v. 68, p. 185-211, Jul./Dec. 2026 http://doi.org/10.5380/dma.v68i.98734 e-ISSN 2176-9109

DMA Desenvolvimento e Meio Ambiente

Biblioteca Digital de Periódicos BDP | UFPR revistas.ufpr.br

Sustainable innovation as a competitive advantage in the chemical sector

Inovação sustentável como vantagem competitiva no setor químico

Gustavo de Oliveira HANAUER[1]*, Dusan SCHREIBER[1], Luciane Pereira VIANA[1]

1 Universidade Feevale (Feevale), Novo Hamburgo, RS, Brazil.

* Contact: gustavo.hanauer@icloud.com

Article received on **February 28, 2025**

Final version accepted on **January 6, 2026**

Published on **August 21, 2026**

Abstract: Sustainable innovation combines economic development, social responsibility and environmental preservation, boosting business competitiveness. This strategic approach makes it possible to address global challenges, such as climate change and resource scarcity, by promoting more efficient and responsible practices. Given this context, this study aims to analyze the process of sustainable innovation as a competitive advantage in companies in the chemical sector. The research was divided into two stages: in the qualitative stage, a single case study was adopted, based on in-depth interviews with employees of Company Q and external experts who were not employed by the company, systematic participant observation and documentary analysis. The information collected was analyzed using the content analysis technique. The results of this stage served as a basis for the preparation of a survey applied in the second stage, with companies in the same sector identified through the ABIQUIM registry and the Company Q database. In the qualitative stage, it was found that the company studied implemented sustainable innovation actions, demonstrating environmental concern, despite the financial constraints that slow down this process. The quantitative analysis indicated that companies in the chemical sector share similar operations and prioritize efficiency, productivity and external relations. Finally, the results showed that sustainable innovation constitutes a competitive advantage by boosting efficiency and reducing environmental impacts, as it reduces operating costs through the efficient use of resources, strengthens corporate reputation and meets the growing demand for environmentally responsible solutions. However, its effectiveness depends on investments in technology, professional training and transformation of organizational culture.

Keywords: competitive advantage; chemical industry; sustainable innovation; sustainability.

Resumo: A inovação sustentável combina desenvolvimento econômico, responsabilidade social e preservação ambiental, impulsionando a competitividade empresarial. Essa abordagem estratégica permite enfrentar desafios globais, como mudanças climáticas e escassez de recursos, promovendo práticas mais eficientes e responsáveis. Diante deste contexto, este estudo tem como objetivo analisar o processo de inovação sustentável, como vantagem competitiva, em empresas do setor químico. A pesquisa foi dividida em duas etapas: na qualitativa, adotou-se o estudo de caso único, baseada em entrevistas em profundidade com colaboradores da Empresa Q e especialistas que não atuam na operação, observação participante e levantamento documental. As informações coletadas foram analisadas por meio da técnica de análise de conteúdo. Os resultados dessa etapa serviram de base para a elaboração de um survey aplicado na segunda etapa, com empresas do mesmo setor identificadas por meio do cadastro da ABIQUIM e pela base de dados da Empresa Q. Na etapa qualitativa, constatou-se que a empresa estudada implementou ações de inovação sustentável, demonstrando preocupação ambiental, apesar das restrições financeiras que retardam esse processo. A análise quantitativa indicou que empresas do setor químico compartilham operações semelhantes e priorizam eficiência, produtividade e relações externas. Por fim, os resultados evidenciaram que a inovação sustentável constitui uma vantagem competitiva ao impulsionar eficiência e reduzir impactos ambientais, pois reduz

custos operacionais por meio do uso eficiente de recursos, fortalece a reputação corporativa e atende à crescente demanda por soluções ambientalmente responsáveis. No entanto, sua efetividade depende de investimentos em tecnologia, capacitação profissional e transformação da cultura organizacional.

Palavras-chave: competitividade; indústria química; inovação sustentável; sustentabilidade.

1. Introduction

Innovation is widely recognized as an essential driver of competitive advantage for companies operating in dynamic environments. Since Schumpeter's early definitions in the 1920s, the concept has been associated with the introduction of new methods and approaches that differ from existing models (Crossan & Apaydin, 2010; Hansen & Wakonen, 1997). As discussions on sustainability have advanced, the concept of sustainable innovation has emerged, seeking to align economic development, social responsibility, and environmental preservation. This concept encompasses the creation of products, processes, and business models that minimize environmental impacts, generate social benefits, and foster positive changes in society (Hanaysha et al., 2025; Li et al., 2025).

Sustainable innovation plays a strategic role in business operations, as it enables the adoption of innovative practices that consider environmental and social impacts throughout the entire production cycle, from raw material sourcing to final disposal. According to Dias et al. (2025), this approach is essential for addressing global challenges such as climate change and resource scarcity, requiring a mindset focused on creating shared value. By incorporating sustainable innovation, companies not only strengthen their competitiveness but also promote corporate responsibility and contribute to a more balanced and sustainable future. Consequently, organizations, particularly those in the industrial sector, have shown increasing interest in adopting sustainable innovation processes. Among the industrial sectors actively pursuing innovation to enhance competitiveness, the chemical manufacturing industry stands out (Carvalho et al., 2021; Ghobakhloo & Ching, 2019; Meincke et al., 2018).

According to Falkenroth-Naidu et al. (2023), the global chemical industry has experienced significant growth, driven by demand from sectors such as the automotive, construction, electronics, and food industries, recording an increase of nearly 25% in 2021 following the pandemic. The Brazilian Chemical Industry Association (ABIQUIM, 2022) reports that the five largest chemical markets are China, the United States, Germany, Japan, and South Korea, with Brazil ranking sixth. In Brazil, the sector generated revenues of USD 187 billion in 2022, representing a 27.3% increase compared with 2021, while industrial chemical products accounted for USD 88 billion, an increase of 24.6%.

Innovation and technological investment are crucial to the development of new products and sustainable processes (Mohan & Katakojwala, 2021).

Fantke et al. (2021) argue that digitalization expands data availability and improves efficiency and productivity. Therefore, the technological transformation of the chemical industry is essential to its competitiveness, growth, and ability to adapt to emerging social and environmental demands (Carvalho et al., 2021; Meincke et al., 2018). The modernization of the chemical sector, grounded in innovation and sustainability, strengthens its competitiveness and enables it to meet new market requirements while reconciling economic growth with environmental and social responsibility (Carvalho et al., 2021; Ghobakhloo & Ching, 2019).

Against this backdrop, this study aims to analyze sustainable innovation as a source of competitive advantage in companies operating in the chemical sector. The first stage of the research adopted a qualitative approach and examined a small chemical company that manufactures adhesives, solvents, and sealants, located in the Vale do Rio dos Sinos region of Rio Grande do Sul, Brazil. The company has operated in Brazil for more than 30 years, serving sectors such as the nautical, footwear, furniture, and upholstery industries. To preserve its identity, the company is referred to in this study by the pseudonym Company Q. The second stage adopted a quantitative approach, involving the development of a questionnaire administered to chemical companies identified in the 2024 register of the Brazilian Chemical Industry Association (ABIQUIM).

This study is structured as follows:

(1) Introduction;

(2) Theoretical background, presenting the characteristics of sustainable innovation;

(3) Methodology, describing the methodological procedures used to collect and analyze the data;

(4) Analysis and discussion of the results obtained from the qualitative and quantitative approaches;

(5) Conclusions.

2. Sustainable Innovation as a Competitive Strategy

The capacity to innovate has been widely recognized as a central element for organizations seeking to maintain a competitive advantage in contexts characterized by rapid change. In a dynamic business environment, the ability to create new solutions and continuously adapt becomes a strategic differentiator for companies' survival and superior performance. Although the contemporary debate on the subject is extensive, the conceptual foundations of innovation date back to Schumpeter's studies in the 1920s, which associated innovation with the introduction of something new, whether in the form of products, processes, or previously nonexistent

methods. This perspective was subsequently expanded by different authors, who emphasize that innovation involves transforming established practices and proposing alternatives capable of generating value and disrupting traditional patterns (Crossan & Apaydin, 2010; Hansen & Wakonen, 1997).

