design. Here is a step-by-step guide we used for organizing

a successful brainstorming workshop. Start by appointing a facilitator responsible for guiding the SPSFG and maintaining focus. Clearly establish context and ensure SPSFG understanding by clarifying the purpose and goals of the session. Define a clear objective to guide the creative process and set a time limit to promote focus and productivity. Choose an appropriate brainstorming technique based on the specific problem, whether it is using the "5 Whys" technique to prevent future obstacles or rapid ideation to generate creative solutions. By following these steps, an SPSFG can effectively leverage the brainstorming method to develop sustainable product strategies for 3C products, fostering both innovation and environmental responsibility. The sustainable product strategies initially developed by SPSFG will undergo further evaluation and final decision making by WDM.

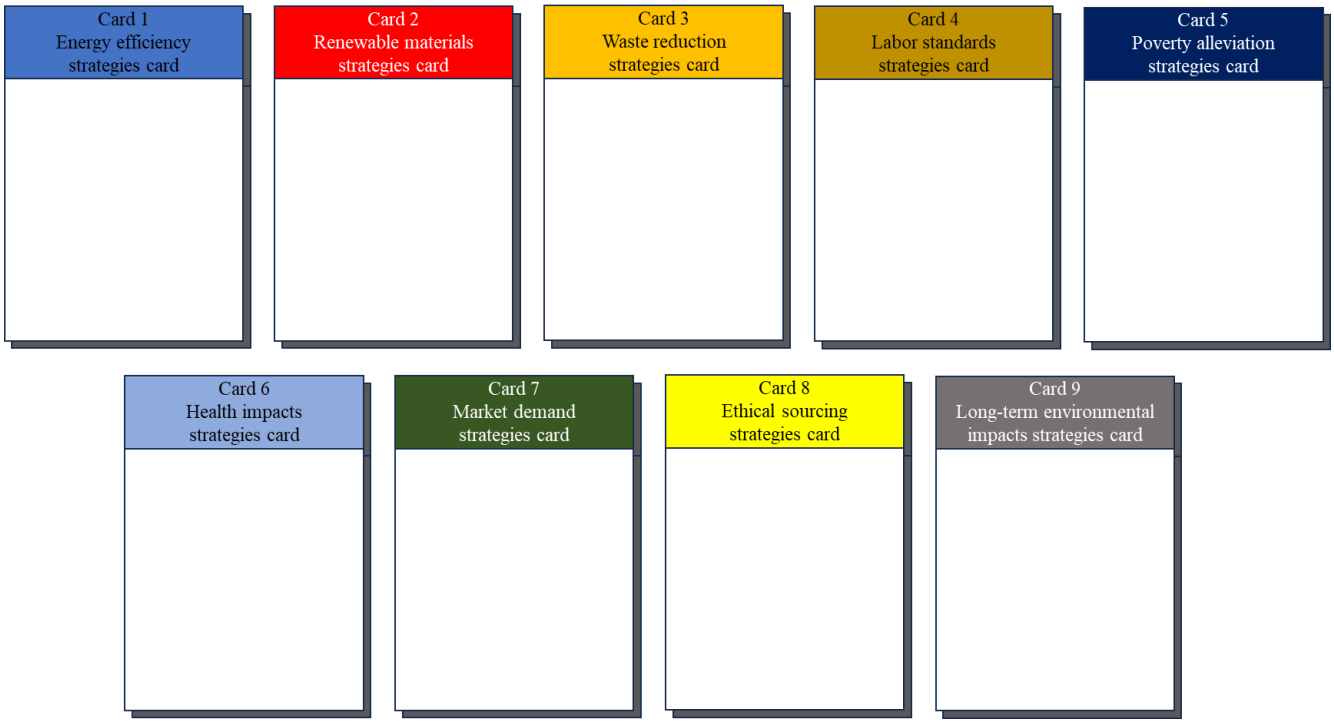
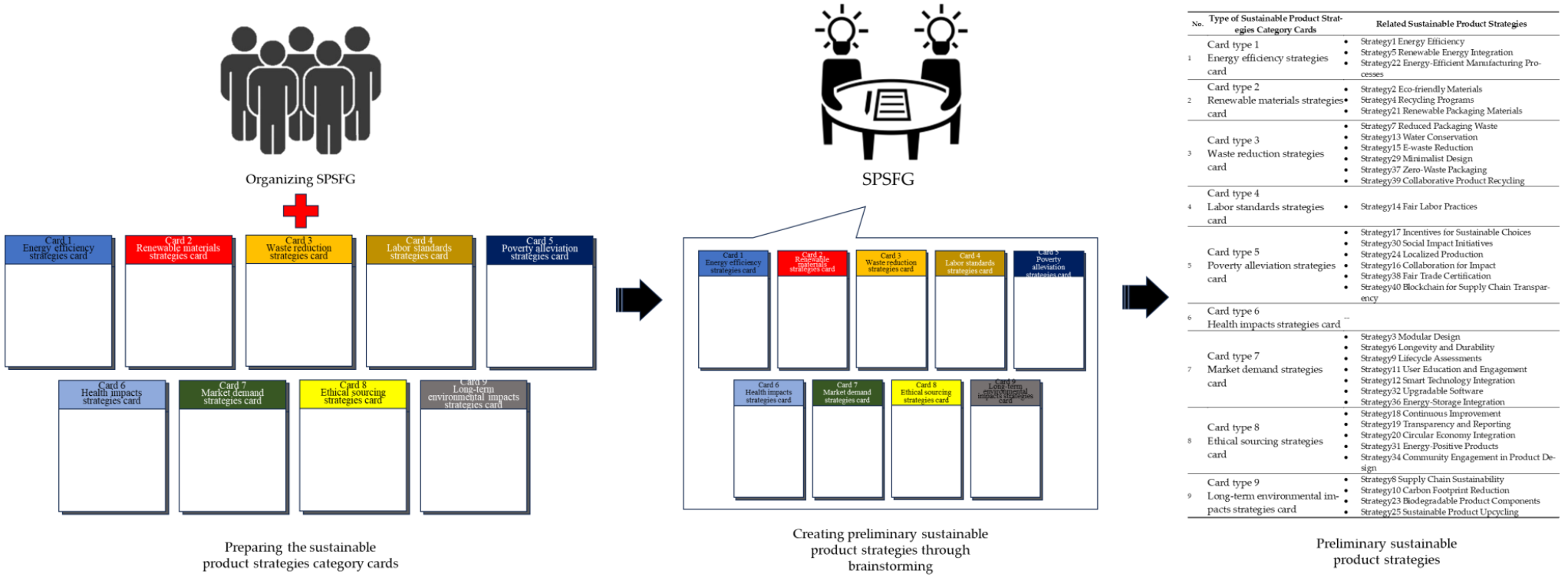


Figure 3. Sustainable product strategies cards.

4.2. Evaluation of Preliminary Sustainable Product Strategies

- Building WDM

The implementation of a WDM for evaluating sustainable product strategies in the 3C (computers, communication devices, and consumer electronics) industry is a structured and systematic process aimed at fostering sustainability aligned with the United Nations' Sustainable Development Goals (SDGs) (refer to Appendix A). The WDM construction process involves several key steps to ensure clarity and logical organization in the evaluation of preliminary sustainable product strategies. To initiate the process, a matrix with 42 columns is created as the foundation (Figure 5). The left two columns are dedicated to accommodating the relevant SDGs goals, while the subsequent two columns on the left are allocated for preliminary sustainable product strategies. On the right side of the matrix, the total weight and the best sustainable product strategies are recorded in two designated columns. The intersection of WDM's SDGs goals and preliminary sustainable product strategies is identified in the blank grid, laying the groundwork for the SPSFG. This blank grid becomes a crucial space for inputting evaluation scores in the future, providing a comprehensive and insightful assessment of the sustainability implications of 3C product strategies. Through this systematic approach, the WDM serves as a powerful tool for organizations in the 3C industry to make informed decisions that contribute positively to both environmental and social aspects.



No.	Type of Sustainable Product Strategies Category Cards	Related Sustainable Product Strategies
1	Card type 1 Energy efficiency strategies card	• Strategy1 Energy Efficiency • Strategy5 Renewable Energy Integration • Strategy22 Energy-Efficient Manufacturing Processes
2	Card type 2 Renewable materials strategies card	• Strategy2 Eco-friendly Materials • Strategy4 Recycling Programs • Strategy21 Renewable Packaging Materials
3	Card type 3 Waste reduction strategies card	• Strategy7 Reduced Packaging Waste • Strategy13 Water Conservation • Strategy15 E-waste Reduction • Strategy29 Minimalist Design • Strategy37 Zero-Waste Packaging • Strategy39 Collaborative Product Recycling
4	Card type 4 Labor standards strategies card	• Strategy14 Fair Labor Practices
5	Card type 5 Poverty alleviation strategies card	• Strategy17 Incentives for Sustainable Choices • Strategy30 Social Impact Initiatives • Strategy24 Localized Production • Strategy16 Collaboration for Impact • Strategy38 Fair Trade Certification • Strategy40 Blockchain for Supply Chain Transparency
6	Card type 6 Health impacts strategies card	--
7	Card type 7 Market demand strategies card	• Strategy3 Modular Design • Strategy6 Longevity and Durability • Strategy9 Lifecycle Assessments • Strategy11 User Education and Engagement • Strategy12 Smart Technology Integration • Strategy32 Upgradable Software • Strategy36 Energy-Storage Integration
8	Card type 8 Ethical sourcing strategies card	• Strategy18 Continuous Improvement • Strategy19 Transparency and Reporting • Strategy20 Circular Economy Integration • Strategy31 Energy-Positive Products • Strategy34 Community Engagement in Product Design
9	Card type 9 Long-term environmental impacts strategies card	• Strategy8 Supply Chain Sustainability • Strategy10 Carbon Footprint Reduction • Strategy23 Biodegradable Product Components • Strategy25 Sustainable Product Upcycling

Preliminary sustainable product strategies

Figure 4. Framework of preliminary sustainable product strategies development.

