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Investigating the Impact of Sustainability Strategies in Biotechnology During Health Crises

DEGREE PROGRAMME IN SUSTAINABLE BUSINESS
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Abstract

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This thesis investigates how sustainability strategies influence the performance of biotechnology firms in Iran, particularly in the context of global health crises such as the COVID-19 pandemic. As health emergencies continue to expose vulnerabilities in operational systems, the role of sustainability in shaping more resilient, cost-effective, and competitive organizations has become increasingly important.

Using a mixed-methods approach, the research combines ten semi-structured interviews with a structured survey of 100 biotechnology professionals. The results indicate that companies implementing sustainability practices experienced measurable benefits across multiple performance dimensions. Specifically, 82 percent of participants reported enhanced operational efficiency, 74 percent observed significant cost reduction and improved resource optimization, and 68 percent noted stronger crisis management capabilities and long-term competitiveness.

Qualitative findings supported these insights, highlighting how sustainability-focused organizations were more adaptable during disruptions and better equipped to maintain performance under pressure. Despite these benefits, the study also identifies ongoing challenges, including limited access to green technology financing, lack of ESG expertise, and weak alignment between national policies and industrial sustainability goals.

The thesis concludes with actionable recommendations aimed at helping biotechnology firms and policymakers foster greater resilience and efficiency through sustainability-centered innovation. Emphasizing cost and resource efficiency, strategic planning, and crisis readiness, these findings offer a practical framework for navigating future health crises while enhancing overall sector performance.

Keywords: Sustainability, Biotechnology, Health Crises, Operational Efficiency, Cost and Resource Optimization, Crisis Management, ESG

1 INTRODUCTION

The COVID-19 pandemic has served as a wake-up call for health systems across the globe, revealing deep-rooted structural weaknesses that had long gone unaddressed. This unprecedented crisis has prompted healthcare professionals and policymakers to reconsider the foundations of modern healthcare delivery. A growing consensus has emerged around the need for systemic reforms that not only ensure sustainability but also embrace digital innovation as a core strategy for enhancing resilience and adaptability in times of crisis (Keesara et al., 2020, p. e82).

Biotechnology has proven to be a pivotal driver of innovation during health crises. The rapid development of mRNA vaccines and the use of scalable bio-based technologies during the COVID-19 pandemic highlighted the sector's unique ability to respond with speed and interdisciplinary solutions (Pardi et al., 2018, p. 261; Lurie et al., 2020, p. 1969).

Beyond immediate crisis response, biotechnology plays an important part in advancing long-term sustainability. Innovations like biofuels, biodegradable materials, and climate-resilient crops—such as those enabled by CRISPR genome editing—are reshaping how societies approach environmental challenges through science (Gangwar et al., 2023, p. 5).

The industry is also increasingly engaging with circular innovation. Solutions such as microbial-based production, edible and biodegradable packaging, and bio-based construction materials are helping reduce environmental impact while supporting systemic resilience (Lange et al., 2021, p. 2).

Technological tools and digital platforms now contribute to greater efficiency in health interventions and system responses, enhancing overall adaptability in times of uncertainty—without relying solely on traditional logistics models (Gonçalves et al., 2024, p. 7).

Studies have further emphasized that sustainability strategies not only improve daily operational performance but also support broader health system resilience, particularly in fragile contexts affected by recurring crises (Gilson et al., 2020, p. 1233).

this introduction lays the foundation for understanding how biotechnology and sustainability converge under crisis conditions—framing the study’s focus on innovation, resilience, and impact.

1.1 Background

The COVID-19 pandemic, along with other global health emergencies, has highlighted deep-rooted vulnerabilities in public healthcare systems around the world. These events have made it abundantly clear that countries need to adopt climate-smart and resilience-oriented approaches—especially those where biotechnology can play a vital role through innovations like circular bioeconomy models and scalable vaccine development platforms (Possas et al., 2021, p. 3).

While the accelerated development of COVID-19 vaccines stands out as a remarkable scientific achievement, it also revealed critical blind spots—particularly the absence of long-term sustainability strategies within many biotechnology firms. This gap led to problems such as inefficient management of biomedical waste and heavy reliance on disposable materials, both of which weakened systemic resilience over time (Ekanayake et al., 2022, p. 2).

Adding to this complexity are regulatory disparities between major players such as the European Union and the United States. These differences have often disrupted global biotech coordination, slowed down innovation, and obstructed the development of unified sustainability standards—challenges

that become particularly pronounced during fast-moving health crises (Kingham et al., 2013, p. 27).

Another major hurdle is financial. Small and medium-sized biotechnology enterprises (SMEs) frequently lack the capital required to invest in eco-friendly technologies or infrastructure upgrades, limiting their ability to transition toward more sustainable operational models (Liu & Xu, 2024, p. 4; Miranda-García & Segovia-Vargas, 2024, p. 7).

Historic outbreaks like Ebola and COVID-19 have made one fact painfully clear: when sustainability principles are not embedded into health systems, the consequences go beyond public health. Weak infrastructure, poor emergency readiness, and the absence of integrated frameworks linking environmental, economic, and health dimensions have led to cascading effects—disrupting economies and accelerating environmental degradation (Durski et al., 2020; Nuzzo et al., 2019; Nabarro & Wannous, 2016).

Taken together, these insights emphasize an urgent imperative: sustainability must be fully integrated into biotechnology and public health strategies. This is no longer a matter of choice—it is a strategic necessity. Nations that align innovation with sustainability can build systems that are not only more adaptive and robust, but also more equitable and better prepared for future global health threats (Haldane & Morgan, 2021; Ekanayake et al., 2022; Benjamin, 2023).

