

AGILE FRAMEWORK FOR QUALITY AND INNOVATION IN EXTENDED LIFE CYCLE ASSESSMENT: THEORETICAL APPROACH

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Purpose: The paper presents a theoretical approach for extended Life Cycle Assessment (LCA): Quality (Q) and Innovation (I) in LCA (QILCA). This model (QILCA) extended to include product innovativeness in the era of mass personalization and Agile product design. Interest in the application of Agile design techniques in various design contexts has grown in recent years, becoming a promising trend in many areas, including customer (user)–product interactions. A product design strategy that incorporates the Agile concept may be the key to success in the age of mass product personalization and relationship marketing between manufacturers and customers (product owners).

Design/methodology/approach: The work is based on applying the principles of agile product development to the LCA phase of product prototyping, which allows us to produce a test-ready design in a short time, with the ability to make changes at any stage of the design process, while taking customer requirements into account.

Findings: Based on a segmented review of the literature, this paper discusses the Agile approach during the prototyping phase from a QILCA perspective.

Research limitations/implications: The presented assumptions and applications of the Agile approach to extended LCA constitute a framework for further research.

Practical implications: The proposed QILCA framework extends the scope of traditional product improvement by including quality, innovation, and LCA, also achieving increasingly higher standards through new or improved product features that are considered innovative in sustainable business.

Originality/value: The Agile approach is being applied to a growing range of product development. Although its (brief) history dates to AI projects, it is now being applied to the design (and improvement) of products in other industries. The authors contribute to the first discussions about the feasibility of implementing the Agile approach to product development.

Keywords: product improvement, Life Cycle Assessment (LCA), Agile.

Category of the paper: conceptual work.

1. Introduction

With the development of remote communication technologies and the intense competition among manufacturers for consumer markets, user (customer) involvement at the product design stage has become important for manufacturers in their pursuit of business objectives. However, the strong political radicalism in favor of environmental protection has led businesses to invest in reducing the negative environmental impact of products throughout their entire life cycle (Burchart-Korol et al., 2020). In corporate (manufacturer) efforts toward environmental protection, cooperation with customers (product users) is essential to create products that meet their needs. Customers expect highly innovative products from manufacturers. Their needs are often aspirations or dreams that producers attempt to realize; therefore, an Agile approach is necessary in the process of product improvement. To ensure that product innovation remains under control, a Life Cycle Assessment (LCA) methodology is needed, assuming that improved products will be recyclable, reusable, or even environmentally “friendly” at every stage of their life cycle. Enterprises monitor the impact of products throughout their entire life cycle, and the LCA methodology is a helpful and continuously evolving tool for this purpose.

Previously, the authors of this publication (we) examined the evolution of LCA frameworks (Siwiec, Pacana 2025a), proposing the integration of: (i) quality criteria into the LCA methodology at the product design stage, introducing the QLCA model (Gajdzik, Siwiec et al. 2024); (ii) cost evaluation (CQ-LCA) (Gawlik et al., 2024; Siwiec, Gajdzik, Pacana et al., 2025; Siwiec, Pacana, 2025b); and (iii) design thinking (DT-QLCA) (Siwiec, Gajdzik, Gawlik et al., 2025; Pacana et al., 2023). The authors have now added to the QLCA model criteria that serve as indicators of product competitiveness and innovativeness at the product improvement stage, following the Agile approach. The proposed extended LCA framework, incorporating quality and innovation aspects of products, has been named the QILCA model. The developed model emphasizes the necessity—particularly in many cases of product improvement—of applying an iterative (nonlinear) improvement process based on Agile methodologies (Fowler, Highsmith, 2001). Agile is a flexible project management approach focused on delivering products through iterative and incremental processes of improvement (Sadia et al., 2021).

The main objective of this publication is to present Agile-based product development within an LCA framework extended to include Quality (Q) and Innovation (I) aspects of designed products. Although many Agile practices existed in project management, the Agile approach had not yet been introduced into LCA at the stages of product design and improvement.

The research gap addressed in this paper lies in the lack of an integrated methodological framework that combines Life Cycle Assessment (LCA) with quality and innovation parameters during the early stages of product design (Balcioglu et al., 2025; Dong et al., 2025; Siwiec, Gajdzik, Gawlik et al., 2025), specifically under Agile project management principles

(Sahu, 2025). While LCA has traditionally focused on environmental impact across the product life cycle, existing literature does not provide systematic approaches that also incorporate iterative customer engagement, dynamic product refinement, and innovation assessment within sustainable design processes (Bossek et al., 2023). Furthermore, Agile methods, though widely applied in software and organizational development, have not yet been effectively operationalized in the context of environmental and quality-driven product optimization (Almalki, 2025; Koudriachov et al., 2025). This gap highlights the need for a holistic model—such as QILCA—that enables rapid prototyping and decision-making based on environmental, quality, and innovation criteria simultaneously.

Based on the current body of scientific publications, it is not yet possible to speak of a systematic Agile approach to the development of new products at the stage of their design and assessment of environmental impact throughout the entire life cycle (enterprises are only beginning to adopt such an approach). In practice, companies apply partial solutions established by individual project teams and R&D managers, based on best practices developed in previous product improvement projects, with significant customer involvement at various stages of refining product functions and specifying the features of improved products.

While open innovation literature is validated to show increased focus on external knowledge streams and customers' involvement in product development (Du et al., 2025; Jiang, Ma, 2025; Steinbeck, 2025; Suzuki, 2025; Tantiathimongkhon et al., 2025), there is still lack research with detailed frameworks of Agile design in sustainability-focused methodologies. Current research avoids specifying open innovation as a managerial or strategic method (Quero et al., 2025; Sabino et al., 2025; Steinbeck, 2025; Tolou-Shams et al., 2025) but doesn't incorporate it with collaborative working instruments such as Agile design or Life Cycle Assessment that facilitate interactive co-creation among stakeholders. Hence, little is known about how open innovation can be efficiently integrated in decision-support models that simultaneously address quality, environmental sustainability, and product innovativeness. The lack of integrative models constrains theoretical advancement as well as open innovation's practical use in sustainable product development.