WDM		SDGs																	The total number of weights	Best sustainable product strategies
No.	**Name of strategy**	G1(w:4)	G2(w:3)	G3(w:3)	G4(w:4)	G5(w:2)	G6(w:1)	G7(w:4)	G8(w:4)	G9(w:3)	G10(w:4)	G11(w:3)	G12(w:2)	G13(w:2)	G14(w:4)	G15(w:3)	G16(w:3)	G17(w:1)		
Strategy1	*Energy Efficiency*																			
Strategy2	*Eco-friendly Materials*																			
Strategy3	*Modular Design*																			
Strategy4	*Recycling Programs*																			
Strategy5	*Renewable Energy Integration*																			
Strategy6	*Longevity and Durability*																			
Strategy7	*Reduced Packaging Waste*																			
Strategy8	*Supply Chain Sustainability*																			
Strategy9	*Lifecycle Assessments*																			
Strategy10	*Carbon Footprint Reduction*																			
Strategy11	*User Education and Engagement*																			
Strategy12	*Smart Technology Integration*																			
Strategy13	*Water Conservation*																			
Strategy14	Fair Labor Practices																			
Strategy15	*E-waste Reduction*																			
Strategy16	*Collaboration for Impact*																			
Strategy17	*Incentives for Sustainable Choices*																			
Strategy18	*Continuous Improvement*																			
Strategy19	Transparency and Reporting																			
Strategy20	*Circular Economy Integration*																			
Strategy21	*Renewable Packaging Materials*																			
Strategy22	*Energy-Efficient Manufacturing Processes*																			
Strategy23	*Biodegradable Product Components*																			
Strategy24	*Localized Production*																			
Strategy25	*Sustainable Product Upcycling*																			
Strategy26	*Closed-Loop Systems*																			
Strategy27	*Waterless Manufacturing*																			
Strategy28	*Biodiversity Conservation*																			
Strategy29	*Minimalist Design*																			
Strategy30	*Social Impact Initiatives*																			
Strategy31	*Energy-Positive Products*																			
Strategy32	*Upgradable Software*																			
Strategy33	*Carbon-Negative Materials*																			
Strategy34	*Community Engagement in Product Design*																			
Strategy35	*Sustainable Transportation Solutions*																			
Strategy36	*Energy-Storage Integration*																			
Strategy37	Zero-Waste Packaging																			
Strategy38	*Fair Trade Certification*																			
Strategy39	*Collaborative Product Recycling*																			
Strategy40	*Blockchain for Supply Chain Transparency*																			

Figure 5. WDM.

- Determine best sustainable product strategies through WDM

Determining the best sustainable product strategies through the WDM (Figure 6) is a systematic approach that enables businesses to assess and compare various sustainability initiatives for their products. This method involves a structured decision-making process, incorporating both qualitative and quantitative factors. The first step typically involves identifying key sustainability criteria relevant to the product and industry, such as environmental impact, social responsibility, and economic feasibility. Subsequently, a list of potential strategies is generated. The Weighted Decision Matrix assigns weights to each criterion based on its importance and then evaluates each strategy against these criteria. The scores are multiplied by the assigned weights, and the results are summed, providing

a quantitative basis for decision making. This process aids in objectively selecting the most viable and sustainable product strategies, aligning business goals with environmental and social responsibility. The sustainable product strategies chosen through WDM evaluation will be utilized to employ GA Technologies in identifying the optimal combination of strategies.

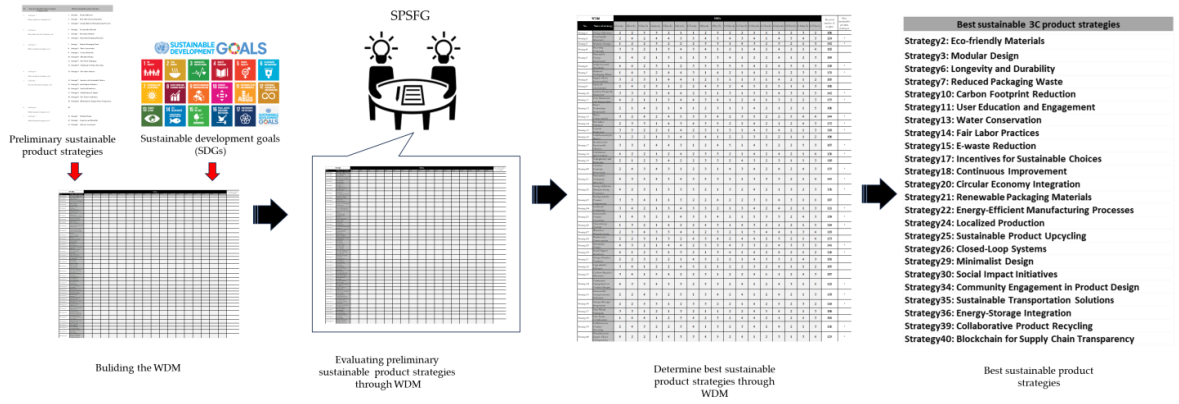


Figure 6. Framework of evaluation of preliminary sustainable product strategies.

4.3. Generation of the Optimal Sustainable Product Strategies Portfolio

Generating the best sustainable product strategies portfolio combination through GA Technologies involves a sophisticated approach to optimizing business strategies for sustainability (Figure 7). This process leverages GA Technologies (Figure 8), a computational method inspired by biological evolution, to find the most effective combination of sustainable product strategies. The steps typically include defining key sustainability parameters, such as environmental impact, resource efficiency, and social responsibility. The genetic algorithm then iteratively refines a diverse set of potential strategies, mimicking the principles of natural selection to favor the most successful ones. This iterative process allows for the exploration of a vast solution space, enabling businesses to identify and implement robust, environmentally friendly, and socially responsible product strategies. This innovative methodology represents a forward-thinking approach to strategic planning, aligning business goals with a commitment to long-term sustainability. GA Technologies will generate the optimal combination of sustainable product strategies. This compilation will be transformed into a comprehensive Sustainable Product Roadmap, serving as a valuable reference for designers and companies engaged in the development of sustainable products.

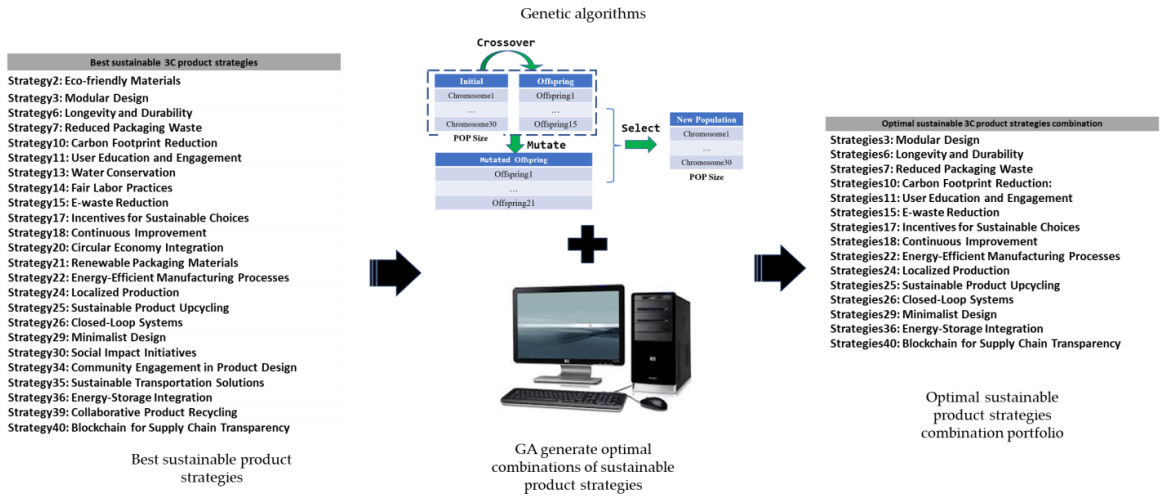


Figure 7. Framework of generation of the optimal sustainable product strategies portfolio.

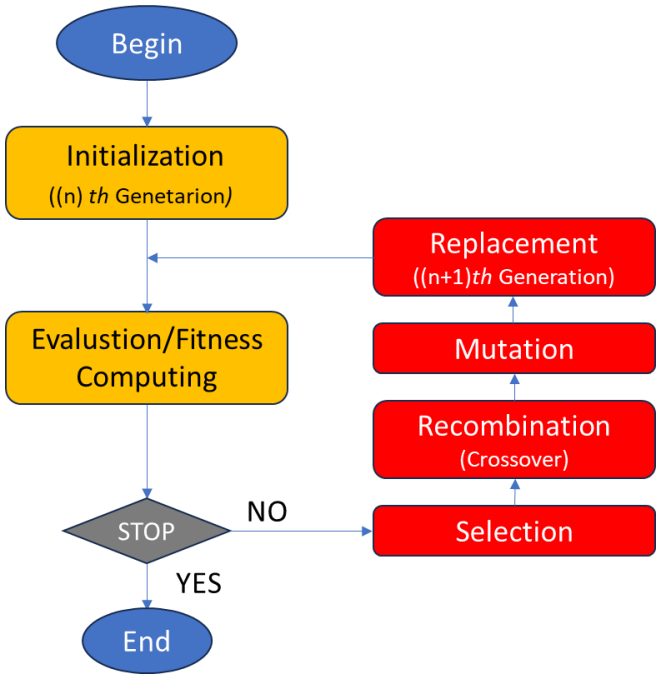


Figure 8. Framework of implement steps of GA.

4.4. Building Roadmap of the Optimal Sustainable Product Strategies Portfolio

The workflow steps (Figure 9) of a Sustainable Product Roadmap involve a meticulous construction process with a focus on strategic planning, customer value, learning, organizational cohesion, and customer excitement. Firstly, constructing a product roadmap requires aligning the organization's plans with its overarching strategy, emphasizing the importance of a clear vision that guides product development. It emphasizes avoiding unnecessary content unrelated to the vision, ensuring a streamlined and purposeful roadmap. Secondly, the roadmap must concentrate on providing tangible value to customers, ensuring that product solutions address real problems rather than merely focusing on delivery. Incorporating a learning mindset is crucial in the third step, transforming the delivery function into a platform for problem solving and goal achievement. This facilitates effective communication and feedback loops with users, leading to valuable insights that can inform adjustments to the product direction and priorities. Fourthly, maintaining a focus on priorities and fostering organizational cohesion is vital. Regular communication with team members helps align everyone with the product roadmap, ensuring a collective understanding of the direction. Lastly, the Sustainable Product Roadmap seeks to make customers excited about the product's future direction. It serves as a lightweight mechanism for validating requirements, allowing users to provide feedback and verify whether the planned direction aligns with their needs and expectations. This customer-centric approach ensures that the product roadmap remains a dynamic and responsive tool, driving continuous improvement and alignment with user preferences. In summary, the workflow steps emphasize strategic alignment, customer value, continuous learning, organizational cohesion, and customer engagement to create a sustainable and effective product roadmap.

4.5. Verifying the Framework of Hybrid Method

In order to validate the efficacy of our framework for a hybrid method for developing optimal sustainable product strategies and a sustainable product roadmap, we will employ OA office furniture (Figure 10) as a case study. The framework comprises several distinct phases, including Preliminary Sustainable Product Strategies Development, Evaluation of Preliminary Product Sustainable Product Strategies, Generation of the Best Sustainable Product Strategies Portfolio, and Building a Roadmap of the Best Sustainable Product Strategies Portfolio. In the initial phase of crafting sustainable product strategies, we

will obtain preliminary sustainable product strategies. During the subsequent evaluation phase, we will discern the most effective sustainable product strategies. Moving on to the generation stage of the optimal sustainable product strategies portfolio, we will consolidate the identified best strategies into a comprehensive portfolio. Ultimately, in the roadmap-building stage for the best sustainable product strategies portfolio, we will meticulously formulate a detailed plan delineating the necessary steps and milestones for implementing these strategies.