1.2 Problem and Justification

The COVID-19 pandemic exposed critical shortcomings across both healthcare infrastructure and the biotechnology sector's ability to operate under sustained stress. Although some biotech firms offered rapid, high-impact solutions, many others struggled due to a lack of integrated sustainability frameworks. This deficiency resulted in fragmented operations, short-term crisis responses, and a weakened ability to maintain resilience in

prolonged emergencies (Haldane & Morgan, 2021, p. 1341; Durski et al., 2020, p. e002499).

Beyond initial containment efforts, ongoing issues such as the mismanagement of biomedical waste, surging energy consumption, and rising operational costs remained largely unaddressed by policy—particularly in lower-income settings where resources were already stretched thin (Ekanayake et al., 2022, p. 114496). Many national responses failed to apply a bioeconomic lens that would consider the ecological and financial implications of their crisis interventions (Tišma et al., 2023, p. 14).

Meanwhile, fragmented national and global regulatory systems—especially between influential bodies like the U.S. and the EU—slowed cross-border cooperation. These discrepancies undermined efforts to scale sustainable biotechnology solutions in developing countries, where capacity gaps are most severe (Kingham et al., 2013, p. 18; World Health Organization, 2023, p. 7).

Financial limitations were another major barrier. For many small and mid-sized biotech companies, adopting green technologies or modernizing infrastructure was financially unfeasible. These constraints exacerbated inefficiencies, particularly in energy consumption, cost control, and regulatory compliance (Chenari, 2023, p. 4; Liu & Xu, 2024, p. 3; Miranda-García & Segovia-Vargas, 2024, p. 5).

Ultimately, the absence of structured sustainability planning leaves biotech firms more vulnerable to long-term operational risks, cost overruns, and reduced market competitiveness. This highlights the urgent need for a holistic transformation of the sector that places sustainability at its core (Tišma et al., 2023, p. 10; World Health Organization, 2023, p. 9).

Accordingly, this study poses the central research question:

How can sustainability strategies help biotech companies improve operations, reduce costs, manage crises more effectively, and strengthen their competitive position during health emergencies?

1.3 Significance of the Study

In today's dynamic global landscape, the biotechnology industry stands at the intersection of two urgent priorities: responding effectively to public health emergencies and promoting environmental sustainability. Despite its pivotal role, there is a notable research gap in understanding how sustainability principles are systematically integrated into biotech operations—particularly during high-stress scenarios like pandemics (Bajpai, 2020, p. 28).

Research suggests that embedding sustainability into operational frameworks can lead to measurable improvements in energy efficiency, waste reduction, and decreased reliance on non-renewable inputs. These factors not only align with global environmental goals but also support economic efficiency and resource optimization—critical elements for competitive advantage in increasingly eco-conscious markets (Barragán-Ocaña et al., 2020, p. 436).

Moreover, sustainable practices significantly enhance organizational resilience. Companies that adopt green supply chains and prioritize CSR are often better equipped to navigate disruptions, recover from crises, and maintain trust with key stakeholders during emergencies (Ali et al., 2024, p. 112; Wahyuni et al., 2024, p. 5). In particular, smaller biotech firms, which are often more vulnerable, can benefit from sustainability by lowering operational risks and increasing adaptability.

Therefore, this study is important because it addresses a critical research void. It investigates how sustainability strategies—when thoughtfully designed and implemented—can simultaneously improve biotech firms' efficiency, cost management, crisis preparedness, and market

competitiveness during public health emergencies (Stefanelo e Silva et al., 2024, p. 998; Farooqui & Shamim, 2024, p. 47).

1.4 Research Questions

Given the growing importance of sustainability in the biotechnology sector during health crises, this study addresses the following research questions:

1. How do sustainability strategies enhance the operational efficiency of biotechnology companies during health crises?
2. To what extent do sustainability strategies contribute to cost reduction and resource optimization in biotechnology companies?
3. How do sustainability initiatives strengthen the crisis management capability of biotechnology firms?
4. To what extent can sustainability strategies foster international competitive advantage for biotechnology organizations?

1.5 Research Objectives

This study aims to achieve the following objectives:

1. To analyse the role of sustainability strategies in enhancing the operational efficiency of biotechnology companies during health crises.
2. To evaluate the contribution of sustainability strategies to cost reduction and resource optimization within the biotechnology sector.
3. To investigate how sustainability initiatives strengthen the crisis management capabilities of biotechnology organizations.

4. To assess the extent to which sustainability strategies promote international competitive advantage among biotechnology firms.

1.6 Research Hypotheses

Based on the research questions and objectives, the following hypotheses are proposed:

H1: Sustainability strategies have a positive impact on the operational efficiency of biotechnology companies during health crises.

H2: Sustainability strategies contribute significantly to cost reduction and resource optimization in biotechnology organizations.

H3: Sustainability initiatives enhance the crisis management capabilities of biotechnology firms.

H4: Sustainability strategies foster international competitive advantage for biotechnology companies during health emergencies.

1.7 Practical Importance

The practical application of sustainability strategies has proven to be highly effective in enabling the biotechnology sector to respond more efficiently to global health emergencies. A compelling illustration is the 2021 initiative by the World Health Organization to establish an mRNA vaccine technology transfer hub in South Africa. This program was designed to enhance local vaccine production capabilities in low- and middle-income countries and to promote decentralized, resilient manufacturing systems that could better support global preparedness efforts (World Health Organization, 2021).