According to Schumpeter (1997), companies primarily pursue innovation for financial reasons, since a new technology can provide a competitive advantage regardless of the sector in which the innovation is applied. According to the Oslo Manual (Organization for Economic Co-operation and Development [OECD], 2018), four main types of innovation can be identified:

(i) product innovation;

(ii) process innovation;

(iii) marketing innovation; and

(iv) business model innovation.

As presented by the Organization for Economic Co-operation and Development (OECD, 2018), product innovation concerns the development of new products or significant improvements to existing ones and also encompasses investment in research and development (R&D). Process innovation, in turn, seeks to improve production stages or the product and service delivery cycle from beginning to end through process automation or any other method capable of increasing performance and/or reducing costs. Marketing innovation focuses on innovative promotional and commercial strategies aimed at expanding brand reach through advertising campaigns, social media, and even the repurposing of products for new market segments. Finally, business model innovation involves restructuring a company's operations and the way it generates value and economic results, including, for example, the establishment of new strategic partnerships and changes to the supply chain (OECD, 2018).

In the pursuit of more sustainable outcomes, the concept of sustainable innovation has emerged as being directly associated with organizations' innovative capacity, since both contribute to positive changes in society and the environment. This approach involves the creation of new products, processes, and business models aimed at reducing negative impacts and strengthening environmental and social sustainability, as demonstrated by recent studies linking sustainable innovation, corporate responsibility, and sustainable performance (Hanaysha et al., 2025; Li et al., 2025).

Sustainable innovation has therefore gained prominence as a strategy that seeks to reconcile economic development with environmental preservation and social responsibility, requiring a systemic understanding of impacts throughout the entire production chain. Furthermore, sustainability-oriented innovation practices are increasingly contributing to addressing global challenges, such as climate change, intensive resource

consumption, and regulatory pressure, by promoting shared value creation and integrating technological efficiency with social and environmental responsibility (Dias et al., 2025; Li et al., 2025).

Within the context of business operations, sustainable innovation plays a central role by guiding companies in the development of solutions that consider environmental and social impacts at every stage of the product life cycle. Current evidence reinforces the view that sustainability-oriented innovative practices strengthen organizational competitiveness, improve environmental performance, and enhance stakeholder engagement, thereby promoting strategies aligned with corporate responsibility (Hanaysha et al., 2025; Li et al., 2025).

Global environmental concerns, such as natural resource depletion and air pollution, have stimulated growing interest among business leaders in promoting sustainable innovation. In manufacturing, for example, sustainable innovation involves the introduction of more sustainable practices and processes aimed at reducing pollution and improving environmental performance. Sustainable innovation can be regarded as one of the most effective ways of alleviating environmental pressure without compromising economic competitiveness. This is because it is driven by both internal and external organizational factors, ranging from efficient resource management and an organizational culture oriented toward greener practices to market demands and requirements (Demirel & Danisman, 2019; Ogiemwonyi et al., 2023; Ogiemwonyi & Harun, 2020; Peng et al., 2021).

According to Silva et al. (2020), the process of seeking and implementing innovation primarily involves monitoring the external environment to identify opportunities for introducing sustainable innovation into the company through innovative ideas and emerging technologies. This process may also be facilitated through collaboration with external agents, such as suppliers and business partners.

Costa et al. (2021) further argue that the appropriate implementation of practices that stimulate sustainable innovation in companies requires green marketing to play a significant role in raising awareness among all those involved regarding the importance of the relationship between people, machines, and the environment. Marketing and communication strategies related to sustainable innovation should focus on conveying ideas that support environmental concerns, such as reducing energy consumption, using recycled materials, and clearly communicating the organization's internal values. Moreover, green marketing seeks to promote environmental education by encouraging practices with lower environmental impacts and creating emotional approaches aimed at consumers who are conscious of the role they play in preserving the planet (Costa et al., 2021; Morales et al., 2022).

Sustainable innovation is intended to improve and maximize resource

utilization in order to achieve desirable social standards capable of generating sustainable benefits for both companies and society. According to the authors, sustainable innovation may be understood as process innovation aimed at improving corporate performance or even as a form of product innovation that promotes sustainability throughout the product life cycle (Ogiemwonyi et al., 2023).

However, managers commonly encounter difficulties in implementing sustainable innovation, including the time required for new management practices to become disseminated. The longer it takes to establish the proposed changes, the longer sustainability-oriented innovation practices take to materialize (Rauter et al., 2023). The authors further argue that problems and failures associated with implementing sustainable innovation may originate from deeper and more deeply rooted organizational factors than those involved in traditional innovation. Sustainability innovations require the development of new capabilities and the knowledge necessary to advance innovative initiatives, including more up-to-date technologies, adaptations to management approaches, changes in the supply chain, and modifications to organizational attitudes and values (Rauter et al., 2023; Urbinati et al., 2023; Weidner et al., 2021).

Some companies have chosen to adopt sustainable innovation by incorporating technologies that help them address environmental challenges and comply with environmental regulations imposed by regulatory authorities (Ogiemwonyi et al., 2023). Rosa et al. (2020) argue that sustainable innovation behavior can strengthen companies' awareness of and attitudes toward environmental challenges. However, sustainable innovation behavior may be regarded as a combination of several values, including ecological, technological, economic, social, and humanistic values (Ogiemwonyi et al., 2023).

Companies' commitment to sustainability, fostered by sustainable innovation, has a significant influence on the decision-making processes of any business. The advancement of this commitment is directly related to increasing technological support and the continuous improvement of innovation performance, which are reflected both directly and indirectly in organizational outcomes (Ogiemwonyi et al., 2023; Rosa et al., 2020).

Accordingly, the integration of sustainable innovation must be accompanied by the maintenance and enhancement of industrial competitiveness. Companies operating within global value networks need to achieve competitive advantages through the creation of sustainable value (Van Erp et al., 2023). According to the authors, the implementation and adoption of sustainable innovation in corporate production processes can provide several competitive advantages, with both short- and long-term effects, while expanding the positive impacts and reducing the negative impacts of business operations. The pursuit of greater industrial

competitiveness therefore serves as a fundamental motivation, emphasizing the strategic importance of sustainability for companies.

According to Rotondo et al. (2023), sustainable innovation can be understood as a gradual process involving continuous improvements across different stages. Initially, emphasis is placed on environmental issues, with a primary focus on improving companies' basic structures. In subsequent stages, attention shifts toward strengthening the value proposition, developing management tools, and adopting a more comprehensive approach to sustainability.

The authors further explain that different strategies are employed at various stages of the process to promote sustainable innovation. Initially, a vision in which sustainability is considered fundamental to the company's future is promoted and disseminated throughout the organization. Subsequently, investments are made in essential structures to enable this vision to be realized. Finally, the outcomes of these actions may indicate that the main challenges facing sustainable innovation are internal in nature and are primarily related to organizational issues. Nevertheless, these barriers may have less impact on companies whose missions are already integrated with sustainability principles (Rotondo et al., 2023).

Against this backdrop, sustainable innovation can become a source of competitive advantage by differentiating a company in the market and strengthening its strategic position, enabling it to reduce costs, respond to emerging demands, and mitigate sustainability-related risks (Porter, 2008). According to the author, competitive advantage is a central concept in strategic management and refers to an organization's ability to distinguish itself in the market and achieve superior performance relative to its competitors. Companies may achieve this advantage through three generic strategies: cost leadership, differentiation, or focus. Cost leadership involves achieving production efficiency in order to offer lower prices, whereas differentiation seeks to create unique products or services. The focus strategy, in turn, concentrates on specific market niches.

In the context of sustainable innovation, competitive advantage derives from an organization's capacity to integrate environmental practices into its production processes, thereby increasing operational efficiency, reducing waste, and strengthening its alignment with regulatory pressures. Furthermore, the incorporation of green capabilities and the development of social and environmental competencies make companies better equipped to respond to market dynamism and growing sustainability requirements (Siddiquei et al., 2025).

In this regard, Siddiquei et al. (2025) add that sustainability-oriented leadership creates internal conditions that support the development of lasting competitive advantages through capabilities that are difficult to imitate, such as a shared vision, social and environmental engagement, and sustainable organizational practices. Evidence also shows that

organizations that develop network- and learning-based capabilities are more resilient to external changes, improve their performance, and consolidate superior competitive positions in contexts of technological and environmental transformation (Bai et al., 2025).