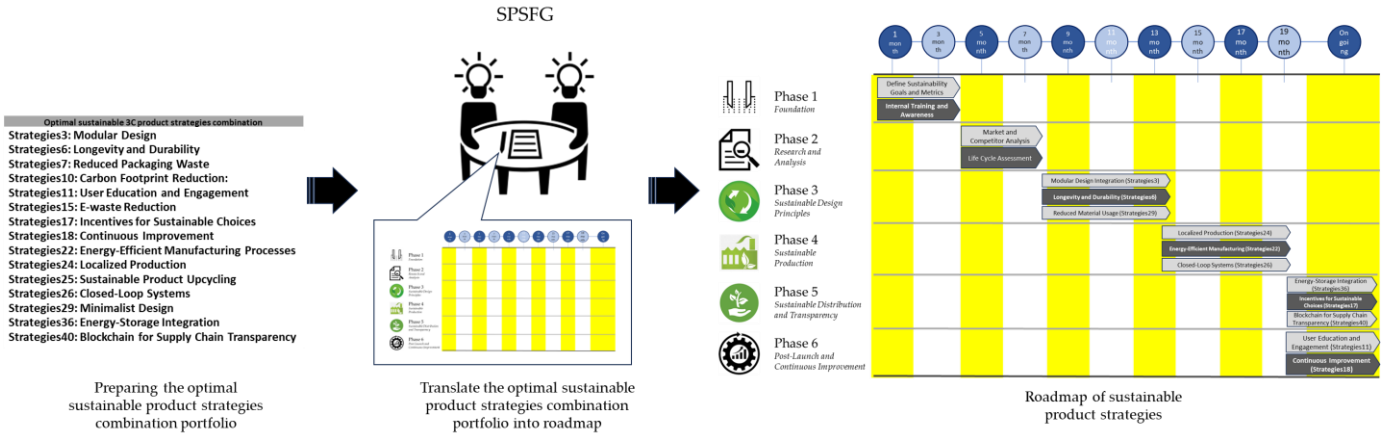


Figure 9. Framework of generation of roadmap.

Figure 10. OA office furniture.

5. Results

5.1. 3C Products' Preliminary Sustainable Product Strategies Created by SPSFG

Table 2 shows the sustainable product strategies' category cards and the related preliminary sustainable product strategies. Table 2 presents the preliminary sustainable product strategies and their definition (reference to Appendix B). These strategies aim to address environmental, social, and economic aspects of sustainability within the 3C industry. Here, we analyze and compare 40 preliminary sustainable product strategies developed by SPSFG, each contributing uniquely to the broader goal of creating eco-friendly and socially responsible products. The 40 preliminary sustainable product strategies can be divided into the following aspects.

Table 2. Preliminary sustainable product strategies.

No.	Type of Sustainable Product Strategies Category Cards	Related Sustainable Product Strategies
1	Card type 1 Energy-efficiency strategies card	• Strategy1 Energy Efficiency • Strategy5 Renewable Energy Integration • Strategy22 Energy-Efficient Manufacturing Processes
2	Card type 2 Renewable materials strategies card	• Strategy2 Eco-Friendly Materials • Strategy4 Recycling Programs • Strategy21 Renewable Packaging Materials
3	Card type 3 Waste reduction strategies card	• Strategy7 Reduced Packaging Waste • Strategy13 Water Conservation • Strategy15 E-Waste Reduction • Strategy29 Minimalist Design • Strategy37 Zero-Waste Packaging • Strategy39 Collaborative Product Recycling
4	Card type 4 Labor standards strategies card	• Strategy14 Fair Labor Practices
5	Card type 5 Poverty alleviation strategies card	• Strategy17 Incentives for Sustainable Choices • Strategy30 Social Impact Initiatives • Strategy24 Localized Production • Strategy16 Collaboration for Impact • Strategy38 Fair Trade Certification • Strategy40 Blockchain for Supply Chain Transparency
6	Card type 6 Health impacts strategies card	--
7	Card type 7 Market demand strategies card	• Strategy3 Modular Design • Strategy6 Longevity and Durability • Strategy9 Life-Cycle Assessments • Strategy11 User Education and Engagement • Strategy12 Smart Technology Integration • Strategy32 Upgradable Software • Strategy36 Energy-Storage Integration
8	Card type 8 Ethical sourcing strategies card	• Strategy18 Continuous Improvement • Strategy19 Transparency and Reporting • Strategy20 Circular Economy Integration • Strategy31 Energy-Positive Products • Strategy34 Community Engagement in Product Design
9	Card type 9 Long-term environmental impacts strategies card	• Strategy8 Supply Chain Sustainability • Strategy10 Carbon Footprint Reduction • Strategy23 Biodegradable Product Components • Strategy25 Sustainable Product Upcycling • Strategy26 Closed-Loop Systems • Strategy27 Waterless Manufacturing • Strategy28 Biodiversity Conservation • Strategy33 Carbon-Negative Materials • Strategy35 Sustainable Transportation Solutions

1. Energy Efficiency:
   - ✓ Similarities: Strategies 1, 12, and 22 all focus on optimizing energy use either through energy-efficient designs or the integration of smart technologies.

- ✓ Differences: Strategy31 stands out by aiming to design products that generate more energy than they consume.

2. Eco-friendly Materials:
   - ✓ Similarities: Strategies 21, 23, and 33 emphasize the use of sustainable and renewable materials in product design.
   - ✓ Differences: Strategy33 goes further by exploring materials with a carbon-negative footprint.
3. Modular Design:
   - ✓ Similarities: Strategies 3, 26, and 32 promote product modularity, either for repair and upgradeability or through closed-loop systems.
   - ✓ Differences: Strategy32 introduces upgradable software as a means of extending product lifespan.
4. Recycling Programs:
   - ✓ Similarities: Strategies 5, 15, 26, and 39 all address the responsible disposal of electronic waste.
   - ✓ Differences: Strategy39 takes a collaborative approach, involving competitors for industry-wide recycling initiatives.
5. Renewable Energy Integration:
   - ✓ Similarities: Strategies 5, 21, 31, and 36 integrate renewable energy sources into product functionality.
   - ✓ Differences: Strategy36 focuses on energy storage solutions to promote efficient energy use.
6. Longevity and Durability:
   - ✓ Similarities: Strategies 6 and 29 emphasize durability to reduce the need for frequent replacements.
   - ✓ Differences: Strategy29 adopts minimalist design principles to reduce material usage.
7. Reduced Packaging Waste:
   - ✓ Similarities: Strategies 7, 21, and 37 aim to minimize packaging waste through eco-friendly materials and designs.
   - ✓ Differences: Strategy37 sets the ambitious goal of zero-waste packaging.
8. Supply Chain Sustainability:
   - ✓ Similarities: Strategies 8, 18, and 38 focus on sustainable and ethical practices within the supply chain.
   - ✓ Differences: Strategy38 seeks fair trade certification to ensure fair wages and ethical treatment.
9. Lifecycle Assessments:
   - ✓ Similarities: Strategy9 is unique in its focus on conducting life-cycle assessments to minimize environmental impact.
10. Carbon Footprint Reduction:
    - ✓ Similarities: Strategies 10 and 33 address the reduction in carbon footprints, with Strategy10 investing in offset programs.
    - ✓ Differences: Strategy33 focuses on carbon-negative materials.
11. User Education and Engagement:
    - ✓ Similarities: Strategies 11 and 31 aim to educate consumers about the environmental impact of products.
    - ✓ Differences: Strategy11 emphasizes responsible use, disposal, and recycling.

In summary, in the landscape of sustainable product strategies, a nuanced approach is essential. Companies must not only focus on individual elements like energy efficiency and eco-friendly materials but also consider the broader ecosystem. Strategies such as collabo-

rative recycling initiatives, fair trade certification, and blockchain for transparency indicate a growing trend toward collective responsibility and ethical practices. This comprehensive analysis underscores the interconnectedness of these strategies and the need for a holistic, multifaceted approach to sustainability in product development. As industries evolve, continuous improvement and transparency will play pivotal roles in shaping a future where products are not just functional but also contribute positively to the environment and society at large.

5.2. 3C Products' Best Sustainable Product Strategies Determined by WDM

Table 3 shows the 3C products' best sustainable product strategies determined through WDM (reference to Appendix C). In the realm of consumer electronics, the pursuit of sustainability has become a paramount consideration for both manufacturers and consumers. "3C Products' Best Sustainable Product Strategies Determined by WDM" serves as an illuminating guide, presenting a comprehensive exploration of cutting-edge sustainable strategies shaping the landscape of 3C (computers, communication devices, and consumer electronics) products. Rooted in a commitment to environmental stewardship and ethical practices, the strategies outlined in this discourse span a spectrum of considerations, ranging from eco-friendly materials and modular design to longevity, reduced packaging waste, and carbon footprint reduction. Delving further, the discourse addresses crucial aspects such as user education, water conservation, fair labor practices, and e-waste reduction. Notably, the strategies extend beyond the product life cycle, encompassing incentives for sustainable choices, circular economy integration, renewable packaging materials, energy-efficient manufacturing processes, and localized production. With an eye on holistic sustainability, the discussion extends to innovative approaches like sustainable product upcycling, closed-loop systems, minimalist design, and social impact initiatives. Additionally, community engagement in product design, sustainable transportation solutions, energy-storage integration, collaborative product recycling, and the integration of blockchain for supply chain transparency underscore the depth and breadth of this exploration. As we navigate the intricate tapestry of sustainable practices, the discourse invites stakeholders to consider not only the environmental impact but also the social and ethical dimensions of 3C product development, paving the way for a future where technological advancement aligns harmoniously with global sustainability goals.

5.3. 3C Products' Optimal Sustainable Product Strategies Combination Portfolio Chosen from GA

Table 4 shows the 3C products' optimal sustainable product strategies combination portfolio chosen from GA. In the ever-evolving landscape of consumer electronics, the quest for sustainability has become a paramount concern. The paradigm shift toward environmentally conscious practices in the design and manufacturing of 3C (computers, communication devices, and consumer electronics) products has given rise to a myriad of strategic options. The synthesis of these strategies has been explored through the lens of a Genetic Algorithm (GA) to identify the most optimal sustainable product strategy combination. This comprehensive portfolio is a result of a rigorous evaluation of various sustainability strategies such as modular design, longevity and durability, reduced packaging waste, carbon footprint reduction, user education and engagement, e-waste reduction, incentives for sustainable choices, continuous improvement, energy-efficient manufacturing processes, localized production, sustainable product upcycling, closed-loop systems, minimalist design, energy-storage integration, and blockchain for supply chain transparency. Each strategy contributes to the overall vision of fostering a more sustainable and eco-friendly approach to 3C product development. The chosen combination not only reflects the current state of the art in sustainable technology but also points toward a future where responsible practices are seamlessly integrated into the core of consumer electronics.