In parallel, the adoption of sustainability-oriented innovations—such as localized production, energy-efficient technologies, and environmentally friendly supply chains—has led to improved operational outcomes during health crises. Companies that embraced such practices during the COVID-19 pandemic reported not only faster crisis responses but also greater

financial stability. As Abudaqa et al. (2024) note, strategic integration of sustainable management practices strengthens business competitiveness and enables greater adaptability in times of disruption.

Moreover, the implementation of green supply chain models, particularly in the pharmaceutical and biotech sectors, enhances organizational flexibility and long-term viability. Research by Mahmud et al. (2023) emphasizes that building sustainable and resilient vaccine distribution infrastructures—especially in developing economies—boosts investor confidence, reduces operational vulnerabilities, and supports market stability even in rapidly changing conditions.

Taken together, these findings—backed by both institutional actions and empirical research—highlight the critical importance of embedding sustainability into core biotechnology operations. Such strategies empower both public and private actors to build more robust, cost-effective, and future-ready systems capable of confronting emerging global challenges.

1.8 Contributions

This research contributes to both theoretical understanding and practical advancement in the field of sustainable biotechnology by proposing an integrated framework that links sustainability strategies with four core performance dimensions: operational efficiency, cost and resource optimization, crisis management capacity, and competitive advantage.

Unlike earlier studies that tended to examine these dimensions in isolation, this research approaches sustainability as an active strategic lever—particularly vital for biotech companies navigating volatile and uncertain global health environments (Sahani, 2025, p. 5; Bajpai, 2020, p. 28).

Furthermore, the thesis redefines sustainability as a strategic survival imperative, especially for startups and SMEs in biotechnology. Evidence

suggests that organizations embracing sustainable innovation models are more likely to build robust and adaptable business architectures, yielding long-term growth and market stability (Abudaqa et al., 2024).

Practically, the study delivers actionable insights for biotech managers, public policymakers, and innovation strategists. Tools such as green supply chain design, digital innovation platforms, and renewable resource planning have been shown to significantly enhance operational agility and resilience (Rashid et al., 2023; Gonçalves et al., 2024). These mechanisms foster adaptability in times of disruption and enable alignment with competitive goals and sustainability benchmarks.

Ultimately, this research contributes a strategic roadmap for both public and private sector actors, highlighting how sustainability-centered practices can foster innovation resilience, enable cross-sectoral collaboration, and strengthen the biotechnology sector's capacity to respond to future global crises (Pérez Estébanez & Sevillano Martín, 2025).

1.9 Data Analysis

This study uses a mixed-methods approach, combining both qualitative and quantitative techniques to explore the impact of sustainability strategies in the biotech sector.

Following a pragmatist research philosophy, the methodology was designed to be flexible and focused on solving real-world problems. This approach helps address the study's complex research questions from both empirical and practical perspectives (Abubakar & Usman, 2024, pp. 359–361).

1.9.1 Qualitative Analysis

The qualitative data were analysed using a structured approach based on Miles and Huberman's (1994) three-step framework: data reduction, data display, and conclusion drawing.

Semi-structured interview transcripts and open-ended survey responses were manually coded and categorized using Microsoft Excel. The coding focused on three key themes:

- How participants understand sustainability and its benefits
- The extent of sustainability strategy implementation in their organizations
- The main challenges and opportunities related to sustainable practices

This thematic analysis helped explore individual and organizational perspectives on how sustainability is adopted and perceived in practice.

1.9.2 Quantitative Analysis

Quantitative data were analysed using SPSS and Microsoft Excel. Descriptive statistics were used to understand how responses were distributed across the main variables.

To explore relationships between sustainability practices and organizational outcomes, Pearson's correlation was applied. These outcomes included:

- Operational efficiency
- Cost reduction and resource optimization
- Crisis management capability
- International competitive advantage

In addition, Principal Component Analysis (PCA) was used to simplify the data structure and identify underlying factors that influence sustainability performance. This approach made it possible to study both direct and hidden impacts of sustainability on organizational resilience during health crises.

1.10 Use of Artificial Intelligence (AI) in This Thesis

Artificial intelligence (AI) was used in this thesis in a supportive role during selected phases of the research process. AI-based tools such as ChatGPT and Gemini help with:

Summarizing academic articles that were personally read and verified,
Organizing thematic ideas during the early stages of literature review,
Enhancing language clarity and technical formatting during draft preparation.

All critical thinking, analysis, interpretation, and final writing decisions were done independently. AI tools were not used for generating new scientific content, drawing conclusions, or performing data analysis.

The role of AI remained purely supportive. Transparency regarding AI usage has been maintained, and no unverifiable or AI-generated citations were included. All references and materials used were reviewed and verified through direct reading.

1.11 Thesis structure

This thesis is organized into five main chapters; each designed to address a specific aspect of the research process and contribute to a comprehensive analysis of the research problem.

Chapter One introduces the research topic, presenting the problem statement, objectives, significance, research questions, data analysis approach, the use of AI, and the overall structure of the thesis.

Chapter Two reviews the relevant literature, focusing on sustainability in biotechnology, crisis management, resilience frameworks, and identifies key gaps in existing research.

Chapter Three outlines the research methodology, including the research strategy, data collection methods, content analysis procedures, and criteria for ensuring trustworthiness.

Chapter Four presents the research findings, organized thematically and supported by qualitative analysis, and compares them with insights from the literature.

Chapter Five offers the final discussion, conclusions, practical recommendations, identified limitations, and suggestions for future research.