Tao (2025) emphasizes that consumer preferences increase competitive pressure among companies, thereby requiring continuous innovation. Consequently, to differentiate themselves in a competitive market environment, companies need to cultivate a favorable green brand image. Emphasizing brand image not only increases companies' visibility in the market but also enhances their perceived value among consumers. This communicated differentiation can serve as a means through which companies obtain a competitive advantage (Zhao et al., 2016).

According to Porter's Five Forces Model, companies operating in highly competitive markets tend to implement different strategies aimed at achieving market differentiation and securing a competitive advantage (Tao, 2025). The author further states that companies must distinguish themselves from their competitors by creating sustainable products and services. This approach not only enhances their market competitiveness but also intensifies the competitive pressure faced by companies within the sector. Therefore, a company's competitive advantage may be based on its resources and distinctive capabilities to generate innovation and communicate it to the market (Boubaker et al., 2022). This assertion is supported by Schilke (2014), who argues that an organization enjoys a competitive advantage when it possesses superior capabilities relative to its current and potential competitors.

3. Materials and Methods

This study was divided into two stages. The first adopted a qualitative, descriptive, and applied approach, using a single-case study conducted in a chemical manufacturing company as its research strategy (Demo, 2022; Yin, 2015). To preserve its identity, the organization is referred to in this study as Company Q. Located in the Vale do Rio dos Sinos region, in the state of Rio Grande do Sul, Brazil, the company is primarily engaged in the production of adhesives, solvents, and sealants.

The following techniques were used for data collection:

(i) in-depth interviews with company employees directly involved in its operations;

(ii) in-depth interviews with chemistry experts who were not employed by the company;

(iii) systematic participant observation; and

(iv) documentary analysis based on internal records provided by the company (Gil, 2008; Malhotra, 2019; Prodanov & Freitas, 2013).

The interviews involved five professionals directly associated with the company's operations and three external experts with experience in the chemical industry who provide consulting services to the organization under analysis. The participants were identified using the codes Q1, Q2, Q3, Q4, Q5, Q6, Q7, and Q8.

Table 1 presents information on five employees (Q1 to Q5), including their department, position, and length of service with the company. Their positions and respective areas are Administrative Director, Financial Analyst, Billing Assistant, Industrial Chemist, and Commercial Coordinator. Their length of service ranges from nine months to more than nine years.

Table 2 presents information on the three external experts interviewed (Q6 to Q8), all of whom have academic backgrounds in chemistry and extensive professional experience in the sector. Their profiles include an industrial chemist who owns a chemical manufacturing company of a size comparable to that of the company examined in this study (Q6), as well as two specialists who work as consultants and higher education lecturers (Q7 and Q8). The interviewees' professional experience ranges from 20 to 40 years, demonstrating a high level of technical expertise and extensive practical knowledge of the chemical industry.

An interview guide was developed based on the literature review. The guide was validated on April 3, 2024, by two doctoral-level specialists in business administration and three employees of the company under analysis to assess the clarity and comprehensibility of the questions (Gil, 2008; Malhotra, 2019). All interviews were audio-recorded and subsequently transcribed. The resulting transcripts were subjected to content analysis in accordance with the guidelines proposed by Bardin (2011). The interviews were conducted between April 4 and July 26, 2024.

For the documentary data collection, which took place between April and July 2024, a checklist was developed to identify the available tools and records, including the enterprise resource planning (ERP) system, chemical reports, licensing records, and other administrative documents. Systematic participant observation was conducted by one of the authors, who was employed by the company at the time and had extensive access to information, operational routines, and internal records. This method followed the approach proposed by Malhotra (2019) and was structured and naturalistic participant observation.

Table 1 Department, position, and length of service of company employees interviewed during the qualitative stage of the research

Identification	Department	Position	Length of service with the company
Q1	Administration	Director	More than 7 years
Q2	Finance	Analyst	1 year
Q3	Billing	Assistant	1 year and 8 months
Q4	Industrial Operations	Industrial Chemist	More than 9 years
Q5	Sales	Coordinator	9 months

Table 2 Academic background, professional role, and years of experience of the experts interviewed during the qualitative stage of the research

Identification	Academic background and professional role	Professional experience
Q6	Industrial chemist and owner of a chemical manufacturing company of a size comparable to that of the company examined in this study	25 years
Q7	Specialist, industrial chemist, consultant in the field, and higher education lecturer	40 years
Q8	Specialist, chemical engineer, consultant in the field, and higher education lecturer	20 years

Data analysis followed the content analysis technique proposed by Bardin (2011) and was organized into three phases. The first phase, pre-analysis, involved developing the interview guides and the documentary data collection checklist, as well as structuring the central ideas. During the analysis phase, tables and analytical frameworks were organized, the collected responses were synthesized, and the main categories were defined as follows: (i) innovations implemented within the company and (ii) indicators of competitive advantages associated with sustainable innovation. Finally, during the data treatment phase, the results were delineated, interpretations were developed, and proposals for improvement were presented.

The second stage of the research adopted a quantitative approach, for which a questionnaire containing closed-ended statements measured on a five-point Likert scale was developed. The objective was to conduct a survey of chemical companies identified through the business registry of the Brazilian Chemical Industry Association (ABIQUIM, 2024) and Company Q's database.

Initially, 171 companies of different sizes and operating in different segments were identified across Brazil. After refining the sample to retain only companies whose primary activity was chemical manufacturing, this number was reduced to 152. Institutional contact details were then obtained from the companies' websites, resulting in 107 email addresses to which the questionnaire was sent.

The research instrument was developed based on the theoretical review and the findings from the qualitative stage, as recommended by Hair et al. (2009). Participant anonymity was maintained. The questionnaire was divided into two sections. The first collected demographic data and information on the respondents' profiles, including gender, company location, years of professional experience, educational attainment, and current position. The second section contained statements related to corporate investment in innovation and technology, operational efficiency, supplier relationships, and quality management.

Prior to data collection, the questionnaire underwent a validation process using the Delphi technique (Wright et al., 1991). Following the

pilot test and the necessary adjustments, emails were sent to the 107 listed companies on August 24, 2024, accompanied by a brief introduction to the study and a link to the online questionnaire. Responses were collected between August 24 and September 6, 2024. According to Hair et al. (2009), a minimum of 30 responses is required for statistical analysis. The data collection process was concluded after 34 responses had been obtained from 28 companies located in the states of Rio Grande do Sul, São Paulo, and Rio de Janeiro.

Descriptive statistical analysis was used to examine the data from the quantitative stage. The mean, standard deviation, and mode of the investigated variables are presented in the analysis and discussion section. According to Hair et al. (2009), the mean represents the central tendency of the responses, indicating the average value assigned by the respondents to each statement evaluated, and is widely used to summarize the overall behavior of the sample. The standard deviation expresses the degree of dispersion of the responses around the mean, making it possible to assess the level of agreement or heterogeneity among participants; lower values indicate greater consensus regarding the perceptions under analysis. The mode, in turn, corresponds to the most frequently observed value within the set of responses and is particularly useful for Likert-type scales, as it identifies the predominant response option among participants. The use of these descriptive measures enables a consistent interpretation of the behavior of the collected data and contributes to understanding participants' perceptions of sustainable innovation and competitive advantage in the chemical industry, as recommended in survey research and instrument validation studies (Hair et al., 2009; Wright et al., 1991).

Table 3 presents information on the 34 survey respondents, who occupied different positions, including coordinators, managers, analysts, and other positions at lower organizational levels, and had different levels of educational attainment, including postgraduate qualifications, undergraduate degrees, technical qualifications, and other forms of education. The table also presents the respondents' gender distribution. Most participants held coordination (23.5%) or management positions (20.6%), while the remaining 55% occupied other positions at lower organizational levels. Regarding educational attainment, professionals with postgraduate qualifications predominated (44.1%), followed by those with undergraduate degrees (23.6%) and technical qualifications (17.6%). In terms of gender, the sample was relatively balanced between men (56%) and women (44%), indicating diversity in the respondents' profiles.

After characterizing the sample, a statistical analysis of the collected data was conducted. Multivariate descriptive analysis was applied to interpret the results, following Hair et al. (2009), including the calculation of measures of central tendency and dispersion.