Table 3. The 3C products' best sustainable product strategies determined through WDM.

Best Sustainable 3C Product Strategies
Strategy2: Eco-Friendly Materials
Strategy3: Modular Design
Strategy6: Longevity and Durability
Strategy7: Reduced Packaging Waste
Strategy10: Carbon Footprint Reduction
Strategy11: User Education and Engagement
Strategy13: Water Conservation
Strategy14: Fair Labor Practices
Strategy15: E-waste Reduction
Strategy17: Incentives for Sustainable Choices
Strategy18: Continuous Improvement
Strategy20: Circular Economy Integration
Strategy21: Renewable Packaging Materials
Strategy22: Energy-Efficient Manufacturing Processes
Strategy24: Localized Production
Strategy25: Sustainable Product Upcycling
Strategy26: Closed-Loop Systems
Strategy29: Minimalist Design
Strategy30: Social Impact Initiatives
Strategy34: Community Engagement in Product Design
Strategy35: Sustainable Transportation Solutions
Strategy36: Energy-Storage Integration
Strategy39: Collaborative Product Recycling
Strategy40: Blockchain for Supply Chain Transparency

Table 4. The 3C products' optimal sustainable product strategies combination portfolio sorted from GA.

Optimal Sustainable 3C Product Strategies Combination
Strategy3: Modular Design
Strategy6: Longevity and Durability
Strategy7: Reduced Packaging Waste
Strategy10: Carbon Footprint Reduction:
Strategy11: User Education and Engagement
Strategy15: E-Waste Reduction
Strategy17: Incentives for Sustainable Choices
Strategy18: Continuous Improvement
Strategy22: Energy-Efficient Manufacturing Processes
Strategy24: Localized Production
Strategy25: Sustainable Product Upcycling
Strategy26: Closed-Loop Systems
Strategy29: Minimalist Design
Strategy36: Energy-Storage Integration
Strategy40: Blockchain for Supply Chain Transparency

5.4. Roadmap of Sustainable Product Strategies of 3C Products

To empower designers and companies to actively contribute to the development of sustainable product strategies for 3C (computers, communication devices, and consumer electronics) products, SPSFG recognizes the importance of transforming the Optimal Sustainable Product Strategies Combination Portfolio into a structured roadmap (Figure 11). This transformation is crucial for implementing the sustainable product strategy effec-

tively. By presenting the Optimal Sustainable Product Strategies Combination Portfolio in a roadmap format, it becomes a more accessible and actionable guide for designers and companies. This strategic shift ensures that stakeholders can engage more meaningfully in the process of developing sustainable product strategies for 3C products. In essence, the roadmap serves as a practical tool that facilitates a step-by-step approach to implementing sustainable strategies. This clarity and organization enable designers and companies to navigate and comprehend the strategic landscape more easily, fostering a more seamless integration of sustainable practices into the product development process. Here is a suggested outline for the sustainable 3C product roadmap in accordance with an optimal sustainable product strategies combination portfolio:

1. Phase 1: Foundation (Months 1–3)
    - ✓ Define Sustainability Goals and Metrics
        - (A) Establish clear and measurable sustainability objectives based on the identified strategies.
        - (B) Set key performance indicators (KPIs) for each strategy to track progress.
    - ✓ Internal Training and Awareness
        - (A) Educate the internal team about the importance of sustainability in product development.
        - (B) Conduct workshops on the specific strategies and their implications.
2. Phase 2: Research and Analysis (Months 4–6)
    - ✓ Market and Competitor Analysis
        - (A) Research competitors' sustainable practices.
        - (B) Identify market trends and demands related to eco-friendly products.
    - ✓ Life-Cycle Assessment
        - (A) Conduct a thorough life-cycle assessment of the product to identify environmental impacts.
        - (B) Prioritize strategies based on impact and feasibility.
3. Phase 3: Sustainable Design Principles (Months 7–12)
    - ✓ Modular Design Integration (Strategy 3)
        - (A) Implement modular design principles to enhance product flexibility and upgradeability.
        - (B) Train design and development teams on modular design concepts.
    - ✓ Longevity and Durability (Strategy 6)
        - (A) Optimize product design for longevity and durability.
        - (B) Explore materials and manufacturing processes that enhance product lifespan.
    - ✓ Reduced Material Usage (Strategy 29)
        - (A) Adopt minimalist design principles to reduce overall material usage.
        - (B) Prioritize simplicity without compromising functionality and user experience.
4. Phase 4: Sustainable Production (Months 13–18)
    - ✓ Localized Production (Strategy 24)
        - (A) Establish localized manufacturing facilities to reduce the environmental impact of transportation.
        - (B) Promote regional job creation and support local economies.
    - ✓ Energy-Efficient Manufacturing (Strategy 22)
        - (A) Implement energy-efficient practices to reduce energy consumption during production.
        - (B) Optimize production lines to minimize waste and enhance overall energy efficiency.
    - ✓ Closed-Loop Systems (Strategy 26)

(A) Implement closed-loop systems for the recovery and reuse of materials.
(B) Design products with easily reintegrated components.

5. Phase 5: Sustainable Distribution and Transparency (Ongoing)
   - ✓ Energy-Storage Integration (Strategy 36)
     (A) Integrate energy storage solutions into products for efficient energy use and storage.
     (B) Explore partnerships with renewable energy companies for comprehensive energy solutions.
   - ✓ Blockchain for Supply Chain Transparency (Strategy 40)
     (A) Implement blockchain technology to enhance transparency in the supply chain.
     (B) Enable consumers to trace the journey of the product from raw materials to end-of-life recycling.
   - ✓ Incentives for Sustainable Choices (Strategy 17)
     (A) Develop a rewards program for customers making sustainable choices.
     (B) Explore partnerships with eco-friendly organizations for joint promotions.
6. Phase 6: Post-Launch and Continuous Improvement (Ongoing)
   - ✓ User Education and Engagement (Strategy 11)
     (A) Develop educational materials for users on sustainable product use.
     (B) Engage with customers through social media and other channels.
   - ✓ Continuous Improvement (Strategy 18)
     (A) Gather feedback on sustainability initiatives and product performance.
     (B) Iterate on strategies based on feedback and technological advancements.

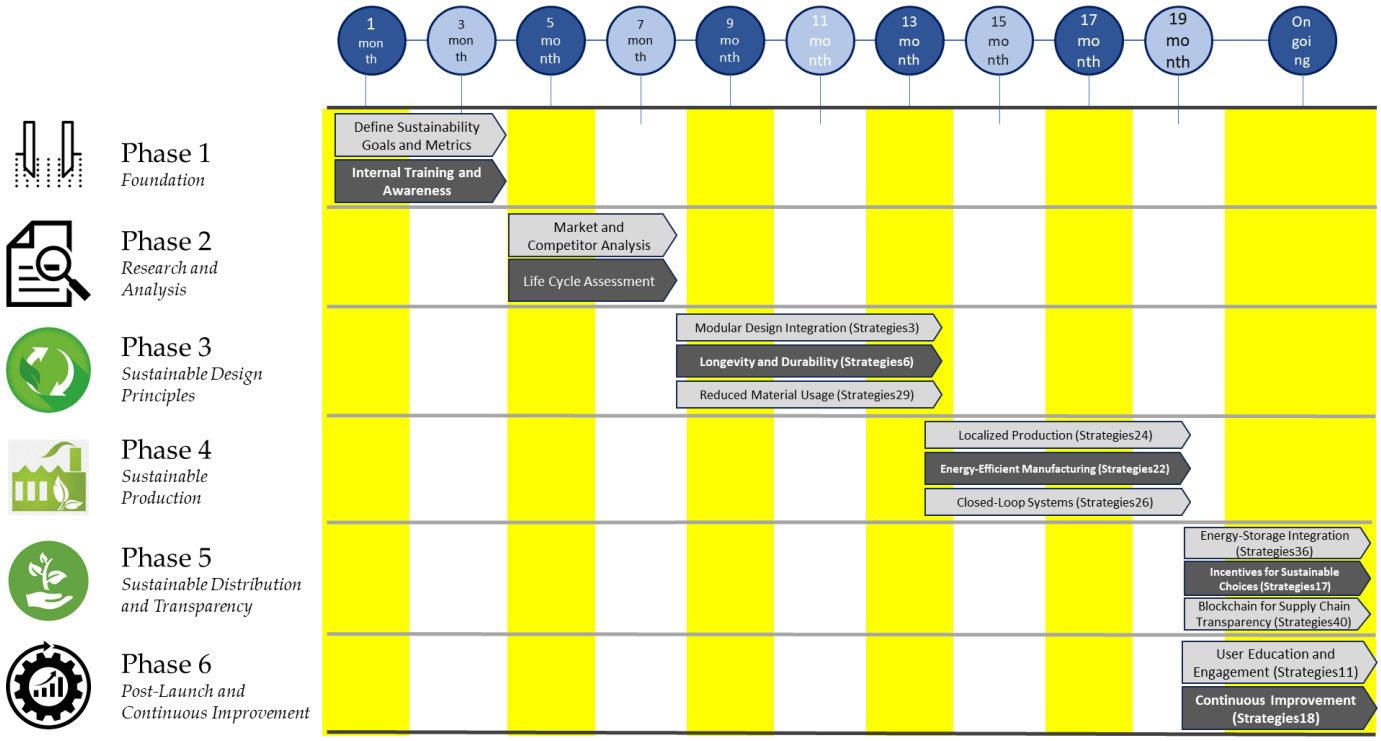


Figure 11. Roadmap of sustainable product strategies of 3C products.

5.5. Verification Results of Hybrid Method

Table 5 displays the optimal sustainable product strategies for OA office furniture. These strategies were derived through the verification of the hybrid method, using OA office furniture as a case study. The explanation of the meaning of optimal sustainable product strategies is provided below. The adoption of optimal sustainable product strategies is imperative in the realm of open architecture (OA) office furniture, where each strategy carries profound connotations and significance. Beginning with material selection, a deliberate choice of environmentally friendly and recyclable materials, such as FSC-certified wood, recycled metal, and low-emission finishes, ensures that the raw materials utilized are sustainable, thereby contributing to a diminished environmental impact. Modular design principles play a pivotal role by allowing easy disassembly and reconfiguration, fostering flexibility and adaptability that extend the furniture's life cycle while concurrently reducing waste. The commitment to energy-efficient manufacturing involves the adoption of lean practices, the utilization of renewable energy sources, and the creation of facilities that minimize energy consumption during production. Embracing a circular economic approach, OA office furniture is designed with the end of life in mind, promoting recycling and refurbishment to establish a closed-loop system that minimizes waste and champions material reuse. Carbon footprint reduction strategies, including optimized transportation, local material sourcing, and energy-efficient logistics, collectively work toward minimizing the overall environmental impact. Obtaining certifications such as LEED, Cradle to Cradle, or GREENGUARD validates the sustainability of OA office furniture, providing transparency and assurance to customers regarding the eco-friendly nature of the products. Waste reduction practices encompass minimizing packaging materials, using eco-friendly packaging, and advocating responsible disposal practices for customers. Employee well-being is prioritized through ergonomic design principles that enhance comfort and contribute to increased productivity and job satisfaction, aligning seamlessly with sustainability goals. Technology integration explores the incorporation of smart technologies, such as energy-saving sensors and automated climate control, optimizing resource utilization and reducing energy consumption. Lastly, supplier engagement involves working closely with suppliers committed to sustainability, collaborating to ensure the responsible sourcing of materials and adherence to ethical labor practices, thereby establishing a comprehensive and sustainable supply chain for OA office furniture. Together, these strategies form a holistic and impactful approach toward creating sustainable, environmentally conscious, and socially responsible office furniture solutions within the framework of open architecture.