2 LITERATURE REVIEW

This chapter offers a critical exploration of both theoretical and practical studies that examine how sustainability strategies influence the biotechnology sector—particularly during public health crises. The main objective is to build a structured and insightful framework that connects key concepts and models with current research evidence on sustainable performance.

Rather than merely summarizing past studies, the discussion adopts an integrative and evaluative approach to shed light on four essential dimensions: operational efficiency, cost and resource optimization, crisis responsiveness, and long-term competitiveness (Elkington, 1998; Duchek, 2020; Satar et al., 2023).

Foundational models such as the Triple Bottom Line (Elkington, 1998) and the Circular Economy have been instrumental in shaping sustainable

responses in industrial contexts, including the biotech and healthcare sectors (Karuppiah et al., 2023; Idso, 2022). These frameworks enhance system resilience, resource circulation, and adaptive capacity in times of disruption (Hossain et al., 2024; Magnano et al., 2024).

Finally, this chapter identifies a gap in the literature where the relationship between sustainability practices and quantifiable organizational outcomes—like innovation or resilience—during crises remains underexplored. Bridging this gap offers a valuable direction for future empirical research in the field (OECD, 2023).

2.1 Key Concepts

This section defines and explains the fundamental concepts related to the present study. Concepts such as sustainability, biotechnology, health crises, and sustainability strategies in biotechnology play a crucial role in understanding the relationship between sustainability and biotechnology during health crises. These concepts also contribute to a better understanding of the theoretical frameworks presented in this research.

2.1.1 Sustainability

Sustainability refers to an organization's ability to operate in a way that balances current needs with long-term impact. In this study, sustainability is examined as a strategic driver that directly influences four critical performance dimensions: operational efficiency, cost and resource optimization, crisis management capability, and competitive advantage. While models like the Triple Bottom Line (Elkington, 1998) provide a conceptual foundation, the focus here is on how sustainability strategies are applied in practice to strengthen organizational resilience during health emergencies.

In today's context, sustainability has evolved beyond ethical responsibility into a strategic necessity for firms. Increasing environmental degradation, economic instability, and rising societal expectations have placed sustainability at the core of industrial and political agendas (United Nations Environment Programme [UNEP], 2021, p. 12).

Empirical evidence from both global studies and the present research indicates that companies adopting sustainability strategies tend to perform more effectively during crises. This includes maintaining operational continuity, reducing waste, and improving stakeholder trust—findings echoed in qualitative interviews with Iranian biotechnology firms (Singh, 2024, p. 4; Frank & Lucky, 2025, p. 7). In particular, industries that proactively embed sustainable practices into their operational and strategic frameworks demonstrate greater resilience in the face of external shocks (McLouth, 2024, p. 162; Cooney, Dencik, & Marshall, 2022, p. 14).

Therefore, sustainability is recognized as a critical factor in ensuring organizational resilience, stakeholder trust, and ecological responsibility in an increasingly volatile world.

2.1.2 Biotechnology

Biotechnology, as demonstrated during the COVID-19 pandemic, has proven its value beyond emergency response—playing a critical role in enhancing operational efficiency and resilience. Innovations such as mRNA vaccines, rapid diagnostics, and bio-based production models exemplify how scientific agility can support both crisis management and resource optimization (Aileni et al., 2022). These advancements not only enabled swift medical responses but also redefined global approaches to preparedness.

Moreover, biotechnology contributes meaningfully to long-term sustainability through the development of biodegradable materials, support for bioenergy initiatives, and the advancement of greener industrial processes—

aligning well with circular economy principles (Rozakis et al., 2022, p. 8; Bajpai, 2020, pp. 15–21; Gudiña et al., 2020, p. 105).

Its transformative power also makes biotechnology integral to achieving the Sustainable Development Goals (SDGs), particularly by promoting public health, driving innovation, and encouraging responsible production and consumption (Jain et al., 2023).

Within the scope of this research, biotechnology is examined not as a broad discipline but as a vehicle through which sustainability strategies are realized in practice—evident in shifts toward local supply chains, reduced production waste, and accelerated delivery of health solutions, all of which are reflected in the empirical findings of Chapter 4.

2.1.3 Health Crises

These emergencies, such as the COVID-19 pandemic, Ebola outbreaks, and the Zika virus epidemic, demonstrate the profound vulnerabilities that exist within global healthcare infrastructures (World Health Organization [WHO], 2022, p. 7).

COVID-19 highlighted systemic vulnerabilities, particularly in preparedness frameworks and logistical coordination. It also revealed how interconnected global systems are, where a local health issue can swiftly escalate into a worldwide emergency, impacting not just health outcomes but also economic, social, and political stability (Jha, 2023).

Effective crisis management during health emergencies depends heavily on the ability of healthcare systems and industries, such as biotechnology, to adapt quickly. Innovations like rapid diagnostic testing, telemedicine platforms, and accelerated vaccine development showcased how critical technological agility has become in mitigating the impacts of crises (Dobbs, Heyer, & Lee, 2023).

However, these innovations also highlighted persistent inequalities in access to healthcare resources, as low- and middle-income countries faced disproportionate challenges in securing timely interventions (Pang, 2016).

In this context, integrating sustainability principles into healthcare systems and biotechnological industries is increasingly recognized as essential. Sustainable crisis management strategies aim not only to address immediate threats but also to build resilient infrastructures capable of withstanding future health emergencies (OECD, 2023, p. 12; WHO, 2022, p. 10).