The next structure of the article included: Section 2. Theoretical approach to product improvement through Agile Design in Quality and Innovations in Life Cycle Assessment (QLCA); Section 3. Discussion about presented theoretical approach; and Section 4. Conclusion.

2. Theoretical approach to product improvement through Agile in Quality and Innovations in Life Cycle Assessment (QILCA)

The diversity of customer requirements, as well as increasing global competitiveness and dynamic market trends, lead companies to direct their product development strategies toward serving individual customers at costs comparable to mass production (Paritala et al., 2017). Customer needs are diverse, and manufactured products should respond to these needs (Lin et al., 2017); hence, it is necessary to involve customers (users) in the product improvement process already at the design stage.

In recent decades, advancements in production lines and supply chains, strongly supported by automation and Industry 4.0 technologies, have provided enterprises with the necessary process flexibility to deliver products to customers with efficiency comparable to both mass production and market position (Gajdzik, 2022; Gajdzik, Jaciow et al., 2024; Wang et al., 2017).

Referring to (Ozdemir et al., 2022), it is worth emphasizing the distinction between customization and mass customization (MC). Product customization dates back to the era of handcrafted, made-to-order goods, where craftsmanship and additional labor naturally resulted in high costs. In contrast, MC refers to affordable customization, making it an attractive and feasible business strategy (Kumar, 2007). However, in mass customization, companies must strongly focus on minimizing the environmental impact of improved products. Failing to adopt this approach already at the product design stage may negatively affect business competitiveness. Mass customization must be consciously controlled and implemented with consideration of the many factors involved in this process (multiple variables must be taken into account in decision-making) (Saniuk et al., 2020). One of the key determinants at the product design stage is the reduction of environmental impacts while ensuring high product quality and attributes perceived as innovative in consumer markets.

Product design and improvement should be carried out in such a way as to enable manufacturers to balance environmental impacts with the characteristics of improved (innovative) products while meeting customer requirements (Gajdzik, Wolniak, 2022a, 2022b). This is achievable if manufacturers consider business requirements, customer demands, and environmental aspects already at the design stage. Product improvement should follow the principles of the LCA methodology, with strong support from multifunctional (cross-functional) project teams capable of applying Agile approaches and building customer engagement during product design (and improvement), making customers aware of the interactions between environmental, quality, and innovation criteria throughout the product life cycle. According to (de Bruijn et al., 2002), intensive interaction between the LCA client and LCA researchers is essential. Such teams should include production engineers and IT specialists, due to the digitalization of production processes and products themselves (in selected consumer markets), as well as R&D and quality (product development) staff,

and representatives of the client (ordering party) (Gajdzik, Wolniak, 2022a). Team composition in Agile-based LCA methodology must remain flexible, depending on the type of product, degree of innovation, environmental impact, and other factors. This flexibility in teamwork stems from the Agile concept itself, which is applied to developmental or organizational projects. Creativity is a key factor in this design process (Gajdzik, Wolniak, 2022b).

According to (Stare, 2014), based on this author's literature review, the Agile concept originates from agile methods of software development (first references to such an approach appeared as early as the 1980s). Agile (concurrent) methods emphasized the simultaneous execution of traditionally sequential project tasks ("fountain" instead of "waterfall") and continuous coordination among participants. In this sense, agile methods were comparable to concurrent engineering, which also emerged in the 1980s. In 1986, an article entitled *The New Product Development Game* was published in the *Harvard Business Review* (Takeuchi, Nonaka, 1986). Although its initial impact was modest, the concepts it introduced later inspired the pioneers of Agile in the United States, who became particularly interested in the iterative and team-based practices of leading Japanese companies described in the article. Since then, an increasing number of companies in Japan, followed by those in the United States and other parts of the world, began to place greater emphasis on improving both workforce capabilities and process efficiency.

Initially, the Agile approach was primarily applied in IT projects, and its widespread adoption occurred only after 2001. In that year, the Agile Manifesto was published (Fowler, Highsmith, 2001), in which a group of designers (17 software engineers) proposed iterative principles for design (software development).

Based on a literature review covering the period from the publication of the Agile Manifesto in February 2001 through December 2024, the Web of Science (WoS) database was searched according to four scopes: (i) using only the keyword "Agile", (ii) using the keywords "Agile" AND "Project", (iii) using the keywords "Agile" AND "Product Development", and (iv) "Agile" AND "Product Development" AND "LCA". Keywords were searched in the title, abstract, and author keywords. The results of this analysis are presented in Table 1.

Table 1.

Results of the literature review about Agile in the period from 2021 to 2024

Field	Number of papers	Paper with highest citations (Top 5)
Agile	8682	(Aheleroff et al., 2021; H. Li et al., 2021; M. Li et al., 2021; Modgil et al., 2022; Troise et al., 2022)
Agile AND Project	1836	(Cico et al., 2021; Edison et al., 2022; Filippetto et al., 2021; Malik et al., 2021; Marzi et al., 2021)
Agile AND Product Development	722	(Buchanan et al., 2023; Cico et al., 2021; Cooper, 2021; Y. Li et al., 2021; Marzi et al., 2021)
Agile AND Product Development AND LCA	4	(Bhagwat et al., 2021; Camañes et al., 2024; Y. Li et al., 2021; Rinne et al., 2022)

Source: own elaboration based on WoS.