Table 5. Optimal sustainable product strategies for OA office furniture.

Sustainable Product Strategies		Content
Strategy1	Material Selection	Choose environmentally friendly and recyclable materials such as FSC-certified wood, recycled metal, and low-emission finishes for OA office furniture. This ensures that the raw materials used are sustainable and contribute to a reduced environmental impact.
Strategy2	Modular Design	Implement modular design principles to allow for easy disassembly and reconfiguration. This promotes flexibility and adaptability, extending the life cycle of the furniture and reducing waste.
Strategy3	Energy-Efficient Manufacturing	Adopt energy-efficient manufacturing processes and facilities. Utilize renewable energy sources and implement lean manufacturing practices to minimize energy consumption during production.
Strategy4	Circular Economy Approach	Embrace a circular economy model by designing OA office furniture with the end of life in mind. Facilitate recycling and refurbishment, encouraging a closed-loop system that minimizes waste and promotes the reuse of materials.

Table 5. *Cont.*

Sustainable Product Strategies		Content
Strategy5	Carbon Footprint Reduction	Evaluate and reduce the carbon footprint of OA office furniture by optimizing transportation methods, sourcing materials locally, and employing energy-efficient logistics. This helps with minimizing the overall environmental impact.
Strategy6	Certifications and Standards	Obtain relevant certifications such as LEED, Cradle to Cradle, or GREENGUARD to validate the sustainability of OA office furniture. These certifications provide transparency and assurance to customers about the eco-friendly nature of the products.
Strategy7	Waste Reduction Practices	Implement waste reduction strategies during both manufacturing and packaging phases. Minimize packaging materials, use eco-friendly packaging, and encourage responsible disposal practices for customers.
Strategy8	Employee Well-Being	Consider ergonomic design principles to enhance the comfort and well-being of employees. Healthy and comfortable workspaces contribute to increased productivity and job satisfaction while aligning with sustainability goals.
Strategy9	Technology Integration	Explore opportunities to integrate smart technologies into OA office furniture. This could include energy-saving sensors, automated climate control, and occupancy sensors to optimize resource utilization and reduce energy consumption.
Strategy10	Supplier Engagement	Work closely with suppliers who share a commitment to sustainability. Collaborate with them to ensure the responsible sourcing of materials and adherence to ethical labor practices, creating a comprehensive and sustainable supply chain for OA office furniture.

6. Discussion

6.1. Framework of Hybrid Method

The concept of the effectiveness of the framework of our hybrid method in creating sustainable product strategies inspires a profound discussion on the intersection of innovation, adaptability, and long-term viability. In today's dynamic and ever-evolving business landscape, the need for a strategic approach that combines the strengths of diverse methodologies becomes increasingly evident. This hybrid framework suggests a nuanced understanding of the complexities involved in product strategy development. The enlightenment lies in the recognition that a one-size-fits-all approach may not suffice in addressing the multifaceted challenges posed by the market, technology, and environmental considerations. By embracing a hybrid methodology, organizations may harness the collective wisdom of proven strategies while also staying agile and responsive to emerging trends. This discussion prompts a deeper exploration into the practical applications and potential benefits of such a hybrid approach, encouraging a shift in mindset from rigid adherence to singular methodologies toward a more adaptive and sustainable paradigm for product strategy formulation.

The study's empirical findings are derived from a specific product context, with key participants being professional 3C product designers, sustainability strategy experts, and 3C product consumers. The sustainable product strategy meeting, lasting around 6 h, follows a streamlined evaluation process. It is important to note that this process may not entirely capture how the toolkit is utilized across the broader product industry. To address this limitation, future cross-sectional studies could investigate variations in tool usage among different types of product companies. Furthermore, longitudinal studies could examine the unique circumstances of these companies to pinpoint potential gaps in their ability to implement sustainable product design.

In light of the evolving landscape shaped by advances in computing technology, the Internet, and ongoing shifts in industry and consumer preferences, traditional manual methods face significant challenges, including outdated technology, restrictive capabilities,

and a lack of immediacy. Consequently, there is a need for future research to develop an interactive collaborative platform for sustainable product strategy development that is grounded in the research framework. This online platform would cater to the dynamic sustainability challenges encountered in users' daily practices, contributing to the development of sustainable products and continuously fostering real-time innovation in sustainable strategies. This approach ensures that sustainable product strategies remain aligned with current trends.

6.2. Sustainable Product Strategies of 3C Products

The outlined strategies for environmental sustainability in product development form a comprehensive framework that goes beyond mere business considerations, embodying a vision rooted in inspiration and enlightenment. By focusing on energy efficiency, eco-friendly materials, modular design, and recycling programs, companies are not only acknowledging their role in reducing environmental impact but are also taking proactive measures to mitigate it. This holistic approach, encapsulated in strategies like renewable energy integration, longevity and durability, and reduced packaging waste, reflects an enlightened understanding of the interconnectedness between product design and the broader ecosystem. Furthermore, the emphasis on supply chain sustainability, life-cycle assessments, and fair labor practices highlights a commitment to ethical and responsible business practices. This reflects an inspiration drawn from a deeper understanding of the global impact of industrial processes and a recognition of the need for conscientious choices throughout the entire product life cycle. The integration of smart technology and artificial intelligence in strategy formulation demonstrates an innovative and forward-thinking approach, where technology becomes a tool for not just product enhancement but also for addressing environmental concerns. Strategies such as water conservation, e-waste reduction, and collaboration for impact underscore a sense of responsibility toward both the planet and society. The call for user education and engagement signifies an understanding that true sustainability extends beyond the production phase to the way consumers interact with and dispose of products. Incentives for sustainable choices, continuous improvement, transparency, and reporting further illustrate a commitment to accountability and a willingness to adapt strategies in the face of evolving environmental standards. Finally, the incorporation of circular economy principles in strategy formulation reflects a paradigm shift toward a regenerative and restorative approach to production and consumption. In essence, these strategies not only serve as a roadmap for businesses to navigate the challenges of the 21st century but also exemplify a collective awakening to the imperative of sustainable and responsible practices. This holistic and interconnected approach to product development is not merely a response to market demands; it is an enlightened understanding of the intrinsic link between business success and environmental stewardship.

Comparing with existing 3C product strategies [68,69], the difference between sustainable 3C product strategies found through the framework and 3C products in general is as following. The 3C product strategies found through the general method primarily focus on market trends, consumer demands, and competitive positioning within specific industries. In contrast, the sustainable 3C product strategies through the framework represent a broader, conscientious approach that extends beyond immediate market considerations. Here are key distinctions:

1. Scope and Vision:
    - 3C Product Strategy: concentrates on meeting consumer demands and gaining a competitive edge within a specific market, which is often driven by trends and technological advancements.
    - Sustainable Product Strategies: encompasses a comprehensive framework that transcends immediate business considerations, emphasizing a vision rooted in environmental stewardship, ethics, and global responsibility.
2. Environmental Considerations:

- 3C Product Strategy: may incorporate technology and innovation but may not explicitly prioritize environmental concerns unless demanded by the market.
- Sustainable Product Strategies: prioritizes environmental sustainability through energy efficiency, eco-friendly materials, modular design, recycling programs, renewable energy integration, and circular economy principles.

3. Ethics and Responsibility:
   - 3C Product Strategy: primarily aims at satisfying consumer needs and gaining a competitive advantage with less emphasis on ethical and responsible business practices.
   - Sustainable Product Strategies: highlights a commitment to ethical practices, fair labor, and responsible business conduct throughout the product life cycle, reflecting a deeper understanding of global impact.
4. Innovation and Technology:
   - 3C Product Strategy: emphasizes technical capabilities, user experience, and innovation to meet evolving consumer expectations and gain a competitive advantage.
   - Sustainable Product Strategies: integrates smart technology and artificial intelligence not just for product enhancement but also for addressing environmental concerns and contributing to a regenerative approach.
5. Consumer Focus:
   - 3C Product Strategy: centers on understanding and meeting the specific needs and behaviors of target customers, often driven by market demands.
   - Sustainable Product Strategies: extends beyond market demands to educate and engage consumers in sustainable practices, acknowledging the interconnectedness between product design and the broader ecosystem.
6. Long-Term Perspective:
   - 3C Product Strategy: primarily concerned with immediate market positioning and gaining a competitive edge.
   - Sustainable Product Strategies: exemplifies a collective awakening to the imperative of sustainable and responsible practices, indicating a long-term perspective beyond current market trends.

In summary, while 3C product strategies address market dynamics and consumer preferences for specific industries, sustainable product strategies adopt a more holistic and interconnected approach, emphasizing environmental consciousness, ethical business practices, and a long-term commitment to sustainability and responsibility.

6.3. Roadmap of Sustainable Product Strategies of 3C Products

The outlined roadmap for sustainable 3C (consumer electronics, communication devices, and computer) products reflects a comprehensive and forward-thinking approach to inspire and enlighten companies on the path to environmental responsibility. The phased approach, beginning with the foundation phase, demonstrates a commitment to internal education and awareness, recognizing that transformation starts with a clear understanding of sustainability goals and metrics. The subsequent research and analysis phase signifies a dedication to informed decision making, as market and competitor practices are thoroughly examined through a life-cycle assessment. This analytical foundation feeds into the design and development phase, where innovative strategies like modular design principles, product flexibility, and efforts to reduce packaging waste are seamlessly integrated. The production and distribution phase underscores a holistic commitment to reducing carbon footprint and e-waste, incorporating energy-efficient manufacturing and take-back programs. Moreover, the inclusion of incentives for sustainable choices highlights a proactive approach to encouraging environmentally conscious decisions. The post-launch and continuous improvement phase emphasizes the significance of ongoing user education, engagement, and iterative enhancements, reinforcing a dynamic commitment to sustain-

ability throughout the product lifecycle. The incorporation of Key Performance Indicators (KPIs) adds a layer of measurability, allowing companies to track success in crucial areas such as product longevity, packaging waste reduction, carbon footprint reduction, and user engagement. This strategic roadmap not only aligns with the identified 3C sustainable product strategies but also serves as an inspirational and enlightening framework for companies navigating the complex terrain of environmental responsibility in product development. It sets a precedent for a meaningful and measurable transformation toward a more sustainable future in the realm of consumer electronics, communication devices, and computer products.