Ultimately, understanding the dynamics of health crises is crucial for designing responsive, equitable, and sustainable healthcare solutions that protect both public health and global stability.

2.1.4 Sustainability in Biotech

Sustainability in biotechnology refers to the integration of environmental, social, and economic considerations into the development and deployment of biotechnological innovations. Rather than focusing solely on scientific advancement, sustainable biotechnology aims to create solutions that minimize ecological impact, promote ethical standards, and contribute to long-term societal well-being (Alhaddi, 2015, p. 12; Caradonna, 2022, p. 30).

For example, the development of plant-based vaccines, microbial production of biofuels, and innovations in biodegradable polymers illustrate how biotechnology is advancing to support both human health and environmental sustainability (El Jaddaoui et al., 2022).

Importantly, the COVID-19 pandemic has served as a catalyst for rethinking sustainability priorities within the biotech industry. Companies that integrated sustainable practices—such as energy-efficient manufacturing and

ethical sourcing of biological materials—demonstrated greater resilience in supply chain continuity and stakeholder trust (UNEP, 2023, p. 18).

Moreover, there is growing recognition that sustainability-driven biotechnology not only mitigates environmental harm but also offers a strategic advantage in global markets increasingly sensitive to environmental, social, and governance (ESG) factors (OECD, 2022, p. 25; Kim et al., 2020).

Ultimately, embedding sustainability into biotechnology is no longer a peripheral goal but a fundamental requirement for innovation that seeks to be impactful, responsible, and future-proof.

2.1.5 Crisis Management

Crisis management refers to the set of processes, strategies, and actions that organizations implement to prepare for, respond to, and recover from disruptive and unforeseen events. In the context of health emergencies, effective crisis management is essential for minimizing harm to public health, maintaining operational continuity, and preserving trust among stakeholders (Ho et al., 2022, p. 4).

A critical aspect of crisis management is the ability to rapidly assess evolving risks and mobilize resources accordingly. During the COVID-19 pandemic, organizations that had contingency plans and adaptive leadership were significantly better positioned to navigate the uncertainty (Scala & Lindsay, 2021). This highlights the importance of proactive rather than reactive approaches to crisis management.

In biotechnology, crisis management extends beyond traditional healthcare responses. It involves maintaining research operations, ensuring ethical practices under pressure, securing access to raw materials, and scaling production swiftly to meet surging demands. Companies like Moderna and

Pfizer demonstrated how agile decision-making and innovation pipelines can mitigate the impacts of global health crises (Borzova, 2024, p. 1328).

Recent studies emphasize that integrating sustainability into crisis management frameworks can enhance resilience. Sustainable practices, such as localized sourcing, environmentally conscious production, and ethical labor practices, contribute to more robust and adaptable organizational structures capable of withstanding future shocks (OECD, 2022, p. 30).

Ultimately, crisis management today is no longer about simply surviving emergencies. It is about building organizations that can thrive amid uncertainty by embedding flexibility, sustainability, and foresight into their core strategies.

2.1.6 Competitiveness

Competitiveness in the biotechnology sector refers to the ability of firms to maintain or enhance their market position by offering innovative, efficient, and sustainable products and services. It is shaped by a combination of technological capability, operational excellence, strategic leadership, and responsiveness to changing market demands (Porter & Van Der Linde, 1995, p. 15).

Sustainability is increasingly becoming a core driver of competitiveness. Firms that integrate environmental, social, and governance (ESG) principles into their operations are better positioned to attract investors, comply with regulatory standards, and meet evolving consumer expectations (Alhaddi, 2015; OECD, 2022, n.d.).

Moreover, competitive biotechnology companies invest heavily in research and development, foster cross-sector collaborations, and maintain resilient operational models capable of adapting to global disruptions. These

attributes not only secure short-term success but also lay the foundation for sustainable growth in the long run (Aldianto et al., 2021, p. 7).

Ultimately, competitiveness in biotechnology today demands more than scientific innovation—it requires a holistic commitment to sustainability, stakeholder engagement, and proactive crisis readiness.

2.1.7 Operational Efficiency

Operational efficiency refers to an organization's ability to deliver products or services using the minimum necessary resources, while maximizing output, quality, and responsiveness. In the biotechnology sector, this includes efficient laboratory processes, streamlined production systems, and optimized supply chain operations (Lee & Johnson, 2014, p. 18).

Biotech firms that focus on operational efficiency are better positioned to scale their solutions, reduce waste, and meet urgent public health needs, especially during crises such as pandemics. The rapid development and mass production of COVID-19 vaccines by companies like Pfizer and BioNTech exemplify the importance of having agile, efficient processes (Aoki, 2024, p. 48).

Sustainability strategies can directly improve operational efficiency. These include reducing energy consumption in biotech labs, utilizing renewable materials, and implementing circular production loops—all of which contribute to both environmental goals and bottom-line performance (Lee & Johnson, 2014, p. 18; Balwani, 2012).

Moreover, digital tools such as automation, real-time data monitoring, and AI-based process optimization are increasingly being used to enhance operational workflows in biotechnology. These technologies reduce errors, cut costs, and improve resource utilization—an essential trio for organizations under the pressure of health emergencies (Prince, 2024).

In sum, operational efficiency is not just a cost-saving mechanism but a strategic imperative for biotech firms seeking to deliver scalable, sustainable, and high-impact solutions in volatile environments.