Table 3 Sociodemographic and professional profile of participants in the quantitative stage (survey) from companies in the Brazilian chemical industry

Respondent profile	Percentage	Number of respondents
Position		
Coordinators	23.5%	8
Managers	20.6%	7
Analysts	11.8%	4
Other lower-level positions with fewer than three respondents each	44.1%	15
Academic background		
Postgraduate qualification	44.1%	15
Undergraduate degree	23.6%	8
Technical qualification	17.6%	6
Other educational backgrounds	14.7%	5
Gender		
Men	56%	19
Women	44%	15

4. Analysis and Discussion of the Results

The application of the methodological procedures described in the previous section resulted in a dataset that is presented and analyzed below. First, the findings from the qualitative stage are presented, highlighting the main evidence and interpretations arising from this phase of the research. This is followed by the quantitative stage, which presents the descriptive analysis of the data and, finally, the relationship between the theoretical framework and the variables associated with sustainable innovation in companies.

4.1. Results of the Qualitative Research Approach

The first two interview questions were interrelated and sought to identify the process and product innovations implemented within the company and in the chemical industry more broadly over the previous five years, as well as the reasons underlying these innovations.

Table 4 summarizes the innovations implemented over the previous five years and their associated motivations, based on the responses provided by the eight interviewees (Q1 to Q8). The findings indicate the adoption of different types of innovation, including reverse logistics practices, raw material substitution, process automation, the digitalization of organizational routines, the implementation of enterprise resource planning systems, the use of digital technologies, and improvements in communication and marketing.

The motivations identified were primarily related to increasing productivity, reducing operating costs, improving customer service, complying with environmental legislation, strengthening brand image,

and mitigating production-related and environmental risks. These findings demonstrate the relationship between innovation, operational efficiency, and competitiveness in the chemical industry.

Table 4 Summary of innovations implemented over the past five years and their associated motivations, based on the perceptions of employees and experts interviewed in the Brazilian chemical industry

Interviewee	Innovations implemented over the past five years	Reasons for innovation
Q1	Implementation of reverse logistics, proper disposal of cardboard boxes and paper, replacement of conventional lighting with LED lamps, implementation of new sales channels, creation of a marketing department, automation of technical support services, among other initiatives.	Increased productivity, reduced costs, improved customer service, and compliance with environmental legislation.
Q2	Recent adoption of a message management platform, redesign of product cans, and recruitment of a new sales management team.	To facilitate communication and the organization of customer service, make packaging more visually appealing, and, above all, boost sales performance.
Q3	In the area of communication, conversation management applications were adopted, together with online sales platforms that streamlined the sales process.	To improve communication and customer service.
Q4	Acquisition of innovative raw materials, creation of a marketing department, proper disposal of packaging, issuance of Waste Transport Manifests, implementation of reverse logistics, digitalization of technical support services, creation of new customer service channels, redesign of the office layout, replacement of conventional lighting with LED lamps, and implementation of a water recirculation system for reactors.	To enter new markets, improve product performance, expand the brand, ensure proper waste disposal, improve customer service, reduce energy costs, and conserve water.
Q5	Development of a sales plan from the ground up, creation of product catalogs, redesign of cans and labels, modernization of the company website, implementation of routine control procedures, replacement of conventional lighting with LED lamps, and adoption of artificial intelligence in certain internal procedures, among other initiatives.	To organize processes, increase efficiency and responsiveness in customer service, standardize negotiations, reduce energy consumption, improve brand image, and increase sales.
Q6	Search for more sustainable products and suppliers, changes to the internal layout, implementation of an ERP system, acquisition of a digital filling machine for tubes, reuse of plastic packaging through cleaning, installation of solar panels, and replacement of conventional lighting with LED lamps.	To improve products and offer customers more options, increase productivity, reduce electricity consumption and costs, facilitate internal processes among employees, and reduce waste generation.
Q7	Investment in process automation, changes to production facilities and internal layouts, remote activation and opening of valves and pipelines, level-control systems, and automation of the production plant.	To increase productivity, reduce costs, prevent occupational risks, improve safety, and increase the accuracy of processes and decision-making.
Q8	Primarily the development of the internet and the Internet of Things, including sensors, robotics, systems and machinery integration, and data processing.	To increase speed and accuracy in production processes and decision-making, minimize risks, and integrate factories and people.

The innovations identified in the interviewees' responses can be grouped into three broad themes: sustainable innovation, automation and management, and strategies for productive and environmental efficiency. These dimensions reflect the integration of technologies and innovative practices aimed at improving sustainability, productivity, and business competitiveness.

According to Dias et al. (2025) and Silva et al. (2020), sustainable innovation is associated with reducing environmental and social impacts throughout the operational cycle. Based on the responses, this approach was materialized through the search for sustainable suppliers, the substitution of raw materials, the implementation of reverse logistics, and the reuse of packaging. Initiatives such as the installation of solar panels, the replacement of conventional lighting with LED lamps, and water recirculation also demonstrate efforts to optimize resource consumption and reduce the resulting environmental impacts (Demirel & Danisman, 2019; Ogiemwonyi et al., 2023).

Investment in automation and management represents another relevant dimension of innovation. The adoption of ERP systems, improvements in technical support services, and the redesign of production layouts reflect the pursuit of greater integration and operational efficiency. According to the OECD (2018), interaction with suppliers and the implementation of management systems are characteristics of open innovation, which enhances competitiveness by incorporating new knowledge and automated processes. This is consistent with the contributions of Crossan and Apaydin (2010), who describe innovation as both a process and an outcome capable of increasing productivity and reducing operational risks.

Finally, strategies for productive and environmental efficiency encompass initiatives related to material reuse, production chain optimization, and improvements in working conditions. Changes to office and production plant layouts were identified by the interviewees as measures capable of enhancing social performance and corporate responsibility, thereby reinforcing the importance of sustainability as a source of competitive differentiation (Morales et al., 2022; Rauter et al., 2023). Thus, innovation is not limited to environmental sustainability but also encompasses improvements in corporate management and operational conditions.

Continuing with the interviews, the next question addressed the initiatives adopted by companies over the previous five years to reduce their environmental impacts. Table 5 presents the main sustainable innovation initiatives adopted by the companies analyzed and the associated competitive advantages, according to the perceptions of the interviewees (Q1 to Q8). The column entitled "Sustainable innovations" highlights energy-efficiency measures, such as replacing conventional lighting with LED lamps and using solar energy, as well as reverse logistics practices,

water reuse, packaging recycling, and the substitution of raw materials with less environmentally harmful alternatives.

In the "Competitive advantage" column, the interviewees associated these initiatives with reduced operating costs, a stronger brand image through green marketing, compliance with environmental legislation, and competitive differentiation in the market. These findings demonstrate that sustainable innovation constitutes a strategic element for strengthening competitiveness in the chemical industry.

Table 5 Sustainable innovation initiatives adopted by the company analyzed and their respective contributions to generating competitive advantages in the Brazilian chemical industry

Interviewee	Sustainable innovations that contributed to competitive advantage, according to the interviewees	Competitive advantage
Q1	Replacement of conventional lighting with LED lamps, proper disposal of products, issuance of final disposal certificates, and implementation of reverse logistics.	Operational and energy efficiency through cost reduction and, consequently, greater capacity to invest in innovation; compliance with environmental legislation; and green marketing.
Q2	Commercialization of water-based adhesives, proper waste disposal in accordance with legislation, reverse logistics involving the exchange of plastic drums, and the recent development of a biodegradable mineral-gas additive.	Green marketing, enabling the company to strengthen its image through sustainable products and waste disposal solutions.
Q3	Development of water-based adhesives to reduce the use of petroleum-derived solvents.	
Q4	Replacement of conventional lighting with LED lamps, installation of automatic lighting systems, implementation of a water reuse system for machine cooling, redesign of the internal layout, equipment improvements for employees, search for raw materials that are less harmful to human health, reverse logistics with customers, and proper disposal of packaging.	Operational and energy efficiency through cost reduction and resource management; strengthening of the brand through green marketing and a sustainability-oriented image.
Q5	Development of products using raw materials that are less harmful to the environment, waste separation and proper disposal, replacement of conventional lighting with LED lamps, and use of cloud-based systems to replace physical filing boxes.	
Q6	Replacement of conventional lighting with LED lamps, search for sustainable raw materials in collaboration with suppliers, water reuse in production processes, installation of solar panels, recycling and reuse of plastic packaging, and improvements in employees' working conditions.	
Q7	Improvements primarily related to process flows and standardization, implementation of an Environmental Management System (EMS), integration of equipment and machinery, and support for start-ups seeking innovative approaches to reducing environmental impacts.	Greater process efficiency and technological innovation through process standardization; encouragement of innovation and the search for sustainable solutions by supporting start-ups.
Q8	Research and development of innovative and less environmentally harmful raw materials, reuse of generated waste to manufacture new products, and promotion of the circular economy within companies.	Investment in the research and development of sustainable raw materials and the reuse of waste in new products could position the company as a benchmark in circular economy and sustainable innovation.