The papers of Y. Li et al. (2021) and Bhagwat et al. (2021) provide examples of higher-order principles as an attempt to contrast Agile product development. Through the two articles, iterative experimentation and interdisciplinary integration are performed as an attempt to address optimization of bioconversion pathways—lignocellulosic biomass to lactic acid and 3-hydroxypropionic acid, respectively. These studies are exemplars of Agile methodology in that they compartmentalized the problem of producing sustainable chemistry into discrete, bite-sized pieces such as feedstock discovery, microbial design, and downstream processing. Some overlap between process simulation and experimental data existed to allow incremental improvement, e.g., Agile sprint cycles. Bhagwat et al. (2021) describe Agile flexibility in terms of combining techno-economic and life cycle assessment in the initial development stages in such a manner that technical viability is balanced against sustainability goals and stakeholder requirements. Interaction among iterative design, environmental research, and stakeholder analysis is a more suitable model of Agile product development for bio industrial innovation.

Camanes et al. (2024) place their work within an adaptive and sustainable product design process. They build an eco-design system based on modularity and professional software support to facilitate rapid prototyping and concurrent decision-making in design in real-time with sustainability analysis. The methodology assists design teams in integrating eco-factors into product development processes continuously practice entirely in line with Agile principles. By enabling open decision-making and time-to-iteration reduction during designing, their software-enabled eco-design capability truly does make sustainability an integral, forward-looking aspect of Agile product design and not an afterthought in terms of regulatory policy. Such synergism is an accurate reflection of the capability for Agile principles to be strategically embraced for long-term innovation by leveraging digital tools as well as systems' feedback (Camañes et al., 2024).

The essence of the Agile approach involves the continuous updating of implementation and detailed planning of smaller cycles (iterations) to carry out a project in line with current results, lessons learned, and new ideas from design participants (members of the project team) and the engaged client. Agile offers a new way of thinking, based on a set of principles presented in Table 2, which emphasizes the ability to adapt a project to the needs of design participants for an improved product through the continuous refinement of designs (prototypes). This approach places strong emphasis on delivering value to customers quickly and fostering close collaboration with clients, who actively participate in product improvement (Takeuchi, Nonaka, 1986).

Table 2.*Characteristics of the Agile Approach in Product Improvement Design*

Agile approach	Description in context of product improvement design
Requirements/ specifications	Agile follows a customer-oriented philosophy with the client at the center of the development process. The approach is dependent on having in-depth familiarity with user requirements and the capacity to react speedily based on their fluctuating demands. Agile encourages frequent iteration, constant early delivery, and constant checking to the extent that the existing product aligns with client goals. One of the major aspects of this process is that the client is directly involved in every step of each product iteration. As the end product is normally not even appropriately defined to start with, Agile employs an incremental approach wherein every iteration possesses a working subset of the product that is gradually polished further. This is made possible through intense interaction between the client and project team, enabling open sharing of ideas and joint problem-solving. Agile teams operate in a flat organizational structure, which enables adaptive working in response to new information and evolving conditions. Initial requirements are established and decomposed into sprint tasks at the beginning. These are not fixed; instead, they are refined through iterative cycles, with lower-priority elements eliminated early in the planning phase to create a well-defined and streamlined path toward the most critical product functionalities.
Project schedule	Agile projects are organized into brief, time-boxed iterations—usually not exceeding eight weeks—fostering ongoing, evolutionary refinement of existing products rather than revolutionary overhaul. Refining tends to target single functions or related sets of functions within products already in the market, with change potentially transferring into redesigning basic structural components. While a generic project schedule is established early on, in-iteration individual planning for every iteration is done just-in-time by the team, allowing for instant response to changing requirements and closeness to the product owner or customer. Perhaps the most distinctive characteristic feature of Agile is autonomy and flexibility granted to self-manuvering teams who plan their work and task assignments themselves. In the interest of ongoing quality control, testing is planned and carried out during the development process effortlessly. Furthermore, Agile promotes open and communicative working in terms of iterative advancement and intimate customer focus, and this evokes imagination, collective ownership, and high-performance output that tends to go beyond original expectations.
Teamwork and collaboration with client	Product development under the Agile system is a spin-off of collaborative efforts by an interdisciplinary team of professionals whose strengths complement each other in various fields. The team not only carries the technical burden of product development, but also its market viability and competitiveness. One of the characteristics of Agile product development is the constant seeking of solutions in the design process, where constructive confrontation—open and intentional debate between differing opinions—is freely encouraged as a way of generating innovation and resolving design issues. Members collaborate in pairs, which enhances synergy, enables sharing of knowledge, and maximizes overall quality of output. Regular stand-up meetings allow for live tracking of progress, task definition, and quick resolution of issues, thereby allowing for transparency and keeping the team focused. Frequent sharing of failures and process inefficiencies is the foundation of Agile culture, which does not treat them as failures but as improvement opportunities fuelling continuous improvement. Visual management aids such as Kanban boards support this by putting workflow into synchronization, bringing issues to the surface, and inspiring team solidarity. Each iteration closes with a scheduled retrospective, at which point the team inspects the performance of its processes, identifies bottlenecks, and defines improvements—a roadmap for eventual and incremental adjustment.

Cont. table 2.

Client collaboration/ engagement	The client, whether a final user or special stakeholder, is a key player at each phase of the project life cycle throughout the Agile development lifecycle. As an interactive and regular participant, the customer is part of the project team and easily accessible to provide feedback, assist in interpreting requirements, and play a part in the changing product. This also comes into play in setting test procedures, where clients with suitable domain knowledge help to explain initial ideas into concrete expectations and suggest major variations. These iterative cycles increasingly evolve fuzzy assumptions into concrete, actionable development goals. Frequent and open communication maintains the client continually informed of progress, permitting prompt review of halfway results and identification of inconsistencies or shortfalls. In this manner, improvement is a process of iterative excellence, whereby every iteration becomes the next one's benchmark for greater performance and value. This model condenses essentially uncertainty and risks by creating frequent, timely understanding for both the team and the client in terms of what has already been accomplished, and which ones remain to be finished. The result is a very malleable, open, customer-centric process which is responsive and long-term in value.
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Source: own elaboration based on (Biały et al., 2023; Boehm, Turner, 2005; Brandon, 2005; Denning, 2010; Feldman, 2018; Flewelling, 2018; Forsberg et al., 2005; Gajdzik, Kopeć, 2022; Gibbs, 2006; Kansy, 2024; Lindstrom, Jeffries, 2004; Meade, Sarkis, 1999; Rothman, 2007; Stare, 2014; Thomsett, 2002; Wysocki, 2019; Stare, 2014).