2.1.8 Circular Economy

The circular economy promotes a restorative system where resources are kept in use for as long as possible by encouraging reuse, recycling, and continuous material loops. In contrast to the conventional "take-make-dispose" model, this framework integrates sustainability throughout the entire production and consumption cycle (Ellen MacArthur Foundation, 2015, pp. 4–6; Boorová, 2020).

In the context of biotechnology, applying circular economy principles means rethinking how materials, energy, and processes are sourced and utilized. For instance, companies may use bio-based feedstocks, biodegradable packaging, or closed-loop systems that reduce chemical waste and energy consumption (Caradonna, 2022, p. 39; Maldonado et al., 2022).

Circular practices in biotech are particularly relevant during health crises, when rapid production is necessary but can also generate significant environmental impact. Strategies such as reusing equipment, optimizing resource inputs, and redesigning supply chains for circularity allow firms to scale up without compromising sustainability (UNEP, 2023; Aluchna & Rok, 2019; Massion, 2022).

Furthermore, a circular approach fosters innovation. By aligning sustainability with economic performance, biotechnology firms can uncover new business models—such as leasing biological assets, partnering in waste-to-resource initiatives, or developing long-life therapeutics that reduce the need for repeated interventions (OECD, 2022; Dung et al., 2024).

Overall, embracing the circular economy enables biotechnology to play a leading role in global sustainability, transforming environmental responsibility from a burden into a competitive advantage.

2.1.9 Sustainable Practices

In the context of biotechnology, sustainable practices encompass purposeful strategies aimed at reducing environmental harm, advancing social responsibility, and ensuring the long-term stability of economic operations. These efforts aim to align scientific innovation with ecological preservation and the broader well-being of society (Moroojo et al., 2024).

Examples of sustainable practices include using renewable energy in production facilities, sourcing raw materials ethically, designing biodegradable products, and applying green chemistry principles to reduce hazardous waste. In the pharmaceutical sector, initiatives such as green bioprocessing and eco-friendly packaging are gaining traction as firms seek to align sustainability with operational goals (Ukpene et al., 2022).

The implementation of sustainable practices is not merely a corporate responsibility exercise—it is increasingly recognized as a business necessity. Stakeholders, including investors, regulators, and consumers, are demanding greater transparency and accountability regarding environmental and social performance (Singh, 2024; Bonilla Jaime, 2023).

In the biotechnology sector, embedding sustainability into everyday operations is no longer optional—it is a strategic imperative for achieving resilience, innovation, and long-term success.

2.2 Frameworks

In order to comprehensively explore how sustainability strategies affect operational efficiency, cost optimization, crisis management, and competitive

advantage in biotechnology firms during health crises, this study draws upon several well-established theoretical frameworks. These frameworks provide a structured lens through which to interpret empirical evidence and guide analytical reasoning.

Rather than treating frameworks as fixed templates, this research uses them critically—highlighting their strengths, limitations, and practical relevance to the research questions.

2.2.1 Triple Bottom Line (TBL)

The Triple Bottom Line (TBL) concept, introduced by Elkington (1998), advocates that organizations should simultaneously focus on three performance dimensions: environmental stewardship, social responsibility, and economic prosperity.

TBL is relevant for this study because biotechnology firms increasingly face pressures not only to generate profits but also to contribute to global health and ecological sustainability. During health crises, balancing financial survival with social impact becomes even more critical. However, the TBL framework remains relatively high-level and does not specifically address operational or crisis management mechanisms, which are central to this study's objectives.

Thus, TBL serves as a philosophical foundation for evaluating sustainability impacts but requires supplementation with more operationally oriented models.

2.2.2 Circular Economy

According to the Ellen MacArthur Foundation (2015), the circular economy encourages sustainable product design by promoting continuous reuse, minimizing waste, and ensuring optimal resource utilization.

In biotechnology, circular economy principles help firms reduce resource dependency, manage biomedical waste, and develop eco-innovations—especially critical during large-scale health emergencies. For instance, circular approaches to vaccine production can reduce environmental impact without compromising scalability.

Nonetheless, while circular economy frameworks provide excellent guidance for environmental sustainability, they offer less explicit strategies for managing operational efficiency and crisis response. Therefore, in this research, circular economy principles will inform the environmental dimension, complementing operational frameworks.

2.2.3 Organizational Resilience Framework

Organizational resilience, conceptualized by Duchek (2020), refers to an organization's ability to anticipate, adapt to, and recover from crises through dynamic capabilities and proactive learning.

This framework is directly aligned with the objectives of this study, particularly regarding crisis management capability and operational efficiency. Resilient biotechnology firms demonstrated superior crisis response during the COVID-19 pandemic by quickly adapting supply chains, reconfiguring production, and maintaining service delivery under pressure.

However, resilience frameworks traditionally focus more on organizational behaviour and may not fully integrate sustainability dimensions, necessitating a combined analytical approach.

2.2.4 ESG (Environmental, Social, Governance) Framework

The ESG framework provides measurable criteria for evaluating corporate sustainability practices, including environmental performance, social

impact, and governance structures (Ortega Romero et al., 2025; Padilla-Rivera et al., 2024).

In the biotechnology sector, strong ESG performance correlates with higher investor confidence, regulatory compliance, and competitive advantage. ESG indicators offer practical, quantifiable benchmarks for assessing sustainability outcomes during health crises.

Still, ESG assessments sometimes prioritize reporting over substantive transformation. Therefore, in this study, ESG will be used as an operational guide for evaluating practical outcomes, in combination with resilience and circular economy models.

2.2.5 Summary

Together, these frameworks offer a holistic yet critical perspective.