The interviewees' responses are consistent with the theoretical perspectives of Porter (2008), Tao (2025), and Zhao et al. (2016), who argue that the adoption of sustainable practices can promote operational efficiency, innovation, and a stronger corporate image. Measures such as the installation of LED lighting, water reuse, and reverse logistics reduce costs and support regulatory compliance, while the search for sustainable raw materials and the substitution of solvents contribute to market differentiation.

Sustainable innovation strengthens competitiveness by integrating research into new materials, efficient resource management, and technology. Collaboration with suppliers, start-ups, and other companies fosters open innovation by combining internal and external resources to develop more sustainable processes. Furthermore, waste reuse and the structuring of innovative initiatives reduce environmental impacts and attract consumers who value responsible businesses (Bai et al., 2025; Boubaker et al., 2022; Demirel & Danisman, 2019; Ogiemwonyi et al., 2023; Ogiemwonyi & Harun, 2020; Peng et al., 2021; Siddiquei et al., 2025).

The final interview question addressed the actions that companies, and the chemical industry more broadly, could adopt to reduce their environmental impacts.

Table 6 presents the main future sustainable innovation actions suggested by the eight interviewees (Q1 to Q8), as well as the potential competitive advantages associated with them. As shown in the column entitled "Further innovations that could be adopted", the proposals primarily involve adopting renewable energy sources, improving waste management and separation, replacing inputs with more sustainable alternatives, digitalizing documents and processes, automating equipment, and investing in employee training and environmental education.

In the column entitled "Competitive advantages generated", the interviewees associated these actions with reduced operating costs, increased production efficiency, an improved corporate image, compliance with regulatory requirements, and the mitigation of environmental risks. These findings indicate that future sustainable innovation depends on both technological investment and cultural and organizational change.

The interviewees' responses reveal a concern with optimizing production processes, saving time, managing resources, and providing better working conditions for employees. The transition toward and implementation of innovative concepts require not only technological changes but also cultural and institutional transformations. Management teams must therefore establish priorities for action, prepare for the challenges and complexities involved, and develop partnerships and collaborative arrangements capable of supporting this transition (Dias et al., 2025; Hanaysha et al., 2025; Li et al., 2025; Silva et al., 2020).

Table 6 Future sustainable innovation actions identified by the interviewees and their potential competitive advantages

Interviewee	What other sustainable innovations could the company adopt to potentially achieve a competitive advantage?	Competitive advantages generated
Q1	• Ensure proper waste disposal; • Install solar panels; • Properly separate waste; • Seek sustainable raw materials.	
Q2	• Choose environmentally friendly inputs; • Use recycled paper, given the large number of documents printed daily; • Install solar panels; • Increase computer storage capacity to enable digital document archiving and thereby reduce paper consumption.	* Reduction in operating costs; * Increased production efficiency; * Improved corporate image in the market; * Compliance with regulatory requirements; * Innovation and creativity; * Risk reduction; * Proper waste management; * Greater sustainability; * Improved internal working environment; * Improved relationships with suppliers.
Q3	• Adopt renewable energy sources; • Replace plastic adhesive tape with paper tape; • Replace bubble wrap with paper-based packaging materials.	
Q4	• Replace restroom faucets with automatic models; • Properly separate waste generated in restrooms, offices, and the cafeteria; • Implement devices for the remote operation of machinery; • Increase cloud storage capacity to expand digital archiving and reduce the use of paper and physical storage boxes; • Promote environmental education among employees and raise awareness of environmental risks, impacts, and potential improvements.	
Q5	• Seek innovative and sustainable raw materials; • Promote a shift in organizational culture toward greater sustainability; • Digitalize documents and processes; • Properly separate waste; • Install solar panels.	
Q6	• Adopt systems with greater data-processing capacity and faster information delivery; • Implement more advanced formulation systems; • Integrate information systems, equipment, and machinery.	
Q7	• Provide courses and training for employees; • Encourage customers to purchase products with lower environmental impacts; • Invest in the research and development of new products that are less harmful to the environment and derived from renewable and biodegradable sources; • Manage internal practices and align economic considerations with the companies' strategic objectives.	
Q8	• Raise awareness among senior corporate leaders regarding environmental issues, sustainability, and greener practices.	

Sustainable innovations adopted by companies can foster competitive advantage by reducing costs, optimizing processes, and strengthening corporate image. As identified in the interview responses, the implementation of clean technologies, reverse logistics, and resource reuse contributes to operational efficiency and compliance with environmental requirements. These practices strengthen the company's image, attract environmentally conscious consumers, and reinforce the brand's sustainability positioning, while research into new materials and the circular economy contributes to product differentiation and innovation. Furthermore, collaboration with start-ups and the integration of equipment and systems foster innovative solutions, making sustainability a strategic differentiator in the market (Bai et al., 2025; Boubaker et al., 2022; Porter, 2008; Siddiquei et al., 2025; Tao, 2025; Zhao et al., 2016).

4.2. Results of the Quantitative Research Approach

This section presents the results of the second stage of the study, which adopted a quantitative approach. Within the construct, the statements address sustainable innovation as a source of competitive advantage in the current business context.

Table 7 presents the results of the descriptive analysis of the variables related to sustainable innovation as a competitive advantage, based on the responses of 34 survey participants. The mean, standard deviation, and mode are presented for each statement evaluated using a five-point Likert scale, in which 1 indicates "strongly disagree" and 5 indicates "strongly agree".

The variables analyzed encompass operations management, production efficiency, sustainable practices, innovation, corporate image, and relationships with external stakeholders. The table shows that the highest mean scores are associated with product quality management (4.74), operational efficiency and productivity (4.65), and investment in improvements to operations management (4.26). These results indicate a high level of agreement among respondents regarding the importance of these factors in determining competitiveness.

Sustainable practices and sustainable innovation also received high mean scores, reinforcing their importance for corporate image and stakeholder relationships. By contrast, the variable related to the adoption of management methods that support a more sustainable approach had a lower mean score (3.85) and greater dispersion, suggesting less consensus among the companies regarding the systematic incorporation of sustainability into their management models.

Based on the results, it can be inferred that most chemical companies primarily value quality management, operational improvement through investment, and high productivity as means of enhancing operational efficiency. In this way, the desired competitive advantage can be achieved

Table 7 Descriptive results for the variables related to sustainable innovation as a competitive advantage, obtained through the survey

Statements	Mean	Standard deviation	Mode
The company invests in improvements to operations management, such as techniques, tools, machinery, or equipment, to remain competitive in the market.	4.26	0.75	4
Efficient operations, characterized by the absence of bottlenecks and high productivity, are crucial to increasing the company's competitiveness.	4.65	0.54	5
Product quality management is a determining factor in establishing a competitive advantage in the market.	4.74	0.57	5
Sustainable practices, such as water conservation, energy conservation, and waste reuse, are essential for achieving a competitive advantage in the market in which the company operates.	4.00	1.04	5
Sustainable innovation, involving the development of new products and processes with lower environmental impacts, improves the company's image among its stakeholders, including consumers, employees, and society.	4.38	0.82	5
Relationships with external agents, such as suppliers and other companies, aimed at improving products and exchanging information, are essential for generating competitive advantage.	4.38	0.65	5
The company adopts management methods that support a more sustainable approach.	3.85	0.86	4

through market differentiation and the strategies adopted by each company (Bai et al., 2025; Carvalho et al., 2021; Ghobakhloo & Ching, 2019; Meincke et al., 2018; Mohan & Katakojwala, 2021; Siddiquei et al., 2025; Tao, 2025).