According to (Wysocki, 2019), the Agile approach can serve as a method for improving products during their design and prototyping stages. A strong user focus is essential, which is why the project team invites a representative of the product's end users to collaborate. The user regularly reviews partial project outcomes to ensure the final product better aligns with customer requirements. Product improvement iterations are repeated whenever the client is not satisfied with the results. Wysocki (2019) also highlights differences between the traditional Waterfall design approach and Agile. These differences include the level of planning detail, risk management, collaboration with the client, and task sequencing. In Waterfall design, project requirements are clearly defined before initiation, and significant changes are not anticipated during execution. Projects are typically routine and repetitive, and project teams often reuse standard design procedures. This approach is linear and sequential (step-by-step), with each phase requiring completion before the next begins. In contrast, in Agile design, client requirements are only partially known, and the process allows for additional iterations during product refinement. Product improvements (including multiple product functions) are structured into iterations known as sprints (Schwaber and Beedle 2001), following the Scrum methodology. At the beginning of each sprint, a backlog of customer requirements is created, specifying the product features targeted for improvement. Members of the Developers Team may introduce a wide range of changes within individual sprints under Scrum (Klaus-Rosińska, Gąsiorowska, 2025; Sadullayev, 2025). In addition to the product owner, who represents client requirements, there is also a Scrum Master, who coordinates Scrum, resolves obstacles, and facilitates communication among stakeholders (Schwaber, Sutherland, 2017).

Sprints form part of the Agile approach and are components of iterations. Sprints are fixed work intervals limited to a specified period (typically weeks), whereas iterations may last longer. Sprints consist of defined activities such as sprint planning and sprint review, while iterations do not necessarily include these formal structures. Iterations are usually

predetermined for the duration of the project, whereas sprint lengths may vary depending on project requirements. In summary, iterations span the overall project timeline, while sprints are shorter time boxes for achieving specific goals. Both sprints and iterations are flexible work structures that can be applied in any type of project or business domain, including new product development. Their structured nature ensures frequent project visibility for teams, continuous feedback collection, and rapid responses to errors, new requirements, and potential risks (Madya et al., 2022; Radhakrishnan, Koumaditis, 2020).

The Agile approach according to the Scrum methodology involves the following stages (Schwaber, Sutherland, 2017):

1. **Defining the project goal:** determining what must be accomplished (establishing what the team is to deliver in each iteration). The execution of this first stage (goal and scope definition) is closely tied to task formulation. At this stage, the Product Backlog is created. According to (de Bruijn et al., 2002), accurate forecasting is crucial at this point, as every task involves a degree of risk. Unjustified simplifications should be avoided, as should extrapolation of LCA results. For example, if the analysis aims to provide a general comparison of two product system types, comparing only a few specific cases is insufficient. The process design must also specify how a task may be modified in light of new information, such as changes in the intended use of LCA, stakeholder involvement, or LCA quality requirements.
2. **Sprint Planning:** establishing the sprint duration and making organizational arrangements, such as setting team pairings or communication formats. Team members are introduced to the Scrum Master, who supervises the project. “Sprints are the heartbeat of Scrum, where ideas are turned into value” (Schwaber, Sutherland, 2017). A new Sprint begins immediately after the conclusion of the previous Sprint. In the context of LCA extended with Q and I, the threefold aspects (quality, innovation, and environment) become key considerations in product improvement.
3. **Sprint Backlog:** identifying what must be completed within the Sprint. The Sprint Goal, selected Product Backlog items, and the delivery plan together form the Sprint Backlog. Planning meetings are organized where the team selects tasks from the Product Backlog (the prioritized task list prepared by the Product Owner). At this stage, tasks are divided into smaller, manageable parts called “user stories.” In product design and improvement within LCA, a holistic perspective is essential, considering all product stages from cradle to grave.
4. **Sprint Execution and Daily Scrums:** the Daily Scrum focuses on progress toward the Sprint Goal and sets an actionable plan for the next day’s work. Daily reporting of tasks and results improves focus and work quality. These meetings enhance communication, identify obstacles, support quick decision-making, and reduce the need for additional meetings. Development occurs within iterations (Sprints), typically lasting 1-4 weeks,

during which the team works on selected tasks from the Sprint Backlog. Frequent team communication is a key success factor.

5. **Sprint Review:** the review is the penultimate event of a Sprint. Its purpose is to evaluate Sprint results and determine future adjustments. The Scrum Team presents its work to key stakeholders, and progress toward the Product Goal is discussed. In an LCA-based approach, the Scrum Team and stakeholders assess Sprint achievements and review changes in the product's environmental impact. Based on this information, participants jointly determine further steps to minimize negative environmental impacts. The Product Backlog may also be updated to reflect new opportunities.
6. **Sprint Retrospective:** during this final stage, the team discusses what went well, what could be improved, and what actions should be implemented in future project work. The goal is continuous improvement of teamwork and product development. The Sprint Retrospective concludes the Sprint.

The Agile approach can be summarized through several key characteristics (Table 3).

