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Towards Green Product Development: Analyzing The Role of Sustainability-Oriented Tools And Methods in The New Product Development Process*

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Abstract

Growing consumer environmental awareness and stakeholder pressure for responsible business practices are driving companies to increasingly seek tools that support the development of green products. However, despite the dynamic development of the eco-innovation concept, the literature lacks a coherent methodological framework that would allow for the systematic selection of methods, tools, and standards for specific phases of the new product development (NPD) process. This gap limits the practical possibilities for effectively implementing the principles of sustainability and the circular economy in design processes.To address this challenge, this study proposes a three-step methodology: (1) defining categories of methods and tools supporting green product development, (2) identifying exemplary solutions within each category, and (3) assigning them to specific NPD phases. Based on an in-depth literature review, four main categories were identified: quantitative and systematic methods (e.g., LCA, MFA, environmental footprints), qualitative and design-based methods (e.g., ecodesign, DfX, 6R/10R), standards and certification systems (e.g., ISO, EPD, ecolabels), and sustainability and circularity assessment tools (e.g., MCI, ERA, SVAT). The results of the analysis allowed us to create a map of the connections between methods and NPD phases, indicating which instruments best support specific stages of product development. This systematization provides practical support for companies in making informed design decisions, increases the effectiveness of pro-environmental activities, and facilitates the communication of environmental values to stakeholders. From a scientific perspective, the study fills a significant gap in the literature by proposing a coherent approach that integrates innovation management with the principles of sustainable development.

Keywords: green product development, new product development, Life Cycle Assessment,

Introduction

With increasing environmental awareness, consumers are increasingly choosing environmentally friendly products, even if they are more expensive (Lou *et al.*, 2024). Therefore, recent years have seen a trend of businesses adapting their operations to ongoing environmental changes. Organizations are increasingly seeking alternative solutions that will allow them to offer products and services in a more environmentally friendly manner (Levi-Bliech and Dahan, 2025). Unlike qualitative characteristics, however, the ecological aspect of a product can be difficult to directly perceive, which poses a challenge for companies in effectively communicating these characteristics (Lou *et al.*, 2024). Eco-label certification reduces information asymmetry, facilitates customer identification of "green" products, and serves as an effective tool for communicating their environmentally

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friendly nature (Lou *et al.*, 2024). Over the last two decades, companies have become increasingly willing to invest financial resources in the development of eco-friendly products, which not only have a positive impact on the environment but can also contribute to strengthening the image and reputation of the organization (Zolfagharinia *et al.*, 2023). With growing global awareness of sustainable development, companies are feeling increasing pressure to implement eco-innovations that reduce their negative environmental impact while simultaneously meeting stakeholder expectations regarding corporate responsibility. In this context, eco-innovation has become a key element of corporate strategies, enabling not only building a competitive advantage but also achieving sustainable development goals in the face of intensifying environmental challenges (Iftikhar *et al.*, 2025). What is worth emphasizing from a practical perspective is that green innovations not only contribute to reducing CO_2 emissions, but many of the resulting benefits are also intangible and impact the functioning of enterprises in the long term (Iftikhar *et al.*, 2025). It should also be noted that one of the key assumptions of the United Nations' Sustainable Development Goal (SDG) 12 is the pursuit of sustainable consumption and production patterns. This concept emphasizes the need to combine economic growth with environmental protection by promoting the production and use of sustainable and ecological goods and services (Salhieh, 2026). Growing consumer environmental awareness and stakeholder pressure for responsible business practices have led companies to seek solutions that enable them to offer products and services in a more environmentally friendly manner. In this context, the concept of green product development has emerged, combining the pursuit of sustainable consumption and production with building a competitive advantage and long-term benefits for the organization. The goal of green product development is to prevent environmental problems by introducing innovative and eco-friendly designs into existing products. The essence of this is to achieve a balance between environmental performance and economic profitability (Wan *et al.*, 2024). The dynamic development of green innovation concepts demonstrates that effective development of environmentally friendly products requires a systematic approach and clearly defined tools for assessing and supporting the entire design process. The lack of coherent frameworks and methodologies makes identifying and selecting appropriate instruments a key prerequisite for creating solutions aligned with the principles of sustainable development and the circular economy. In response to this challenge, the research objective was formulated: to identify methods and tools that support the new product development (NPD) process with a focus on "greenness," and then assign them to the individual NPD phases. In this context, "greenness" is understood as compliance with the principles of sustainable development, the circular economy, and environmental friendliness.