7. Conclusions

This study delves into the technical information and SOP (Standard Operating Procedure) considerations associated with strategy development tools in the creation of a sustainable product strategy within the sustainable product development process. Our investigation focuses on the impact of technologies such as SPSFG, Brainstorming, WDM, and GA in advancing and generating sustainable product strategies. The contribution of this study lies in enhancing methodological frameworks that facilitate the development of sustainable product strategies through four key aspects: (1) conducting a critical literature review on the concept of sustainable product strategies and the methodological frameworks for their creation; (2) defining a methodological framework for crafting a sustainable product strategy and outlining the implementation method to provide designers and companies engaged in sustainable product development with a standardized ideation process; (3) presenting case studies on sustainable 3C products; and (4) offering suggestions and outlining future directions for sustainability strategies in the context of sustainable 3C products, drawing insights from the perspective of sustainable product professionals.

The study's findings yield valuable insights into the enhancement of tools for creating sustainable product strategies and provide guidance on how future professionals in sustainable product design can collaborate to maximize the benefits of sustainability in the creation of strategies for 3C products. Bridging the gap between these insights and practical manufacturing represents a significant research contribution to both the theoretical and practical aspects of sustainable product generation processes and sustainable product design. Moreover, in the contemporary landscape of product development, a robust framework that integrates hybrid methods is indispensable for crafting optimal sustainable product strategies and delineating a comprehensive sustainable product roadmap. This framework not only addresses the imperative environmental concerns but also considers the intricate interplay of social, economic, and health consequences. By amalgamating diverse methodologies, it enables a holistic approach that transcends traditional silos, fostering a symbiotic relationship between ecological viability and societal well-being. This innovative framework ensures that sustainable product strategies are not only environmentally sound but also attuned to the broader context of social equity, economic resilience, and public health. Consequently, it not only paves the way for eco-friendly product innovation but also mitigates potential adverse effects on social structures, economic systems, and public health, thereby contributing to a harmonious and sustainable future.

The development of optimal sustainable product strategies across various sectors, including health systems, education, the environment, industrial and agricultural activities, energy generation, and resource management, necessitates a comprehensive approach. Employing a hybrid method proves instrumental in achieving this multifaceted goal. This integrated approach combines diverse methodologies and tools to create a robust framework that addresses the unique challenges posed by each sector. By leveraging the strengths of different methods, such as quantitative analysis, qualitative assessment, and systems thinking, the hybrid approach enables a more nuanced understanding of the intricate interdependencies within these sectors. Through the careful integration of data-driven insights and qualitative considerations, decision-makers can formulate sustainable strategies that not only optimize resource utilization but also foster long-term environmental, social, and

economic benefits. This holistic methodology facilitates a more effective response to the complex and interconnected challenges faced by health systems, education, environmental preservation, industrial and agricultural practices, energy generation, and resource management, paving the way for a more sustainable future.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Due to privacy, study details data cannot be provided.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A. Content of SDGs

No.	Goal's Name	Content
Goal 1 (G1)	No Poverty	End poverty in all its forms everywhere.
Goal 2 (G2)	Zero Hunger	End hunger, achieve food security and improved nutrition, and promote sustainable agriculture.
Goal 3 (G3)	Good Health and Well-Being	Ensure healthy lives and promote well-being for all at all ages.
Goal 4 (G4)	Quality Education	Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all.
Goal 5 (G5)	Gender Equality	Achieve gender equality and empower all women and girls.
Goal 6 (G6)	Clean Water and Sanitation	Ensure availability and sustainable management of water and sanitation for all.
Goal 7 (G7)	Affordable and Clean Energy	Ensure access to affordable, reliable, sustainable and modern energy for all.
Goal 8 (G8)	Decent Work and Economic Growth	Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all.
Goal 9 (G9)	Industry, Innovation and Infrastructure	Build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation.
Goal 10 (G10)	Reduced Inequalities	Reduce income inequality within and among countries.
Goal 11 (G11)	Sustainable Cities and Communities, Responsible Consumption and Production	Make cities and human settlements inclusive, safe, resilient, and sustainable.
Goal 12 (G12)	Responsible Consumption and Production	Ensure sustainable consumption and production patterns.
Goal 13 (G13)	Climate Action, Goal	Take urgent action to combat climate change and its impacts by regulating emissions and promoting developments in renewable energy.
Goal 14 (G14)	Life Below Water	Conserve and sustainably use the oceans, seas and marine resources for sustainable development.
Goal 15 (G15)	Life on Land, Goal	Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss.
Goal 16 (G16)	Peace, Justice and Strong Institutions	Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels.
Goal 17 (G17)	Partnerships for the Goals	Strengthen the means of implementation and revitalize the global partnership for sustainable development.

Appendix B. Preliminary Sustainable Product Strategies and Their Definition

No.	Name of strategy	Definition of Strategy
1	Strategy1 Energy Efficiency	• Develop products that are energy-efficient to reduce overall power consumption. • Implement power-saving modes and technologies to enhance energy efficiency.
2	Strategy2 Eco-friendly Materials	• Utilize sustainable and recyclable materials in product design and packaging. • Minimize the use of hazardous substances, such as lead, mercury, and other harmful materials.
3	Strategy3 Modular Design	• Design products with modular components to facilitate repair and upgrades, extending the product's lifespan. • Enable users to replace individual parts instead of replacing the entire product.
4	Strategy4 Recycling Programs	• Establish take-back and recycling programs to responsibly dispose of electronic waste. • Encourage customers to return old products for proper recycling.
5	Strategy5 Renewable Energy Integration	• Explore ways to incorporate renewable energy sources into product functionality, such as solar panels or kinetic energy harvesting.
6	Strategy6 Longevity and Durability	• Design products with durability in mind to reduce the frequency of replacements. • Focus on creating high-quality products that withstand wear and tear.
7	Strategy7 Reduced Packaging Waste	• Minimize packaging materials and opt for eco-friendly packaging solutions. • Use packaging materials that are easily recyclable or biodegradable.
8	Strategy8 Supply Chain Sustainability	• Collaborate with suppliers who adhere to sustainable and ethical practices. • Implement strict environmental and social responsibility standards throughout the supply chain.
9	Strategy9 Lifecycle Assessments	• Conduct life-cycle assessments to understand and minimize the environmental impact of products from manufacturing to disposal.
10	Strategy10 Carbon Footprint Reduction	• Implement measures to reduce the carbon footprint of the manufacturing and distribution processes. • Invest in carbon offset programs to compensate for unavoidable emissions.
11	Strategy11 User Education and Engagement	• Educate consumers about the environmental impact of electronic products. • Encourage responsible use, disposal, and recycling practices among consumers.
12	Strategy12 Smart Technology Integration	• Develop products with smart features that optimize energy use and resource consumption. • Implement artificial intelligence to enhance energy efficiency and user experience.
13	Strategy13 Water Conservation	• Minimize water usage in manufacturing processes. • Implement water-saving features in products, if applicable.
14	Strategy14 Fair Labor Practices	• Ensure fair labor practices in manufacturing facilities, promoting workers' rights and well-being.
15	Strategy15 E-Waste Reduction	• Design products with a focus on reducing electronic waste through innovative and sustainable solutions. • Implement programs to refurbish and reuse electronic components.
16	Strategy16 Collaboration for Impact	• Collaborate with industry peers, NGOs, and governmental bodies to address environmental challenges collectively.
17	Strategy17 Incentives for Sustainable Choices	• Provide incentives for customers who choose sustainable products, such as discounts or extended warranties.
18	Strategy18 Continuous Improvement	• Regularly review and update sustainability practices based on advancements in technology and environmental standards.
19	Strategy19 Transparency and Reporting	• Be transparent about sustainability efforts and regularly report progress to consumers and stakeholders.
20	Strategy20 Circular Economy Integration	• Embrace the principles of the circular economy, focusing on product reuse, repair, and recycling to minimize waste.
21	Strategy21 Renewable Packaging Materials	• Utilize packaging materials made from renewable resources, such as plant-based plastics or bio-based materials. • Explore innovative, sustainable alternatives to traditional packaging.
22	Strategy22 Energy-Efficient Manufacturing Processes	• Implement energy-efficient practices in the manufacturing phase to reduce energy consumption during production. • Optimize production lines to minimize waste and enhance overall energy efficiency.
23	Strategy23 Biodegradable Product Components	• Incorporate biodegradable materials into product components to facilitate eco-friendly disposal. • Ensure that these materials do not compromise product performance and functionality.

No.	Name of strategy	Definition of Strategy
24	Strategy24 Localized Production	• Establish localized manufacturing facilities to reduce the environmental impact of transportation. • Promote regional job creation and support local economies.
25	Strategy25 Sustainable Product Upcycling	• Design products with features that allow for easy upcycling or repurposing. • Provide guides or suggestions for users on creative ways to repurpose or upcycle the product.
26	Strategy26 Closed-Loop Systems	• Implement closed-loop systems that enable the recovery and reuse of materials from old products in the manufacturing of new ones. • Design products with components that can be easily reintegrated into the production cycle.
27	Strategy27 Waterless Manufacturing	• Explore manufacturing processes that require little to no water, reducing the environmental impact on water resources. • Invest in technologies that enable waterless production without compromising product quality.
28	Strategy28 Biodiversity Conservation	• Assess and mitigate the impact of product manufacturing on local ecosystems. • Support biodiversity conservation initiatives in areas affected by manufacturing activities.
29	Strategy29 Minimalist Design	• Adopt minimalist design principles to reduce the overall material usage in product construction. • Prioritize simplicity without compromising functionality and user experience.
30	Strategy30 Social Impact Initiatives	• Implement programs that contribute to social well-being in communities where manufacturing takes place. • Support education, healthcare, or other social initiatives to create a positive impact.
31	Strategy31 Energy-Positive Products	• Design products that generate more energy than they consume during regular use. • Explore integration with renewable energy sources to achieve energy-positive functionality.
32	Strategy32 Upgradable Software	• Develop products with upgradable software to extend the product lifespan through digital enhancements. • Enable users to access new features and capabilities through software updates.
33	Strategy33 Carbon-Negative Materials	• Source materials that have a carbon-negative footprint, helping to offset emissions during the manufacturing process. • Collaborate with suppliers to identify and utilize such materials.
34	Strategy34 Community Engagement in Product Design	• Involve local communities in the design process to ensure products meet specific needs and preferences. • Foster a sense of ownership and connection between the community and the product.
35	Strategy35 Sustainable Transportation Solutions	• Explore sustainable transportation options for product distribution, such as electric or hybrid vehicles. • Optimize logistics to minimize the environmental impact of product transportation.
36	Strategy36 Energy-Storage Integration	• Integrate energy storage solutions into products to promote efficient energy use and storage. • Explore partnerships with renewable energy companies for comprehensive energy solutions.
37	Strategy37 Zero-Waste Packaging	• Design packaging with the goal of zero waste, ensuring that all materials are either recyclable or compostable. • Encourage consumers to participate in responsible disposal practices.
38	Strategy38 Fair Trade Certification	• Seek fair trade certification for products to ensure fair wages and ethical treatment throughout the supply chain. • Support fair trade initiatives and organizations.
39	Strategy39 Collaborative Product Recycling	• Collaborate with competitors to create industry-wide product recycling initiatives. • Establish shared infrastructure for efficient and widespread product recycling.
40	Strategy40 Blockchain for Supply Chain Transparency	• Implement blockchain technology to enhance transparency in the supply chain. • Enable consumers to trace the journey of the product from raw materials to end-of-life recycling.