Table 3.
Key Features of Agile in Product Improvement

Feature	Description
Flexibility and Adaptability	Agile enables rapid responses to changes in requirements or priorities, which is crucial in dynamic projects.
Frequent Delivery of Functionality	Through its iterative approach, functional elements of the product are delivered regularly (e.g., each sprint), allowing for quick testing and feedback collection.
Strong Collaboration with the Client	The client remains engaged throughout the entire project, helping to create a product that meets actual needs.
Risk Identification and Problem Solving	Iterations make it possible to quickly detect and resolve issues before they escalate.
Transparency	Regular meetings (e.g., Daily Scrum) and the visibility of the backlog ensure that progress is clear to all stakeholders.

Source: Own work on basis: (Brandon, 2005; Forsberg et al., 2005; Lindstrom, Jeffries, 2004; Rothman, 2007; Schwaber, Sutherland, 2017; Wysocki, 2019).

Although the Agile approach has several specific characteristics (principles) related to iteration, teamwork (teams focused on product improvement), and collaboration with the client (the client's representative is a permanent team member), it is this last feature that constitutes the essence of product improvement. According to Agile methodology, it is recommended—even necessary—to strengthen collaboration with the client or their representative. The representative must be available 24/7 to provide additional information about the functions (features) of the improved product (Meade, Sarkis, 1999). The client (or their representative) is a permanent member of the team and actively participates in daily product improvement activities (Brandon, 2005). Their involvement must be strong enough to allow them to propose changes and take part in their evaluation (adding value). The client or their representative should participate in the development of testing procedures (Gibbs, 2006), as this gives them direct influence over product development through regular testing of intermediate outcomes and reporting shortcomings and errors to the team (Brandon, 2005). Agile enables teams to

maximize product value through flexible project work while adapting the design to client needs, thus facilitating the effective delivery of high-quality and innovative improved products (Cao et al., 2009).

The Agile approach must be adapted to specific projects and their implementation conditions in different product improvement contexts to ensure optimal outcomes (Bialy et al., 2023). Agile methodologies are gaining increasing recognition for their ability to respond rapidly to customer needs regarding product functions or features (continuous product improvement processes), particularly in Industry 4.0. Agile aims to enhance performance and the quality of final deliverables by enabling development teams to respond effectively to changes and progressively refine customer expectations, ensuring maximum end-user satisfaction and continuous feedback (reporting progress in project work) (Tripathi, Chattopadhyaya, Bhadauria et al., 2021; Tripathi, Chattopadhyaya, Mukhopadhyay et al., 2021).

Open innovation theory evolved as the core theme of innovation management to replace the earlier R&D closed system operation mainly from internal sources (Sabino et al., 2025; Szromek, Bugdol, 2025). Chesbrough elaborated further that open innovation is a managed inflow and outflow of knowledge beyond the company boundary for the intent of triggering internal innovation and further external use of innovation markets. Under this paradigm, companies no longer need to own development teams or research labs; instead, they create networks of partners that include research institutions, universities, start-ups, competitors, and customers. Knowledge and technology resources thus flow between internal and external collaboration partners to develop a dynamic collaboration innovation network (Brilhante, Romero, 2025; Sirolli et al., 2025; Steinbeck, 2025; Yun et al., 2023; Yun, Zhao, 2020; J. Zhou et al., 2025). Theoretical underpinnings of open innovation have their roots in network theory, absorptive capacity, and evolutionary economics. Network theory revolves around interfirm relations with the objective of making and sharing knowledge as well as depicting how collaborative network firms can gain access to a wider array of technological capabilities. Absorptive capacity is all about how the firm can recognize, absorb, and exploit knowledge from outside, which is at the heart of open innovation. Evolutionary economics does suggest the path-dependent and cumulative process of innovation and the extrapolation of the firms' learning and recombinant ability with the assistance of the external partners. The two theory foundations are intellectual underpinnings of the collaborative and system-scope of the open innovation (Delay et al., 2025; Ullah et al., 2025; X. Xie, Yu, 2025).

Open innovation is typically divided into two complementary processes, i.e., inbound and outbound. Looking outward for outside knowledge using, for example, engaging customers through co-designing, purchasing technology from research organizations, or utilizing online platforms to crowd-source ideas makes up inbound open innovation. Spilling inside knowledge using, for example, licensing technologies, spinning off companies, or sharing R&D results with partners makes up outbound open innovation. Hybrid categories, or paired processes for

some purpose, both have levels and are particularly applicable in tomorrow's companies where sharing knowledge and co-evolving is key to success in sustainability initiatives (Rodríguez-Núñez et al., 2025; Salvalai et al., 2025; X. Wang, Luan, 2025).

Increased value in open innovation is purely attributed to Industry 4.0 challenges and the world's sustainability agenda. The need to supply personalized products and rapid-changing technology compels companies to think beyond their fences in order to obtain complementary capabilities and innovate in cutting cycles. At the same time, sustainable development poses solutions for which no single actor can have anything to contribute, since environmental and societal issues traverse entire value chains. That is where open innovation increasingly entered realms such as a circular economy, eco-innovation, and life cycle assessment. Collaborative innovation networks enable the company to engineer solutions that address not only customers' requirements but also rules', nature's, and society's needs (Huynh et al., 2025; Moradi, Hepsø, 2025; Yun et al., 2020, 2023).

For this purpose, the integration of open innovation concepts and Agile and QILCA model serves the optimal theoretical basis for the given framework. Incremental development and continuous involvement of stakeholders are the focus points of Agile design, whereas QILCA incorporates innovation, quality, and environmental factors in designing products. The model incorporates the open innovation approach through the integration of customer input and external knowledge in every step of the design. It displays how co-creation openness and knowledge exchange can be traced to create sustainable, innovative, and high-quality products in turbulent market conditions (Carbonell-Alcocer et al., 2024; Gajdzik, Siwiec et al., 2024; Jiang et al., 2025; Siwiec, Gajdzik, Gawlik et al., 2025; L. Zhou et al., 2024). Table 4 presents example criteria for evaluating product improvement potential in terms of quality, innovation, and environmental impact.