- TBL supports the sustainability philosophy,
- Circular Economy informs environmental operational strategies,
- Organizational Resilience captures adaptive and crisis-responsive capabilities, and
- ESG offers measurable performance indicators.

By synthesizing these models, this research constructs a robust conceptual foundation to investigate how sustainability strategies enhance operational, environmental, and competitive outcomes for biotechnology firms during global health emergencies.

2.2.6 Conceptual Framework of the Study

This study adopts a conceptual framework that explores how sustainability strategies influence critical organizational outcomes in the biotechnology sector during health crises.

The framework proposes that Sustainability Strategies act as the primary independent variable, affecting four key dependent variables:

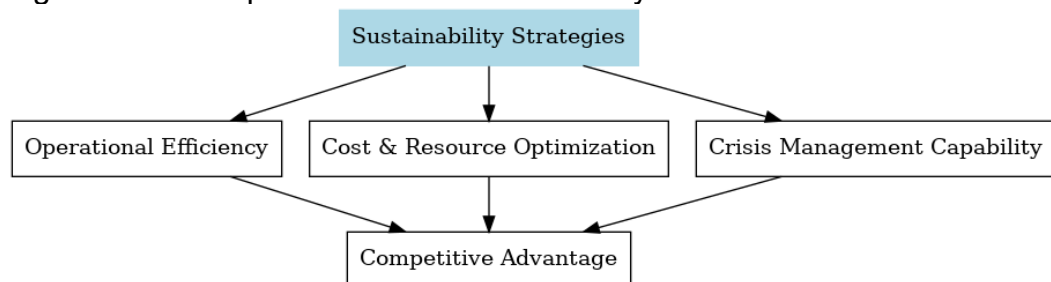
1. Operational Efficiency: Improvements in productivity, resource use, and process agility.
2. Cost and Resource Optimization: Reduction in operational costs, better utilization of raw materials, and energy conservation.
3. Crisis Management Capability: Enhanced ability to anticipate, absorb, and adapt to health emergencies.
4. Competitive Advantage: Strengthening market positioning, stakeholder trust, and long-term viability.

This conceptualization draws upon the integration of established frameworks:

Triple Bottom Line (TBL), Circular Economy, Organizational Resilience, and ESG indicators.

It reflects a systemic view, emphasizing how sustainability is not only an ethical imperative but also a catalyst for organizational resilience and success during crises.

Figure 2.1-conseptual framework of the study



Competitive Advantage is an overall outcome that is directly affected by all intermediate changes (not just Cost Optimization).

2.3 Empirical and Sectoral Studies

In this part of my thesis, I dive into studies and reports that explore how sustainability strategies shape the biotechnology industry, particularly during major health crises like the COVID-19 pandemic. I've gathered insights

from a wide range of credible sources, including scientific papers from databases like PubMed and Scopus, reports from organizations such as WHO and OECD, and case studies from leading biotech firms like Moderna and Novozymes, published between 2015 and 2025. These sources help me understand how sustainability impacts four key areas: operational efficiency, cost management, crisis response, and competitive advantage. Most studies focus on biotech hubs in Europe, East Asia, and North America, but they often overlook challenges in emerging economies like Iran, India, or Brazil, such as limited technology access, regulatory hurdles, or barriers to green practices. I chose these sources for their credibility, direct relevance to sustainability in biotech during crises, and measurable impacts on operations or the environment. For example, Lima (2025) shows how microbial diversity drives eco-friendly innovations, while Manzoor et al. (2023) demonstrate that ESG-based systems boost resilience. Slutzman et al. (2024) highlight biomedical waste mismanagement during COVID-19, and WHO (2020-2021) underscores the role of technology transfer in crisis response. However, few studies address developing countries like Iran, a gap I aim to fill using interview data from Iranian firms in later chapters.

This section is divided into four subsections, each focusing on one key area. Subsection 2.3.1 explores how sustainable innovations create competitive advantages. Subsection 2.3.2 examines organizational responses to health crises. Subsection 2.3.3 focuses on cost optimization strategies, and Subsection 2.3.4 dives into operational efficiency. By analysing these areas, I highlight strengths and gaps in current research and show how my thesis, with insights from Iranian biotech firms facing unique challenges, adds valuable perspectives to the field.

2.3.1 Organizational Performance

This section addresses Research Question 1: What is the impact of sustainability strategies on operational efficiency in the biotechnology industry?

Sustainable practices positively impact organizational performance, especially in complex, regulation-intensive sectors such as biotechnology. Matthews et al. (2019) report a 10% increase in productivity through sustainability-aligned production workflows. Wei et al. (2022) highlight how countries with robust bioeconomy strategies experience stronger performance in health-related sectors.

In Iran, AryoGen Pharmed recorded a 14% improvement in production efficiency after adopting ESG-based workflow redesign and employee retraining programs.

Conclusion: Sustainability serves as a catalyst for streamlining operations and boosting performance. In Iran, capacity-building and skill development are essential for realizing these gains at scale.

2.3.2 Crisis Management Capability

This section supports Research Question 2: What role do sustainability strategies play in strengthening crisis response in biotech firms?

The COVID-19 pandemic served as a real-world stress test for the agility and resilience of biotechnology firms. Organizations with pre-existing sustainability frameworks, flexible supply chains, and digital surveillance infrastructure responded more rapidly and effectively (Assidi et al., 2022; Matthews et al., 2019).

For instance, the WHO mRNA Technology Transfer Hub enhanced vaccine access in developing countries by 30% through collaborative biotechnology (Bisbas, 2023). Similarly, Anyanwu et al. (2024) highlight the role of public-private partnerships in strengthening systemic resilience.