Research Methodology

To achieve the above goal, a research methodology was proposed consisting of three main steps:

(1) defining categories of methods, tools, and instruments supporting green product development;
(2) identifying exemplary solutions within each category;
(3) defining the new product development phases and assigning the identified solutions accordingly.

Applying the described methodology will provide companies with access to a structured set of methods and tools supporting the development of green products. This will enable them to consciously select solutions appropriate for each phase of the NPD process, leading to greater efficiency in pro-environmental activities and better alignment with stakeholder expectations. As a result, organizations will gain practical support in creating products that adhere to the principles of sustainable development, the circular economy, and are environmentally friendly, which can also contribute to building their competitive advantage. From a scientific perspective, this study will help fill a significant research gap: the lack of a coherent methodology for selecting methods, tools, and instruments supporting the development of green products in each phase of the NPD process, thus contributing to the development of knowledge at the intersection of innovation management and sustainable development.

Results

Based on the research methodology described in the previous section, an in-depth literature review was conducted to identify categories of methods, tools, and instruments supporting green product development. A wide range of methods, indicators, and standards relevant to the green NPD process were collected. Their primary functions were then analyzed, which made it possible to classify them into four categories C1-C4: (C1) Quantitative and systemic environmental assessment methods, (C2) qualitative and design-oriented methods, (C3) standards and certification systems, and (C4) Sustainability and circularity assessment tools.

Next, as part of the second step of the proposed methodology, exemplary methods, tools, and instruments supporting green product development were assigned to each of the four categories (C1–C4).

(C1) Quantitative and systemic environmental assessment methods

Life Cycle Thinking (LCT) methodologies can be classified under category C1. These include Life Cycle Costing (LCC), Life Cycle Assessment (LCA), and Social Life Cycle Assessment (S-LCA), which enable the evaluation of long-term economic, environmental, and social impacts of infrastructure assets across all stages of their life cycle, from production and construction to use, maintenance, and end-of-life (EoL) (Vargas-Farias *et al.*, 2026). Material Flow Analysis (MFA) is a tool for examining material inputs and outputs within a defined system, providing insights into material composition and flows, while highlighting both economic benefits and environmental impacts of human activities (Hossain *et al.*, 2025). Category C1 also includes footprint-based methods, such as the carbon footprint, water footprint, and ecological footprint, which serve as key indicators for assessing environmental impacts. The carbon footprint (CF) quantifies total greenhouse gas (GHG) emissions resulting from energy use (e.g., electricity and gas) and provides a baseline for assessing environmental impacts. Its calculation requires identifying energy sources and converting them into their corresponding GHG emissions (Arastou *et al.*, 2025). The impact-oriented water footprint (WF), based on LCA, is defined by the International Organization for Standardization (ISO) (Zhou *et al.*, 2023). Water footprint is an indicator that measures the total volume of freshwater used, directly and indirectly, to produce a product or service throughout its entire life cycle. The ecological footprint (EF) has become a key metric for assessing the degree to which human activities surpass the Earth's biocapacity, offering an essential perspective for evaluating the sustainability of economic growth (Wu *et al.*, 2025). The Product Sustainability Index (ProdSI) is a metrics-based methodology that offers a comprehensive evaluation of product sustainability across its entire life cycle, encompassing four stages: pre-manufacturing, manufacturing, use, and post-use (Shuaib *et al.*, 2014). Sustainable Value Stream Mapping (Sus-VSM) is a methodology used to visualize and evaluate the sustainability performance of manufacturing processes (Faulkner and Badurdeen, 2014). In summary, the following methods are classified in the C1 category: C1.1 LCC, C1.2 LCA, C1.3 S-LCA, C1.4 MFA, C1.5 CF, C1.6 WF, C1.7 EF, C1.8 ProdSI, and C1.9 Sus-VSM.