Table 4.

Framework of QILCA: Examples of Product Evaluation Criteria

Criteria Category	Example Indicators
Quality (Q)	- Ease of use (user-friendliness) - Functional reliability - Precision and accuracy of performance - Ergonomics and user comfort - Resistance to external conditions (e.g. dust, humidity, temperature) - Long-term consistency of performance - Aesthetic quality and material finish
Innovativeness/Innovations (I)	- Ease of assembly and installation - Level of technological complexity - Degree of automation - Productivity and throughput - Operational lifespan - Ease and frequency of servicing - Ease of repair - User safety and integrated safety mechanisms - Ease of maintenance - Modularity and adaptability - Integration with digital technologies (e.g. IoT, smart systems)

Cont. table 4.

Environmental Aspects (E)	- Emission of harmful substances or by-products - Energy consumption during operation - Energy loss or inefficiency - Use of recyclable materials - Reusability of components - Environmental footprint across the life cycle (LCA) - Compliance with environmental regulations - Potential for circular reuse or remanufacturing - Use of eco-friendly or biodegradable materials - Packaging sustainability (e.g. minimal, recyclable)
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Source: own elaboration based on (Ekmekci, Nebati, 2019; Koomson, 2025; Luo et al., 2025; Moses et al., 2025; Qin, 2025; Shivani, 2025; Z. Xie, Yang, 2025).

Complex projects in Agile are carried out using single teams as well as larger units (teams of teams). One product is one backlog. All Scrum teams work on a shared product backlog. Hierarchy is kept to a minimum to avoid unnecessary bureaucracy. Teams regularly synchronize (e.g., through Scrum of Scrums meetings).

Application example: Product improvement projects with high interdependence between components. Teams, called “Squads”, are autonomous and responsible for specific product functions. “Tribes” are groups of Squads working toward a common goal. Additionally, “Chapters” and “Guilds” facilitate knowledge-sharing across teams. Teams maintain a high degree of autonomy while remaining aligned with organizational objectives. Product design relies heavily on collaboration and cross-functional teamwork. During the planning phase, sprints are defined, with each sprint dedicated to enhancing specific product functions assigned to the project team. The team is responsible not only for the successful completion of the project but also for ensuring the product’s competitiveness and success in the market (Forsberg et al., 2005). Constructive confrontation is a standard method for generating new ideas and solving problems (Forsberg et al., 2005). Work is performed in pairs rather than individually (Brandon, 2005; Lindstrom, Jeffries, 2004; Rothman, 2007). The team discusses work results, ideas, and product improvement challenges (Rothman, 2007). Team members regularly review their mistakes and learn from them—after each iteration, they evaluate the adequacy of assessments, methods, and techniques, identify errors, and plan future improvements (Boehm, Turner, 2005).

Given the complexity and specificity of projects, sprints are defined to help the development team organize and break down the project into smaller, autonomous tasks. At this stage, both the team and the client’s representative (product user) must establish an initial set of key (potential) quality, innovation, and environmental criteria for the improved product. Iterations focus on achieving a satisfactory level of product quality and business competitiveness while designing an environmentally friendly product. The QILCA model ensures more precise product improvement by incorporating critical improvement areas that meet customer needs while safeguarding the environment, with product innovativeness serving as a key factor for manufacturer competitiveness (Siwiec, Pacana, 2024a, 2024b). In line with the Agile approach, the client participates in product verification against power of influence of quality, innovation, and environmental criteria. Figure 1 presents the simplified QILCA model in Agile Design.