The results suggest that chemical companies are concerned with process efficiency, the competitiveness generated by their operations, and the development of strong external relationships. Such operational efficiency can be achieved through effective relationships with suppliers and external support mechanisms (Costa et al., 2021; Morales et al., 2022; Silva et al., 2020). In this case, competitive advantage may be associated with the strategic partnerships established both for new product development and process improvement (Boubaker et al., 2022; Porter, 2008).

Regarding operations management, the pursuit of efficiency and results remains one of the main priorities for ensuring greater organizational competitiveness and sustainability (Boubaker et al., 2022; Schilke, 2014). Operational excellence requires a perspective that encompasses investments in technology, processes, and human resources, highlighting the importance of a holistic approach to maximizing performance and fostering continuous innovation (Demirel & Danisman, 2019; OECD, 2018; Ogiemwonyi et al., 2023; Ogiemwonyi & Harun, 2020; Peng et al., 2021).

Crossan and Apaydin (2010) emphasize that innovation is regarded as a source of competitive advantage in environments characterized by constant transformation and should be interpreted as both a process and an outcome. The adoption of new production methods and management systems can generate competitive advantage; therefore, the theoretical

perspectives proposed by these authors support the interpretation of the results obtained in this study (Hansen & Wakonen, 1997; Dias et al., 2025; Hanaysha et al., 2025; Li et al., 2025).

Most respondents appear to be concerned with the sustainable image communicated by their companies, while also valuing external relationships and demonstrating awareness of the sustainable practices adopted within their organizations (Zhao et al., 2016). This finding is supported by Silva et al. (2020), who argue that external collaboration is essential for fostering sustainable solutions within companies.

The mean score of 3.85 for the adoption of management methods that promote sustainability suggests that chemical companies may favor business models and managerial methods oriented toward objectives other than sustainability. This finding indicates that, without incentives for more sustainable management practices, the implementation of new routines and processes tends to become more complex (Meincke et al., 2018).

It can therefore be observed that a substantial proportion of the companies value operational efficiency and establish practices aimed at improving their relationships with stakeholders and external agents. Accordingly, efficient operations, effective resource management, sustainable practices, and strong external relationships can help companies achieve competitive advantage and distinguish themselves in the market. However, waste reuse, circular economy practices, and the promotion of more sustainable management methods are not yet widespread. This may affect both operational efficiency and the image communicated by companies, making it more difficult to generate competitive advantage and develop ideas for sustainable innovation.

It can be concluded that most respondents understand competitive advantage as being associated with factors such as operational efficiency (Rosa et al., 2020; Rotondo et al., 2023; Van Erp et al., 2023), cost and waste management (Dias et al., 2025; Hanaysha et al., 2025; Li et al., 2025), external relationships (Costa et al., 2021; Morales et al., 2022; Silva et al., 2020), the implementation of new technologies and employee training in their use (Rauter et al., 2023; Urbinati et al., 2023; Weidner et al., 2021), and cultural and institutional change (Demirel & Danisman, 2019; Ogiemwonyi et al., 2023; Ogiemwonyi & Harun, 2020; Peng et al., 2021). When properly aligned with the company's strategy, all these factors can contribute to the generation of competitive advantage.

4.3. Analytical Synthesis of Convergences and Divergences

Figure 1 presents a conceptual map that synthesizes the main findings of the study by illustrating how sustainable innovation serves as a central driver of competitive advantage in the Brazilian chemical industry. Based on the empirical data, the map demonstrates how sustainable innovation emerges

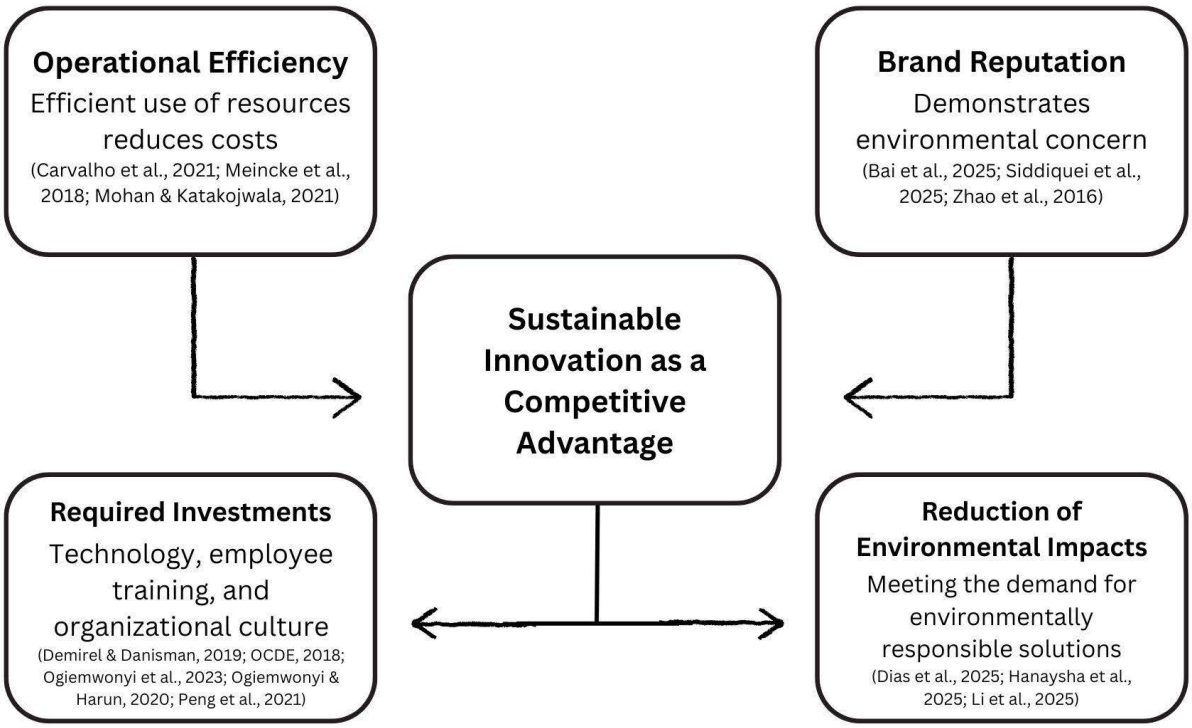

Figure 1
Conceptual map of the results.

from the interaction among operational efficiency, brand reputation, environmental impact reduction, and organizational investment.

The combination of operational efficiency, which enables cost reductions through the more effective use of resources allocated to business operations, and environmental concern, which contributes to preserving brand reputation, allows sustainable innovation to emerge as a source of competitive advantage. However, sustainable innovation can only be effectively translated into competitive advantage when supported by the necessary investments in technology, employee training, and organizational culture. These investments contribute to reducing environmental impacts and developing environmentally responsible solutions.

The conceptual map presented in Figure 1 synthesizes four empirical dimensions that jointly support sustainable innovation as a source of competitive advantage, represented by the central block. On the left, "Operational Efficiency" refers to cost reduction through the efficient use of resources. The arrow connecting "Operational Efficiency" to "Sustainable Innovation as a Competitive Advantage" indicates that productivity gains and cost reductions enhance the feasibility and adoption of sustainable innovative practices.

On the right, "Brand Reputation" represents stakeholders' perceptions of the company's environmental commitment. Therefore, the arrow connecting "Brand Reputation" to "Sustainable Innovation as a Competitive Advantage" indicates that reputational benefits, together with external pressures and expectations, stimulate sustainable innovation and reinforce its strategic role.

In the lower-left section, "Required Investments", encompassing technology, employee training, and organizational culture, function as enabling conditions. The connection between this block and the central block therefore indicates that sustainable innovation depends on these investments in order to become consolidated. In the lower-right section, "Reduction of Environmental Impacts" represents the main operational and environmental outcome of these practices. The arrow connecting "Required Investments" and "Reduction of Environmental Impacts" indicates that investment and internal capabilities enable the implementation of changes that reduce environmental impacts and generate environmentally responsible solutions. Thus, the arrows establish a logic in which drivers, namely efficiency and reputation, foster sustainable innovation; capabilities, represented by investment, enable its implementation; and outcomes, represented by environmental impact reduction, materialize the environmental performance associated with competitive advantage.