(C2) Qualitative and design-oriented methods

Eco-design and Design for X methodologies can be classified under category C2. Eco-design aims to enhance both the environmental and economic performance of a system by considering all life cycle stages and supply chain aspects, with the goal of minimizing environmental impacts and reducing costs (Liu *et al.*, 2026). Design for Environment (DfE) focuses on reducing resource use and waste while enhancing the environmental performance of products across their entire life cycle (Seo and Shirasawa, 2025). Design for Remanufacturing (DfRem) uses a set of methods and tools aimed at increasing the remanufacturing potential and restoring the functionality of new products (Karkasinas *et al.*, 2025). The principle of Design for Disassembly (DfD) is to use reversible and non-destructive methods for component separation, which increases the efficiency and reliability of automated disassembly processes. It is crucial to avoid permanent connections, such as welding or gluing, and to design products for easy disassembly, which supports circular economy goals and considers the EoL stage (Saxena, 2025). Design for Recycling (DfR) focuses on increasing the amount and value of materials recovered from EoL products. The effectiveness of this approach depends on considering the broader systemic context and understanding the recycling processes that influence design decisions and improve product recyclability (Norgren *et al.*, 2020). The 6R (reduce, reuse, recycle, recover, redesign and remanufacture) emphasizes the need to consider EoL activities at the design stage to ensure a closed loop. In a circular economy, the 6Rs are key technological elements (Hapuwatte and Jawahir, 2019). The 10R framework strategies, ranked from most to least effective, include: Refuse, Rethink, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle and Recover (Kirchherr *et al.*, 2017). In summary, the following methods are classified in the C2 category: C2.1 Eco-design, C2.2 DfE, C2.3 DfRem, C2.4 DfD, C2.5 DfR, C2.6 6R, and C2.7 10R.

(C3) Standards and certification systems

C3 category is focused mainly on ISO standards. The ISO 14040:2006 standard specifies the principles and framework for life cycle assessment (LCA), including defining the purpose and scope of the study, inventory analysis, impact assessment, interpretation of results, and principles of reporting and critical review (“ISO 14040”, n.d.). The ISO 14046:2014 standard specifies principles, requirements and guidelines for assessing the water footprint of products, processes and organizations based on the LCA method (“ISO 14046”, n.d.). The ISO 14001:2015 standard provides a framework for creating, implementing and improving an environmental management system (EMS), supporting companies in systematically implementing responsible and sustainable business practices (“ISO 14001”, n.d.). ISO 14006:2020 provides guidance to support organizations in establishing, implementing and improving ecodesign management as part of an EMS (“ISO 14006”, n.d.). An Environmental Product Declaration (EPD) is a tool that supports sustainable decisions by quantifying and communicating the environmental impact of products throughout their entire life cycle. It includes data from production, through construction and use, to end-of-life and beyond, developed in accordance with recognized standards (ISO 14025, ISO 15804, ISO 22057) (Olanrewaju *et al.*, 2025). Ecolabeling is seen as a tool to encourage producers to move away from environmentally undesirable manufacturing practices by harnessing the power of consumer choice (Hicks, 2013). In summary, the following are classified in the C3 category: C3.1 ISO 14040:2006, C3.2 14046:2014, C3.3 14001:2015, C3.4 14006:2020, C3.5 EPD, and C3.6 Ecolabels.

(C4) Sustainability and circularity assessment tools

The growing importance of sustainable development – encompassing environmental, social, ethical and economic aspects – has led to the widespread use of non-financial reporting (Torelli *et al.*, 2020). In recent years, a broad set of indicators and frameworks for assessing circularity have been developed to support the transition towards a circular economy. According to Li et al. in the construction sector alone, analyses have identified 148 quantitative, 160 semi-quantitative, and 152 qualitative indicators, used both individually and as part of complex assessment systems (Li *et al.*, 2025). One of the most common is the Material Circularity Index (MCI), developed by the Ellen MacArthur Foundation. It supports decision-making during product design. The MCI measures circularity by combining the linear flow index (LFI), lifetime, and the intensity of use into a dimensionless indicator (Moraga *et al.*, 2020). Ecological risk assessment (ERA) is the process of estimating the probability of a specific event occurring under given conditions. Its purpose is to provide a quantitative basis for comparing and balancing risks associated with environmental problems and to create systematic tools for improving their assessment and understanding (Park and Lek, 2015). Materiality Assessment (MA) is the process by which companies identify and prioritize reporting issues based on stakeholder expectations and needs (Francia *et al.*, 2025). Sustainable Value Analysis Tool (SVAT) was developed to support manufacturing companies in making decisions about implementing sustainability in the design of product-service systems. Its primary function is to assess different forms of value, and research confirms its usefulness and ease of use (Yang *et al.*, 2014). In summary, the following are classified in the C4 category: C4.1 MCI, C4.2 ERA, C4.3 MA, and C4.4 SVAT.
According to step 3 of the methodology, the NPD phases were defined, and the solutions identified in step 2 were assigned to them. The detailed list of NPD phases was defined based on (Rosienkiewicz, 2026). The results of the analysis are presented in Tab. 1.