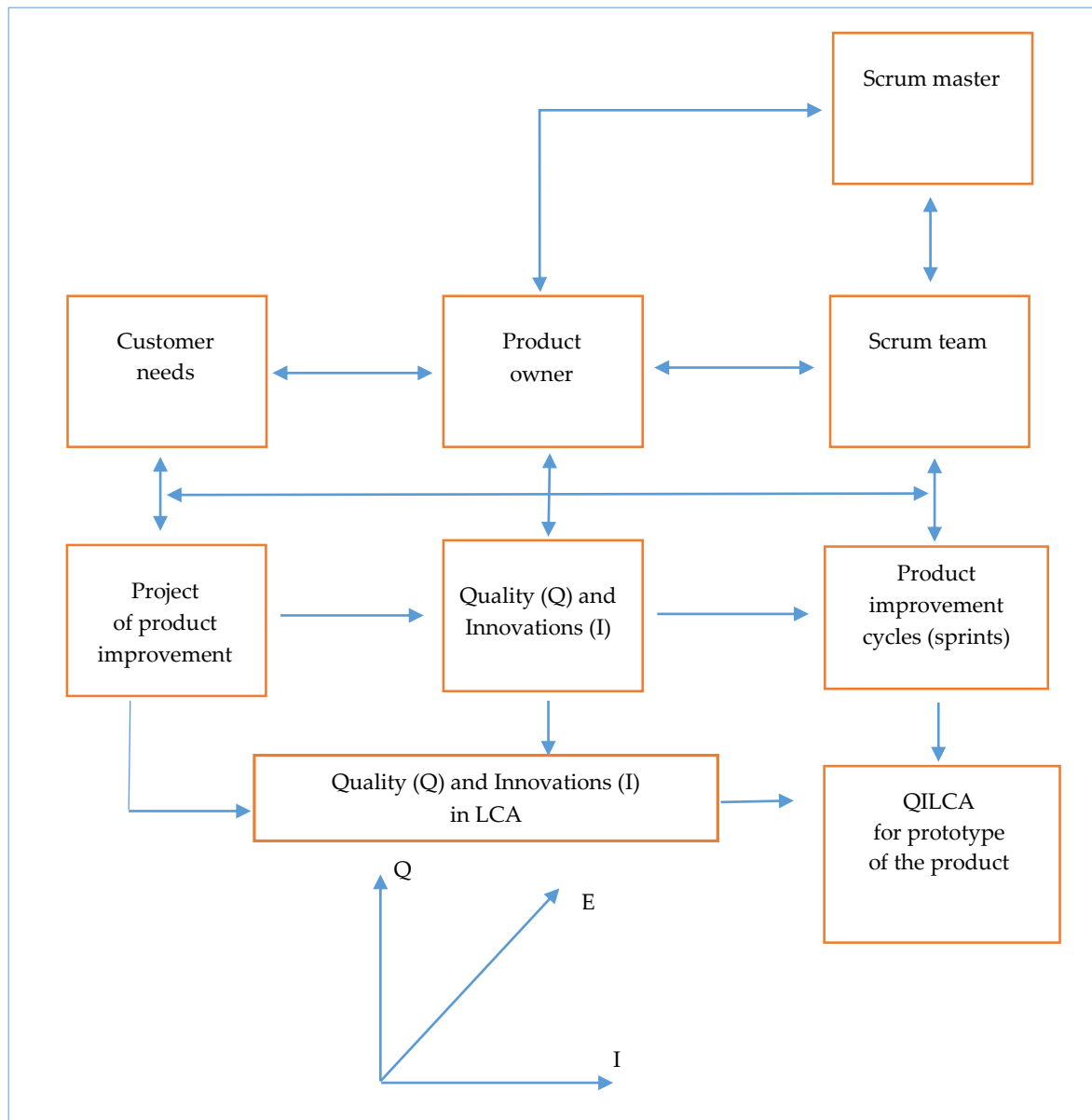


Figure 1. Simplified QILCA model in Agile Design.

Source: own elaboration.

3. Discussion

Presentation of results captures the dramatic extension of the classical LCA philosophy to encompass product quality (Q) and innovation (I) dimensions in Agile principles. Convergence of the three parties—quality, innovation, and ecoburden—presents a tale of shift away from classical linear life cycle calculation methods towards a dynamic cyclical decision-support approach embraced already at the conceptual design stage. Literature review evidence (Table 1) supports prevalence of limited number of studies that integrate Agile with LCA and innovation, thereby justifying the need for proposed QILCA model as a counter to the

researched existing gap. A broad scope of the Agile approach with all its concentration on sprints, iterations, and open dialogue with the client comes equipped with the ability to speed up product testing and attribute product functionality to user needs better while at the same time being able to track environmental impacts in real-time.

Theoretical research findings suggest that the iterative feature of Agile can be applied efficiently in product development so that development can be conducted with sustainability as the focus. The QILCA model has the capability of concurrent assessment of environmental optimisation and quality and innovation needs, a primary area of differentiation from other ecodesign support tools. Basic model abilities, i.e., mapping of product characteristics to Q and I requirements and to the environmental impact indicator (LCA), make it possible for early recognition of potential design improvement opportunities. These outcomes indicate that the approach set forth in this work can be applied to lead firms towards sustainable performance without reducing competitiveness—an ever-growing challenge with mass customization-industry segments.

The proposed QILCA model can ignite a broader discussion on applying Agile principles from IT departments to product engineering and manufacturing, potentially ushering in a new era of product design software for Industry 4.0 (I4.0) and 5.0 (I5.0). Its indicators and cyclic trends offer a foundation for industry case studies and experimental research, enabling the calibration of criterion weights, validation of applicability, and cross-industry transferability. Moreover, the model opens pathways for integration with digital twins, multi-criteria decision support systems, and quality management system advancements that could yield measurable gains in future product optimization.

Conventional Life Cycle Assessment (LCA) process can be supported by integrating quality and innovation drivers at the start of the product design cycle into environmental study integration with recursive Agile-type design researching clients' technical and usability requirements together. This extension entails the incorporation of quality attributes (functionality, ergonomics, reliability, and durability) into core LCA indicators, and innovation attributes such as technological innovation, modularity, information system compatibility, and automation potential.

The envisioned QILCA model is a seminal extension of traditional LCA practice with the introduction of quality and innovation dimensions and hence filling a gap in the literature constructed in scientific literature (Balcioglu et al., 2025; B. Dong et al., 2017). The LCA had previously focused on the overall environmental burden of a product along the product life cycle (Finkbeiner et al., 2006), whereas the new approach enables the double evaluation of quality and innovativeness as design strategic product dimensions. The iterative process of the model, having been tried and proven under Agile protocols, identifies a need for faster product validation along with better correlation of design parameters to customer needs (Sadia et al., 2021). Studies show that combining the different dimensions of measurement, i.e., quality, innovation, and environmental dimensions, allows for more stringent regulation of rules for

sustainable development with an emphasis on optimizing products in terms of function and price (Gajdzik, Siwiec et al., 2024).

In the era of sustainable consumption, customers are increasingly aware of products that reduce their environmental impact after purchase. Research by Gajdzik et al. (2023) confirmed this pattern over a long period of time (compared across decades). However, in the manufacturer market, the concept of a new model QILCA could be useful because it would accelerate the transfer of knowledge across sectors (Sroka et al., 2014).

Agile components integrated into the QILCA model align with increasing use of agile project management in sectors other than IT (Bai et al., 2018; Falco, Robiolo, 2021). Scrum and other Agile methods can maintain iterative and cyclic iteration, ongoing testing, and product changes that morph to facilitate rapid response toward changing market and customer needs, as disseminated by Schwaber and Sutherland (2017). Empirical data of Bhagwat et al. (2021) and Camañes et al. (2024) testify that iterated design cycles and the use of digital tools in eco-designing can practically reduce environmental footprint and time-to-market. Its use in product design under LCA thus facilitates, with ongoing environmental influence tracking and optimization, inducing innovation activity and improving project risk management (Radhakrishnan, Koumaditis, 2020; Wysocki, 2019).