Appendix C. Number of WDM Weights of 3C Products' Sustainable Product Strategies

WDM		SDGs																	The total number of weights	Best sustainable product strategies
No.	Name of strategy	G1(w:4)	G2(w:3)	G3(w:3)	G4(w:4)	G5(w:2)	G6(w:1)	G7(w:4)	G8(w:4)	G9(w:3)	G10(w:4)	G11(w:3)	G12(w:2)	G13(w:2)	G14(w:4)	G15(w:3)	G16(w:3)	G17(w:1)		
Strategy1	*Energy Efficiency*	2	2	5	3	2	1	1	2	3	2	2	1	1	1	2	3	2	106	
Strategy2	*Eco-friendly Materials*	2	4	2	4	4	3	5	4	5	4	3	4	1	4	5	4	3	124	*
Strategy3	*Modular Design*	1	2	2	3	2	2	2	3	3	1	4	3	2	3	2	1	3	142	*
Strategy4	*Recycling Programs*	3	3	2	1	3	4	3	4	1	2	1	4	2	4	2	1	4	102	
Strategy5	*Renewable Energy Integration*	1	4	2	1	3	1	1	3	3	4	1	2	2	4	1	2	3	104	
Strategy6	*Longevity and Durability*	4	4	2	3	1	2	3	5	3	5	5	4	2	4	5	1	3	128	*
Strategy7	*Reduced Packaging Waste*	1	4	3	2	4	4	3	1	4	2	1	4	2	1	2	3	3	131	*
Strategy8	*Supply Chain Sustainability*	3	2	3	1	4	4	1	2	3	1	1	3	1	4	2	1	2	105	
Strategy9	*Lifecycle Assessments*	2	4	2	3	1	2	2	4	3	2	4	5	2	5	1	1	3	106	
Strategy10	*Carbon Footprint Reduction*	3	3	2	3	4	4	2	3	1	3	1	5	3	4	3	1	5	142	*
Strategy11	*User Education and Engagement*	4	2	1	1	3	4	4	3	4	1	2	4	1	3	2	2	3	135	*
Strategy12	*Smart Technology Integration*	2	1	4	2	1	4	1	2	3	1	3	4	2	1	2	1	5	106	
Strategy13	*Water Conservation*	3	2	4	2	4	5	3	3	4	2	3	5	2	2	5	4	4	144	*
Strategy14	Fair Labor Practices	2	3	3	1	4	3	4	3	5	2	2	4	2	1	2	4	3	172	*
Strategy15	*E-waste Reduction*	3	5	2	2	1	4	2	3	1	3	1	4	3	4	2	1	3	118	*
Strategy16	*Collaboration for Impact*	3	2	2	1	3	4	3	4	1	2	2	3	2	2	1	1	2	106	
Strategy17	*Incentives for Sustainable Choices*	3	3	1	4	4	3	1	2	4	5	1	4	3	2	2	5	3	107	*
Strategy18	*Continuous Improvement*	4	2	2	1	2	4	2	3	3	2	1	4	2	4	2	1	4	126	*
Strategy19	Transparency and Reporting	2	1	2	3	4	2	2	3	3	2	4	3	2	3	1	5	3	110	
Strategy20	*Circular Economy Integration*	2	4	3	4	3	1	2	3	1	4	3	4	2	4	2	4	3	135	*
Strategy21	*Renewable Packaging Materials*	4	3	5	4	3	4	3	5	3	1	1	3	3	3	2	1	4	145	*
Strategy22	*Energy-Efficient Manufacturing Processes*	4	2	3	1	3	3	5	2	1	3	2	4	2	1	3	2	3	136	*
Strategy23	*Biodegradable Product Components*	3	5	4	1	1	3	2	2	4	2	2	3	1	4	3	1	1	107	
Strategy24	*Localized Production*	3	4	2	1	3	4	3	3	2	1	3	4	2	4	2	1	3	121	*
Strategy25	*Sustainable Product Upcycling*	3	4	3	2	1	4	3	3	4	2	1	5	3	3	2	4	3	138	*
Strategy26	*Closed-Loop Systems*	1	3	2	1	4	2	2	4	3	1	4	3	2	1	2	1	5	118	*
Strategy27	*Waterless Manufacturing*	2	3	4	3	3	4	1	2	3	2	1	5	4	4	1	3	4	119	
Strategy28	*Biodiversity Conservation*	2	2	3	1	3	2	4	3	4	2	4	4	2	3	2	1	4	133	
Strategy29	*Minimalist Design*	4	3	2	1	4	4	2	3	3	4	3	3	2	4	3	5	3	141	*
Strategy30	*Social Impact Initiatives*	4	1	2	3	1	3	2	1	3	4	1	4	2	4	2	1	2	126	*
Strategy31	*Energy-Positive Products*	2	2	3	2	2	1	4	3	2	2	1	4	3	3	2	4	3	101	
Strategy32	*Upgradable Software*	3	4	1	2	2	4	5	2	1	2	2	3	2	4	1	1	2	105	
Strategy33	*Carbon-Negative Materials*	3	4	1	5	4	2	2	3	1	2	2	4	1	1	2	4	3	107	
Strategy34	*Community Engagement in Product Design*	4	3	3	4	3	3	2	5	3	2	4	1	2	4	3	1	1	122	*
Strategy35	*Sustainable Transportation Solutions*	2	2	4	3	2	5	1	3	4	2	4	1	2	4	2	1	3	139	*
Strategy36	*Energy-Storage Integration*	2	2	5	3	1	2	3	3	2	2	1	4	2	5	2	3	2	118	*
Strategy37	Zero-Waste Packaging	3	3	1	2	1	3	2	1	1	2	2	4	5	4	2	1	3	106	
Strategy38	*Fair Trade Certification*	1	4	4	1	2	3	4	2	3	2	4	4	2	1	2	1	3	101	
Strategy39	*Collaborative Product Recycling*	2	4	3	2	2	3	4	1	3	2	3	4	2	4	2	1	3	126	*
Strategy40	*Blockchain for Supply Chain Transparency*	4	2	2	1	4	3	3	4	5	2	4	1	2	3	1	3	4	125	*

(*: indicates the best sustainable product strategies. This result is obtained through the total number of weights in WDM).

References

1. Ciroth, A.; Finkbeiner, M.; Traverso, M.; Hildenbrand, J.; Kloepffer, W.; Mazijn, B.; Prakash, S.; Sonnemann, G.; Valdivia, S.; Ugaya, C.M.L.; et al. *Towards a Life Cycle Sustainability Assessment: Making Informed Choices on Products*; UN Environment Programme: Paris, France, 2011; p. 2011.
2. De Medeiros, J.F.; Ribeiro, J.L.D.; Cortimiglia, M.N. Success factors for environmentally sustainable product innovation: A systematic literature review. *J. Clean. Prod.* **2014**, *65*, 76–86. [CrossRef]
3. Dangelico, R.M.; Pujari, D. Mainstreaming Green Product Innovation: Why and How Companies Integrate Environmental Sustainability. *J. Bus. Ethics* **2010**, *95*, 471–486. [CrossRef]
4. Yazirlıoğlu, L. Sustainable Design Considerations for Emotional Durability Product Longevity through Product Care Activities by Repair Enthusiasts. Master's Thesis, Graduate School of Natural and Applied Sciences, Isparta, Türkiye, 2021.
5. Ramani, K.; Ramanujan, D.; Bernstein, W.Z.; Zhao, F.; Sutherland, J.; Handwerker, C.; Choi, J.; Kim, H.; Thurston, D. Integrated Sustainable Life Cycle Design: A Review. *J. Mech. Des.* **2010**, *132*, 091004. [CrossRef]
6. Charter, M.; Tischner, U. *Sustainable Solutions: Developing Products and Services for the Future*; Routledge: Oxford, UK, 2017.
7. Rashid, L.; Yahya, S.; Shamee1, S.A.; Jabar1, J.; Sedek, M.; Halim1, S. Eco product innovation in search of meaning: Incremental and radical practice for sustainability development. *Asian Soc. Sci.* **2014**, *10*, 78–88. [CrossRef]
8. Branco, M.C.; Rodrigues, L.L. Corporate Social Responsibility and Resource-Based Perspectives. *J. Bus. Ethics* **2006**, *69*, 111–132. [CrossRef]
9. Chatty, T.; Harrison, W.; Ba-Sabaa, H.H.; Faludi, J.; Murnane, E.L. Co-Creating a Framework to Integrate Sustainable Design into Product Development Practice: Case Study at an Engineering Consultancy Firm. *Sustainability* **2022**, *14*, 9740. [CrossRef]
10. Niemann, J.; Tichkiewitch, S.; Westkämper, E. *Design of Sustainable Product Life Cycles*; Springer Science & Business Media: Berlin/Heidelberg, Germany, 2008.
11. Zhang, H.C.; Kuo, T.C.; Lu, H.; Huang, S.H. Environmentally conscious design and manufacturing: A state-of-the-art survey. *J. Manuf. Syst.* **1997**, *16*, 352–371. [CrossRef]
12. Hartman, L.P.; Rubin, R.S.; Dhanda, K. The Communication of Corporate Social Responsibility: United States and European Union Multinational Corporations. *J. Manuf. Syst.* **2007**, *74*, 373–389. [CrossRef]
13. Khalid, A. *Sustainable Marketing and Its Impact on Society: A Study of Marketing Strategies and Opportunities Promoting Eco-Friendly Lifestyle*; SSRN: Amsterdam, The Netherlands, 2023.
14. Sdiri, H. Do Environmental Commitment and Innovation Influence Export Intensity? Firm-level Evidence from Tunisia. *Int. J. Innov. Manag.* **2023**. [CrossRef]
15. Nagib, M.A. Improving Sustainable Development of the Modern Company: Challenges and Opportunities. Master's Thesis, Ural Federal University, Ekaterinburg, Russia, 2023.
16. Zheng, P.; Ni, L. *Smart Phone and Next Generation Mobile Computing*; Elsevier: Amsterdam, The Netherlands, 2010.
17. Rasche, P.; Jablonski, J.; Theis, S.; Wille, M.; Mertens, A. Desktop PC, Tablet PC, or Smartphone? An Analysis of Use Preferences in Daily Activities for Different Technology Generations of a Worldwide Sample. In Proceedings of the ITAP 2018: Human Aspects of IT for the Aged Population. Acceptance, Communication and Participation, Las Vegas, NV, USA, 15–20 July 2018; pp. 3–20.
18. Poulová, P.; Klímová, B.; Pulkrábková, D. *Use of Mobile Devices—A Survey Study*; Springer: Singapore, 2019.
19. Gandotra, P.; Jha, R.K.; Jain, S. Green communication in next generation cellular networks: A survey. *IEEE Access* **2017**, *5*, 11727–11758. [CrossRef]
20. Stutz, J. The three-front war: Pursuing sustainability in a world shaped by explosive growth. *Sustain. Sci. Pract. Policy* **2010**, *6*, 49–59. [CrossRef]
21. Winston, W.; Mintu-Wimsatt, A.T. *Environmental Marketing: Strategies, Practice, Theory, and Research*; Routledge: Oxford, UK, 2013.
22. Gardner, J.E. Decision making for sustainable development: Selected approaches to environmental assessment and management. *Environ. Impact Assess. Rev.* **1989**, *4*, 337–366. [CrossRef]
23. Gupta, V. *Innovation Mechanisms in Start-Ups: Practice, Strategies and Impacts*; Springer: Cham, Switzerland, 2022.
24. Van Weenen, J.C. Towards sustainable product development. *J. Clean. Prod.* **1995**, *3*, 95–100. [CrossRef]
25. Kara, S.; Ibbotson, S.; Kayis, B. Sustainable product development in practice: An international survey. *J. Manuf. Technol. Manag.* **2014**, *25*, 848–872. [CrossRef]
26. Brynjarsdottir, H.; Håkansson, M.; Pierce, J. Sustainably unpersuaded: How persuasion narrows our vision of sustainability. In Proceedings of the CHI'12: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, Austin, TX, USA, 5–10 May 2012; pp. 947–956.
27. Smith, M.J.; Pangsapa, D.P. *Environment and Citizenship: Integrating Justice, Responsibility and Civic Engagement*; Bloomsbury Publishing: London, UK, 2008.
28. Atkinson, M.M.; Coleman, W.D. Policy networks, policy communities and the problems of governance. *Governance* **1992**, *5*, 154–180. [CrossRef]
29. Stephens, E.; Martin, B. *Business Policy and Strategic Management*; ED-Tech Press: London, UK, 2019.
30. Khurana, A.; Rosenthal, S.R. Towards Holistic "Front Ends" in New Product Development. *J. Prod. Innov. Manag.* **1998**, *15*, 57–74. [CrossRef]
31. Oliveira, M.G.; Rozenfeld, H. Integrating technology roadmapping and portfolio management at the front-end of new product development. *Technol. Forecast. Soc. Chang.* **2010**, *77*, 1339–1354. [CrossRef]