Based on the combined analysis of the qualitative and quantitative stages, this advantage can be understood as emerging from the convergence of four dimensions:

(i) operational efficiency, evidenced by the rational use of resources and cost reduction (Carvalho et al., 2021; Meincke et al., 2018; Mohan & Katakojwala, 2021);

(ii) corporate reputation, strengthened by the adoption of environmentally responsible practices that increase stakeholder trust (Bai et al., 2025; Siddiquei et al., 2025; Zhao et al., 2016);

(iii) the reduction of environmental impacts, resulting from initiatives such as reverse logistics, raw material substitution, and energy optimization (Dias et al., 2025; Hanaysha et al., 2025; Li et al., 2025); and

(iv) the required investments, encompassing technology, employee training, and cultural changes that are essential to sustaining innovative processes (Demirel & Danisman, 2019; OECD, 2018; Ogiemwonyi et al., 2023; Ogiemwonyi & Harun, 2020; Peng et al., 2021).

The integration of these elements demonstrates that sustainable innovation is not limited to isolated practices but constitutes a strategic mechanism capable of aligning economic performance, social and environmental responsibility, and competitive positioning in the chemical industry.

Furthermore, the results relating to the analytical categories show that the innovations implemented by Company Q, such as reverse logistics, raw material substitution, and automation, are aligned with the principles of sustainable innovation described by Hanaysha et al. (2025) and Li et al. (2025). However, an important divergence was identified. While the literature emphasizes structural investment and long-term strategies to

sustain sustainable innovation, the company analyzed adopts incremental and low-cost solutions because of financial constraints. This reveals a gap between the idealized theoretical perspective and the everyday practices of small chemical manufacturing companies.

When these findings are related to the perceived competitive advantages, they converge with the arguments of established authors such as Porter (2008), who associate sustainability with cost reduction, operational efficiency, and a stronger corporate image. Nevertheless, the findings indicate that, in practice, the competitiveness perceived by the interviewees is primarily associated with operational efficiency, rather than with sustainability as a central strategy. This differs from studies that identify sustainable innovation as a driver of new business models and greater differentiation (Demirel & Danisman, 2019; Rotondo et al., 2023). In other words, sustainability appears as a complementary element rather than as a strategic driver of competitiveness.

Finally, both the qualitative and quantitative stages reveal a contradiction. Although there is awareness of the importance of sustainable practices and several improvements have been suggested, including greater digitalization, environmental education, and the use of renewable energy, the adoption of sustainable management methods remains limited. This gap corroborates part of the literature that identifies cultural and institutional difficulties in incorporating sustainability into organizational practices (Rauter et al., 2023; Weidner et al., 2021). Thus, the evidence shows that, although companies recognize the strategic role of sustainable innovation, its consolidation as a long-term competitive advantage depends on strengthening organizational culture, expanding technological capabilities, and overcoming the internal barriers that restrict the full adoption of these practices.

5. Conclusions

Sustainable innovation integrates economic growth, social responsibility, and environmental preservation, thereby strengthening corporate competitiveness. This strategy enables the development of more efficient and sustainable solutions and helps companies address global challenges such as climate change and resource scarcity.

Against this backdrop, the general objective of this study was to analyze sustainable innovation as a source of competitive advantage in companies operating in the chemical industry. Based on the data obtained during the qualitative stage, it was found that Company Q continuously seeks innovation, whether through internal initiatives, such as employee training and process changes, or external drivers, including relationships with suppliers and business partners. However, because the company operates under financial constraints, it has had to reinvent itself and

identify affordable alternatives for implementing sustainable innovation. Nevertheless, it has succeeded in adopting several innovative initiatives.

The data analysis revealed obstacles to the adoption of new practices in the chemical industry, including the high level of investment required for technology, the need for training and adaptation, and the importance of changing senior management's mindset regarding more modern and digital processes and the promotion of innovation. The findings also highlighted the importance of increasing production efficiency by reducing waste and optimizing resource use, as well as implementing new technologies in operational processes to generate the differentiation required to achieve competitive advantage.

Evidence from both the qualitative and quantitative stages indicates that companies in the chemical industry are aware of their potential role as sources of environmental harm and are seeking affordable alternatives to foster innovation and implement innovative and sustainable practices in their operations. Furthermore, most interviewees understand that competitive advantage can be achieved through digital solutions and new technologies, effective resource management, external relationships, and sustainable practices, thereby strengthening the company's brand image and market position.

The survey presents several limitations, particularly regarding the number of responses obtained, which restricts the generalization of the findings to the chemical industry. In addition, online data collection may have captured perceptions that were more closely aligned with institutional discourse than with actual organizational practices. Companies that are more sensitive to sustainability issues may also have been more willing to participate in the research, potentially producing a more favorable picture than the average reality of the industry. These limitations indicate the need for larger samples and more robust quantitative methods in future studies.

This study therefore broadens the understanding of the role of sustainable innovation in the competitiveness of the chemical industry by providing a practical perspective on the challenges companies face, including high costs, the need to raise awareness among different hierarchical levels, and the demand for employee training. Accordingly, the study can serve as a reference for companies seeking to strategically plan and foster innovation and thereby become more competitive within their respective market segments.

Although the findings cannot be generalized to all chemical companies in Rio Grande do Sul or Brazil, the study confirmed that sustainable innovation, when encouraged and aligned with corporate strategy, can generate competitive advantage and strengthen a company's market image.

Finally, further research is recommended to investigate ways of fostering sustainable innovation, the circular economy, and open innovation in the chemical industry. It is also essential to examine the

effects of cultural transformation and employee training on organizational outcomes. Comparative studies involving different industrial sectors may contribute to identifying best practices that promote competitiveness and sustainability in the global business environment.

Acknowledgments

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil (CAPES) – Finance Code 001.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Use of Artificial Intelligence Tools

During the preparation of the manuscript, the artificial intelligence tool Scopus AI (Elsevier, 2026) was used exclusively to conduct a preliminary review of the literature, synthesize concepts, and assist with the organization of the text.

References

Associação Brasileira da Indústria Química. (2022). *O desempenho da indústria química brasileir*a. https://abiquim-files.s3.us-west-2.amazonaws.com/uploads/guias_estudos/o_desempenho_da_industria_quimica_bra_2022.pdf

Associação Brasileira da Indústria Química. (2024). *Associadas.* https://abiquim.org.br/abiquim/associadas.

Bai, L., Liu, X., Leng, X., Yao, Y., Yang, Y., Li, D., Zhao, Y. & Yin, H. (2025). Relational embeddedness, organizational learning ambidexterity, and competitive advantage in digital healthcare. *Scientific Reports*, *15*(1), 33024. https://doi.org/10.1038/s41598-025-18708-1

Bardin, L. (2011). *Análise de conteúdo*. Almedina Brasil.

Boubaker, S., Dang, V. A., & Sassi, S. (2022). Competitive pressure and firm investment efficiency: Evidence from corporate employment decisions. *European Financial Management, 28*(1), 113–161. https://doi.org/10.1111/eufm.12335

Carvalho, A. V., Enrique, D. V., Chouchene, A., & Charrua-Santos, F. (2021). Quality 4.0: An overview. *Procedia Computer Science, 181*, 341–346. https://doi.org/10.1016/j.procs.2021.01.176

Costa, R., Conceição, M. M., Silva, A. R., & Conceição, J. T. P. (2021). Green marketing: The importance of sustainable consumption for businesses. *Research, Society and Development, 10*(7), e16812. https://doi.org/10.33448/rsd-v10i7.16812

Crossan, M. M., & Apaydin, M. (2010). A multi-dimensional framework of organizational innovation: A systematic review of the literature. *Journal of Management Studies, 47*(6), 1154–1191. https://doi.org/10.1111/j.1467-6486.2009.00880.x

Demirel, P., & Danisman, G. O. (2019). Eco-innovation and firm growth in the circular economy: Evidence from European small- and medium-sized enterprises. *Business Strategy and the Environment, 28*(8), 1608–1618. https://doi.org/10.1002/bse.2336

Demo, P. (2022). *Avaliação qualitativa*. Autores Associados.