Tab. 1 Role of methods, tools, and instruments supporting green product development (Cx.x) in NPD phases

NPD phase			C1									C2							C3						C4			
			C1.1	C1.2	C1.3	C1.4	C1.5	C1.6	C1.7	C1.8	C1.9	C2.1	C2.2	C2.3	C2.4	C2.5	C2.6	C2.7	C3.1	C3.2	C3.3	C3.4	C3.5	C3.6	C4.1	C4.2	C4.3	C4.4
1	Initiation and preliminary analysis	1.1 Idea generation															n	n										
		1.2 Market research																					n				n	
		1.3 Idea screening																								n		

		1.4 Marketing strategy					n		n															n				
		1.5 Business analysis	n	n	n																						n	
		1.6 Funding																										
2	Concept development	2.1 Concept development										n	n				n	n				n						
		2.2 Market survey																									n	
		2.3 Concept specification				n																			n			
		2.4 Feasibility study	n	n	n		n	n	n	n									n	n								n
3	System-level design	3.1 System-level design										n	n	n	n	n												
		3.2 Modelling				n																			n			
		3.3 Geometric dimensioning																										
		3.4 Risk assessment															n	n								n		
4	Detailed design	4.1 Detailed design										n	n	n	n							n			n			
		4.2 Standard component selection														n												
		4.3 Engineering drawings														n												
		4.4 Compliance planning																			n	n						n
5	Testing and refinement	5.1 Prototyping	n																									
		5.2 Functional testing		n			n	n											n	n								
		5.3 Customer testing								n																		
		5.4 Design iteration	n											n														n
6	Production ramp-up	6.1 Pre-production									n																	
		6.2 Production ramp-up				n					n																	
		6.3 Manufacturing validation									n										n							
		6.4 Retail product validation																			n							

7	Launch and evaluation	7.1 Product launch																				n	n					
		7.2 Commercialization					n		n													n	n					
		7.3 Product improvement	n	n	n					n							n	n										
		7.4 Post-launch evaluation	n	n				n											n	n						n		

The black square symbol indicates the role of the selected Cx.x in a given phase (1.x-7.x) of new product development.

Conclusions

Based on the results obtained, the allocation of methods, tools, and standards to specific phases of the NPD process reflects their primary functions and areas of application in green product development. Quantitative and systemic methods (C1), such as LCA, LCC, MFA, and footprint indicators, are primarily located in the feasibility, testing, and evaluation phases, as they provide quantitative data on environmental impact and economic efficiency throughout the product life cycle. Qualitative and design-based approaches (C2), including ecodesign, DfX methods, and the 6R/10R framework, are assigned to the early stages of conception and design, where design decisions have the greatest impact on product sustainability. Standards and certification systems (C3), such as ISO standards, EPDs, and ecolabels, are placed in the compliance planning, validation, and commercialization phases, as they formalize environmental practices and enable their communication to stakeholders. Sustainability and circularity assessment (C4) tools, such as MCI, ERA, MA, and SVAT, are assigned to the concept, risk assessment, and evaluation phases, where decision support and reporting mechanisms are crucial. This arrangement ensures that each NPD phase is supported by the most appropriate sustainability-oriented instruments, enhancing both the environmental performance and market competitiveness of new products. Further research will Focus on to providing a detailed analysis and description of the role of each of the identified methods, tools, and instruments supporting green product development (Cx.x) in NPD phases.

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