Literature review also shows the application of the QILCA model to mass product customization and Industry 4.0 where emphasis on elastic design processes and directing environmental intelligence into decision-making increases (Gajdzik, Jaciow et al., 2024; Kumar, 2007). Quality and innovation requirements, such as reliability, ergonomics, modularity, or inter-operability with digital technology (Ekmekci, Nebati, 2019; Luo et al., 2025), are inevitable factors of the building of competitive advantage, and their coordination with LCA outcomes exceeds the challenges facing sustainable development. Its adoption is capable of propelling value-added product creation at low environmental effort, as facilitated by TRIZ innovation and product lifecycle management research (Livotov, Petrov, 2023). The QILCA model thus represents a move towards end-to-end assessment tools with customer, business, and environmental concerns.

The results of the research are in line with macro-level studies of embedding LCA methodology into quality management theory and innovation theory by stressing the importance of systemic product design strategy in the Industry 4.0 (I4.0) environment. Following the product life cycle theory of Finkbeiner et al. (2006), analysis of environmental impacts should be conducted during the design phase. However, these analyses are primarily retrograde exercises with little to give back to product design. QILCA methodology, on the other hand, is targeted from an early point in the development cycles, bridging models of quality management (TQM, ISO/IEC 25010) and modes of innovation management (TRIZ) to environmental considerations according to quality management system guidelines and sustainable product development guidelines (Jiao, Chen, 2006; Livotov, Petrov, 2023; Rahman, Alam, 2022). Theoretical framework makes sure that balancing at the same time the quality and

innovation dimensions have the highest potential for gaining competitive advantage with minimal environmental threat (Gajdzik, Wolniak, 2022b).

Theoretical excellence of the QILCA model is more than the jurisdiction of single measurement approach, offering an eclectic decision-support system in product design. This method is based on MCDM-logic to enable compromise of each other conflicting quality, innovation, and environmental demands (Mu, Pereyra-Rojas, 2017; Siwiec, Pacana, 2024b; Pacana, Siwiec, 2024). Weighting and ranking logic-based QILCA-defined criteria enable open project management of multicomplex projects in precision-based industries like automotive, aviation, and electronics (Gajdzik, Burchart-Korol, 2011; Gajdzik, Siwiec et al., 2024; Siwiec, Gajdzik, Pacana et al., 2025). In addition, the model includes customer value (Voice of Customer) as a philosophy and thus user expectation is a design starting point such that new but eco-friendly products are created (Barravecchia et al., 2023).

Paper conclusions are that QILCA model is open innovation compliant, with the end aim being to include customers and stakeholders directly in product innovation and development. In being part of the future stages of the product design process, the model positions outside partners as co-creators of innovation. This approach embodies the open innovation concept, where knowledge and ideas outside a company are a resource and may be a counterbalance to market mismatch risks (Asad et al., 2023; Azhar Mohd Harif et al., 2022; Han et al., 2021). Ecological transformation through open innovations, however, requires a holistic approach and government support (Burchart, Przytuła, 2024, 2025; Zhou, Zhang et al., 2022, Zhou, Zhang et al., 2025). A holistic approach to eco-innovations is to view them as part of a broader, complex system rather than as isolated solutions, allowing for consideration of the entire product life cycle, its relationship with environmental and social impacts, and integration with existing processes to achieve sustainability in a broader context (Zhou, Richardson-Barlow et al., 2025).

The cyclical nature of QILCA also mirrors openness in the innovation process. The regular reviews, retrospectives, and sprints permit ongoing uptake of new ideas, quick prototyping, and continuously constructed products from continuously changing demands in the markets. The activities permit ongoing sharing of knowledge among organizations and the ecosystem, again mirroring openness of organizational boundaries. The model thus mirrors open innovation's collaborative, knowledge-sharing culture.

QILCA also is open innovation friendly because it unites environment drivers, quality drivers, and innovation drivers. Sustainable innovation is more a matter of coordination across large networks of partners such as technology providers, research centers, NGOs, and authorities. The model creates a formal mechanism of coordination so that product innovation responds to both customer demand and environment and society demand. The same multi-dimension also creates legitimacy and, in market, marketability of innovations.

The scalability and transferability of QILCA enable it to effectively govern open innovation ecosystems. Because the framework can be applied across diverse industries, including Industry 4.0 and mass customization environments, it supports the replication and dissemination of best practices. By enabling collaborative platforms that enhance competitiveness through continuous and integrated improvement processes, the model promotes both knowledge exchange and organizational learning. Consequently, QILCA strengthens innovation networks that extend across organizational boundaries.

5. Conclusion

Our proposed integration of Agile principles into product design and Life Cycle Assessment (LCA) offers significant value for both clients and businesses by enhancing flexibility, responsiveness, and sustainability-oriented decision-making. Nevertheless, the Agile framework is not universally applicable to all product improvement and customization processes. Certain products, particularly those characterized by rigid regulatory requirements, highly standardized production systems, or limited design flexibility, may not benefit from iterative Agile methodologies. In such cases, traditional development approaches may provide greater stability and predictability. Therefore, the successful implementation of QILCA depends on aligning Agile practices with the specific technical, organizational, and market conditions of the product development environment.

Through the proposed QILCA framework within an Agile approach, the authors hope to initiate a discussion on the possibilities of applying Agile to product improvement, but by using the QLCA model, i.e., a strong integration of LCA with the quality criteria of the improved product, which must incorporate features of innovativeness (I). Ultimately, both categories of improvement must be strongly correlated with either a positive environmental impact of the product or a reduced environmental burden compared to the previous product (the criterion of improved environmental performance).

With this paper, the authors invite scientific and business discussion on the feasibility of applying the Agile approach, beyond IT products (the IT market), to the improvement of products across their entire LCA.

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