32. Ahmad, S.; Wong, K.Y.; Tseng, M.L.; Wong, W.P. Sustainable product design and development: A review of tools, applications and research prospects. *Resour. Conserv. Recycl.* **2018**, *132*, 49–61. [CrossRef]
33. Schulte, J.; Knuts, S. Sustainability impact and effects analysis—A risk management tool for sustainable product development. *Sustain. Prod. Consum.* **2022**, *30*, 737–751. [CrossRef]
34. Romli, A.; Prickett, P.; Setchi, R.; Soe, S. Integrated eco-design decision-making for sustainable product development. *Int. J. Prod. Res.* **2015**, *53*, 549–571. [CrossRef]
35. Carvalho, M.M.; Fleury, A.; Lopes, A.P. An overview of the literature on technology roadmapping (TRM): Contributions and trends. *Technol. Forecast. Soc. Chang.* **2013**, *80*, 1418–1437. [CrossRef]
36. Parker, A.; Tritter, J. Focus group method and methodology: Current practice and recent debate. *Int. J. Res. Method Educ.* **2006**, *29*, 23–37. [CrossRef]
37. Wilkinson, S. Focus group methodology: A review. *Int. J. Soc. Res. Methodol.* **1998**, *1*, 181–203. [CrossRef]
38. Then, K.L.; Rankin, J.A.; Ali, E. Focus Group Research: What Is It and How Can It Be Used? *Can. J. Cardiovasc. Nurs.* **2014**, *24*, 16–22. [PubMed]
39. Plummer-D'Amato, P. Focus group methodology Part 1: Considerations for design. *Int. J. Ther. Rehabil.* **2008**, *15*, 69–73. [CrossRef]
40. Dilshad, R.M.; Latif, M.I. Focus group interview as a tool for qualitative research: An analysis. *Pak. J. Soc. Sci.* **2013**, *33*, 191–198.
41. Onwuegbuzie, A.J.; Dickinson, W.B.; Leech, N.L.; Zoran, A.G. A Qualitative Framework for Collecting and Analyzing Data in Focus Group Research. *Int. J. Qual. Methods* **2009**, *8*, 1–21. [CrossRef]
42. Hoffmann, E. Consumer integration in sustainable product development. Consumer integration in sustainable product development. *Bus. Strategy Environ.* **2007**, *16*, 322–338. [CrossRef]
43. Pohlmann, C.R.; Scavard, A.J.; Alves, M.B.; Korzenowski, A.L. The role of the focal company in sustainable development goals: A Brazilian food poultry supply chain case study. *J. Clean. Prod.* **2020**, *245*, 118798. [CrossRef]
44. Putman, V.L.; Paulus, P.B. Brainstorming, Brainstorming Rules and Decision Making. *J. Creat. Behav.* **2009**, *43*, 29–40. [CrossRef]
45. Paulus, P.B.; Kenworthy, J.B. Effective brainstorming. In *The Oxford Handbook of Group Creativity and Innovation*; Oxford University Press: Oxford, UK, 2019; pp. 287–305.
46. Ritter, S.M.; Mostert, N.M. How to facilitate a brainstorming session: The effect of idea generation techniques and of group brainstorm after individual brainstorm. *Creat. Ind. J.* **2018**, *11*, 263–277. [CrossRef]
47. Rickards, T. Brainstorming Revisited: A Question of Context. *Int. J. Manag. Rev.* **1999**, *1*, 91–110. [CrossRef]
48. Al-Samarraie, H.; Hurmuzan, S. A review of brainstorming techniques in higher education. *Think. Ski. Creat.* **2018**, *27*, 78–91. [CrossRef]
49. Besant, H. The Journey of Brainstorming. *J. Transform. Innov.* **2016**, *2*, 1–7.
50. Pugh, S. *Total Design: Integrated Methods for Successful Product Engineering*; Addison-Wesley Publishing Company: Boston, MA, USA, 1991.
51. Saaty, T.L. *The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation*; McGraw-Hill: New York, NY, USA, 1980.
52. French, S.; Delbecq, A. *Organizational Decision Making*; University of Notre Dame Press: Notre Dame, IN, USA, 1976.
53. Triantaphyllou, E. *Multi-Criteria Decision Making Methods: A Comparative Study*; Springer: Berlin/Heidelberg, Germany, 2000.
54. Parnell, G.S.; Driscoll, P.D.; Henderson, D.J. *Decision Making in Systems Engineering and Management*; John Wiley & Sons: Hoboken, NJ, USA, 2013.
55. Kramer, O. Genetic Algorithms. In *Genetic Algorithm Essentials*; Springer: Berlin/Heidelberg, Germany, 2017.
56. Hodgett, R. *Decision Matrix Analysis: A Powerful Decision-Making Tool*; Gower Publishing: Aldershot, UK, 2014.
57. Jong, K.D. Learning with genetic algorithms: An overview. In *Machine Learning*; Springer: Berlin/Heidelberg, Germany, 1988.
58. Srinivas, M.; Patnaik, L.M. Genetic algorithms: A survey. *Computer* **1994**, *27*, 17–26. [CrossRef]
59. Forrest, S.; Mitchell, M. What Makes a Problem Hard for a Genetic Algorithm? Some Anomalous Results and their Explanation. *Mach. Learn.* **1993**, *13*, 285–319.
60. Srinivas, M.; Patnaik, L.M. Adaptive Probabilities of Crossover and Mutation in Genetic Algorithms. *IEEE Trans. Syst. Man Cybern.* **1994**, *24*, 656–667. [CrossRef]
61. DeJong, K.A.; Spears, W.M. An Analysis of the Interacting Roles of Population Size and Crossover in Genetic Algorithms. In Proceedings of the International Conference on Parallel Problem Solving from Nature, Dortmund, Germany, 1–3 October 1990; Springer: Berlin/Heidelberg, Germany, 2005; pp. 38–47.
62. Marquis, J.; Deeb, R.S. Roadmap to a Successful Product Development. *IEEE Eng. Manag. Rev.* **2018**, *46*, 51–58. [CrossRef]
63. Münch, J.; Trieflinger, S.; Bogazköy, E.; Eißler, P.; Roling, B.; Schneider, J. Product Roadmap Formats for an Uncertain Future: A Grey Literature Review. In Proceedings of the 2020 46th Euromicro Conference on Software Engineering and Advanced Applications (SEAA), Kranj, Slovenia, 26–28 August 2020; pp. 26–28.
64. Eißler, P.; Schneider, J.; Roling, B. Product roadmap alignment–achieving the vision together: A grey literature review. In *Agile Processes in Software Engineering and Extreme Programming—Workshops*; Springer Nature: Berlin/Heidelberg, Germany, 2020.
65. Münch, J.; Trieflinger, S.; Lang, D. Product Roadmap—From Vision to Reality: A Systematic Literature Review. In Proceedings of the 2019 IEEE International Conference on Engineering, Technology and Innovation (ICE/ITMC), Valbonne, France, 17–19 June 2019; pp. 17–19.

66. Trieflinger, S.; Münch, J.; Bogazköy, E.; Eißler, P.; Schneider, J.; Roling, B. How to Prioritize Your Product Roadmap When Everything Feels Important: A Grey Literature Review. In Proceedings of the 2021 IEEE International Conference on Engineering, Technology and Innovation (ICE/ITMC), Cardiff, UK, 21–23 June 2021; pp. 21–23.
67. Petrick, I.J.; Echols, A.E. Technology roadmapping in review: A tool for making sustainable new product development decisions. *Technol. Forecast. Soc. Chang.* **2004**, *71*, 81–100. [CrossRef]
68. Wu, H.H.; Tang, Y.T.; Shyu, J.W. A case of applying importance-performance analysis in identifying key success factors to develop marketing strategies. *Qual. Quant.* **2010**, *44*, 1207–1218. [CrossRef]
69. Ma, M.Y.; Chen, Y.C.; Li, S.R. How to build design strategy for attractiveness of new products. *Adv. Inf. Sci. Serv. Sci.* **2011**, *3*, 17–26.