Dias, C., Mersmann, L., Pires, J. R. A., & Fernando, A. L. (2025). From lignocellulosic biomass to nanolignin: Sustainable solutions for a greener future. *Industrial Crops and Products, 238*, 122286. https://doi.org/10.1016/j.indcrop.2025.122286

Elsevier. (2026). *Scopus AI* (Large language model). www.scopus.com

Falkenroth-Naidu, K., Hong, S., Littmann, A., & Sellschop, R. (2023, January 23). *A new operations formula for the chemicals sector*. McKinsey & Company. https://www.mckinsey.com/industries/chemicals/our-insights/a-new-operations-formula-for-the-chemicals-sector

Fantke, P., Cinquemani, C., Yaseneva, P., Mello, J., Schwabe, H., Ebeling, B., & Lapkin, A. A. (2021). Transition to sustainable chemistry through digitalization. *Chem, 7*(11), 2866–2882. https://doi.org/10.1016/j.chempr.2021.09.012

Ghobakhloo, M., & Ching, N. T. (2019). Adoption of digital technologies of smart manufacturing in SMEs. *Journal of Industrial Information Integration, 16*, 100107. https://doi.org/10.1016/j.jii.2019.100107

Gil, A. C. (2008). *Métodos e técnicas de pesquisa social* (6ª ed.). Atlas.

Hair, J. F., Jr., Black, W. C., Babin, B. J., & Anderson, R. E. (2009). *Análise multivariada de dados* (6ª ed.). Bookman.

Hanaysha, J. R., Abusharbeh, M., Dwikat, S. Y., Shubita, M. F., Sharif, M. N., & Alshdaifat, S. M. (2025). Impact of corporate social responsibility, technological capability, and green entrepreneurial orientation on green innovation and sustainable performance. *World Development Sustainability, 7*, 100233. https://doi.org/10.1016/j.wds.2025.100233

Hansen, S.-O., & Wakonen, J. (1997). Innovation, a winning solution? *International Journal of Technology Management, 13*(4), 345–358. https://doi.org/10.1504/IJTM.1997.001668

Li, Y., Zhang, W., Li, B., & Wang, H. (2025). Antecedent configurations of green innovation and corporate sustainable development performance: Evidence from Chinese heavy-polluting enterprises. *Sustainable Futures, 10*, 101343. https://doi.org/10.1016/j.sftr.2025.101343

Malhotra, N. K. (2019). *Pesquisa de marketing: Uma orientação aplicada* (7ª ed.). Bookman.

Meincke, H., Nickel, J.-P., & Westerheide, P. (2018). Chemistry 4.0 – growth through innovation in a transforming world. *Journal of Business Chemistry, 15*(1), 42–53. https://doi.org/10.17879/09179496834

Mohan, S. V., & Katakojwala, R. (2021). The circular chemistry conceptual framework: A way forward to sustainability in Industry 4.0. *Current Opinion in Green and Sustainable Chemistry, 28*, 100434. https://doi.org/10.1016/j.cogsc.2020.100434

Morales, P., Flikkema, M., Castaldi, C., & Man, A.-P. (2022). The effectiveness of appropriation mechanisms for sustainable innovations from small and medium-sized enterprises. *Journal of Cleaner Production, 374*, 133921. https://doi.org/10.1016/j.jclepro.2022.133921

Organization for Economic Co-operation and Development. (2018). Oslo Manual 2018: Guidelines for collecting, reporting and using data on innovation (4th ed.). OECD Publishing. https://doi.org/10.1787/9789264304604-en

Ogiemwonyi, O., Alam, M. N., Hago, I. E., Azizan, N. A., Hashim, F., & Hossain, M. S. (2023). Green innovation behaviour: Impact of Industry 4.0 and open innovation. *Heliyon, 9*(6), e16524. https://doi.org/10.1016/j.heliyon.2023.e16524

Ogiemwonyi, O., & Harun, A. B. (2020). Consumption of green product as a means of expressing green behaviour in an emerging economy: The case of Malaysia. *Environment and Urbanization Asia, 11*(2), 297–312. https://doi.org/10.1177/0975425320938538

Peng, H., Shen, N., Ying, H., & Wang, Q. (2021). Can environmental regulation directly promote green innovation behavior? Based on the situation of industrial agglomeration. *Journal of Cleaner Production, 314*, 128044. https://doi.org/10.1016/j.jclepro.2021.128044

Porter, M. E. (2008). *Competitive advantage: Creating and sustaining superior performance*. Simon & Schuster.

Prodanov, C. C., & Freitas, E. C. (2013). *Metodologia do trabalho científico: Métodos e técnicas da pesquisa e do trabalho acadêmico* (2ª ed.). Editora Feevale. http://www.feevale.br/comum/midias/8807f05a-14d0-4d5b-b1ad-1538f3aef538/ebook%20metodologia%20do%20trabalho%20cientifico.pdf

Rauter, R., Globocnik, D., & Baumgartner, R. J. (2023). The role of organizational controls to advance sustainability innovation performance. *Technovation, 128*, 102855. https://doi.org/10.1016/j.technovation.2023.102855

Rosa, P., Sassanelli, C., Urbinati, A., Chiaroni, D., & Terzi, S. (2020). Assessing relations between circular economy and Industry 4.0: A systematic literature review. *International Journal of Production Research, 58*(6), 1662–1687. https://doi.org/10.1080/00207543.2019.1680896

Rotondo, F., Giovanelli, L., & Ezza, A. (2023). Implementing sustainable innovation in state universities: Process and tools. *Journal of Cleaner Production, 391*, 136163. https://doi.org/10.1016/j.jclepro.2023.136163

Schilke, O. (2014). On the contingent value of dynamic capabilities for competitive advantage: The nonlinear moderating effect of environmental dynamism. *Strategic Management Journal, 35*(2), 179–203. https://doi.org/10.1002/smj.2099

Schumpeter, J. A. (1997). *Teoria do desenvolvimento econômico: Uma investigação sobre lucros, capital, crédito, juro e ciclo econômico*. Nova Cultural.

Siddiquei, A. N., Ahmed, Z., Zaman, K., Badar, K., Khosa, M., & Zameer, H. (2025). Top management's green inclusive leadership and sustainable competitive advantage in manufacturing firms: The enabling role of internal CSR communication. *Journal of Environmental Management, 395*, 127825. https://doi.org/10.1016/j.jenvman.2025.127825

Silva, S. E., Venâncio, A., Silva, R. J., & Gonçalves, C. A. (2020). Open innovation in science parks: The role of public policies. *Technological Forecasting and Social Change, 151*, 119844. https://doi.org/10.1016/j.techfore.2019.119844

Tao, Z. (2025). From green demand to deceptive practices: A cross-cultural study on the impact of consumer green preferences on corporate greenwashing behavior in China, Republic of Korea, and Malaysia. *Sustainable Futures, 9*, 100440. https://doi.org/10.1016/j.sftr.2025.100440

Urbinati, A., Esfandabadi, Z. S., & Petruzzelli, A. M. (2023). Assessing the interplay between open innovation and sustainability-oriented innovation: A systematic literature review and a research agenda. *Business Ethics, the Environment & Responsibility, 32*(3), 1078-1095. https://doi.org/10.1111/beer.12540

Van Erp, T., Haskins, C., Visser, W., Kohl, H., & Rytter, N. G. M. (2023). Designing sustainable innovations in manufacturing: A systems engineering approach. *Sustainable Production and Consumption, 37*, 96–111. https://doi.org/10.1016/j.spc.2023.02.007

Weidner, K., Nakata, C., & Zhu, Z. (2021). Sustainable innovation and the triple bottom line: A market-based capabilities and stakeholder perspective. *Journal of Marketing Theory and Practice, 29*(2), 141–161. https://doi.org/10.1080/10696679.2020.1798253

Wright, J. T. C., Johnson, B. B., & Biazzi, J. L. (1991). *O uso da técnica Delphi na elaboração de cenários*. Petrobras.

Yin, R. K. (2015). *Estudo de caso: Planejamento e métodos* (5ª ed.). Bookman.

Zhao, Z.-Y., Zuo, J., Wu, P.-H., Yan, H., & Zillante, G. (2016). Competitiveness assessment of the biomass power generation industry in China: A five forces model study. *Renewable Energy, 89*, 144–153. https://doi.org/10.1016/j.renene.2015.12.035