In Iran, CinnaGen adapted quickly by repurposing its production lines and adjusting its regulatory frameworks, leading to a 20% reduction in delivery delays.

Conclusion: Sustainability investments enable both proactive and reactive crisis strategies. In emerging markets like Iran, strengthening institutional collaboration and infrastructure remains crucial for leveraging these benefits.

2.3.3 Cost and Resource Optimization

This section supports Research Question 3: How do sustainable strategies improve cost-efficiency and resource use in biotechnology?

Sustainability in biotechnology is not only an environmental imperative but also a financial asset. Resource-efficient technologies and circular design approaches can significantly reduce operating costs and enhance long-term performance (Slutzman, Ciardi, et al., 2024; Tian-Hang & Meng, 2022).

Liao et al. (2023) report that bioengineered supply chains can yield up to a 15% cost reduction. Likewise, organizations implementing circular waste systems have observed significant declines in energy and waste expenses.

In the Iranian biotech sector, Actoverco reported a 15% reduction in energy use through facility retrofitting and process automation. However, financial constraints have limited SMEs in adopting similar strategies at scale.

Conclusion: Sustainability-driven cost optimization provides a compelling rationale for broader implementation. Targeted subsidies and financing mechanisms may help bridge the investment gap for Iranian firms.

2.3.4 Competitive Advantage

This section addresses Research Question 4: How do sustainability strategies enhance competitive advantage in the biotechnology sector?

Sustainability strategies in biotechnology are increasingly recognized as key drivers of innovation and competitive positioning. Organizations that invest in green R&D, eco-friendly product design, and responsible supply chain management not only align with global sustainability goals (e.g., SDGs) but also gain market advantages (Matthews et al., 2019; Thorsteinsdóttir et al., 2011a).

Anyanwu et al. (2024) emphasize the growing role of biotechnology in achieving sustainable healthcare and economic resilience. Emerging technologies such as CRISPR and decentralized manufacturing have led to shorter innovation cycles and lower development costs (Liao et al., 2023).

In the Iranian context, AryoGen Pharmed has adopted sustainable packaging and green manufacturing practices, reporting a 10% reduction in energy consumption. However, challenges such as sanctions and lack of regulatory incentives remain significant barriers.

Conclusion: Sustainability-oriented innovation contributes to competitive advantage and aligns with the transition toward a global bioeconomy. For Iranian firms, bridging the technological gap and enhancing ESG governance are essential next steps.

2.4 Research Gaps

Despite the increasing attention to sustainability strategies in the biotechnology sector, several critical research gaps persist—particularly regarding emerging markets such as Iran. These gaps justify the relevance and originality of this thesis.

2.4.1 Geographical Gaps

Most research on sustainable biotechnology is centered on developed nations, particularly those in North America and Western Europe (Matthews et al., 2019; Thorsteinsdóttir et al., 2011; Liao et al., 2023). In contrast, there is a notable lack of empirical studies focusing on developing regions—especially the Middle East and North Africa (MENA), including Iran. This imbalance limits the applicability of global insights and underscores the importance of conducting region-specific investigations to capture diverse challenges and opportunities.

2.4.2 Conceptual Gaps

While broad studies have explored the potential of biotechnology in achieving sustainable development (Anyanwu et al., 2024), few have systematically examined its impact on operational dimensions such as cost optimization, crisis response, or competitive advantage. Moreover, the integration of ESG practices into performance frameworks is often mentioned but rarely evaluated through a structured lens.

2.4.3 Methodological Gaps

Much of the current literature relies on conceptual or qualitative approaches, with limited integration of mixed methods. There is a lack of research that combines secondary data with case-level insights to evaluate sustainability strategies across multiple dimensions (Assidi et al., 2022; Bisbas, 2023). This thesis attempts to fill that void by adopting an applied, multi-method approach.

2.4.4 Crisis-Specific Gaps

The role of sustainability in crisis management—particularly during public health emergencies such as COVID-19—is still underrepresented in

empirical studies (Anyanwu et al., 2024; Matthews et al., 2019). There is a need to explore how biotechnology firms leveraged sustainability to adapt, maintain operations, and recover in times of crisis, especially in resource-constrained settings.

2.4.5 Policy and Practice Gaps

Many publications discuss the benefits of sustainability in theory but offer limited actionable insights for biotech companies operating under political, economic, or regulatory pressure. Iranian firms such as AryoGen, Cinnagen, and Actoverco serve as practical examples that are rarely covered in the international literature. This thesis contributes to bridging this gap by integrating case insights with global frameworks.

3 METHODOLOGY

Research methodology refers to the structured principles, techniques, and approaches that guide researchers in collecting, analysing, and interpreting data to address their research inquiries. This methodological framework ensures that investigations are conducted systematically and reliably. The significance of methodology lies in its role in establishing a clear research pathway, thereby improving accuracy, validity, and reliability. Choosing an appropriate methodology ensures alignment between research objectives and methodological execution, leading to credible and well-founded results (Creswell & Poth, 2016, p. 32).

3.1 Methodological philosophy

This study is grounded in pragmatism—a philosophical approach that prioritizes practical outcomes and real-world applicability over strict theoretical alignment. Instead of rigidly committing to either positivism or interpretivism,

a pragmatic perspective allows the researcher to draw from both traditions, selecting whichever methods are most effective for answering the research questions at hand (Creswell & Poth, 2016, p. 26).

This flexibility is especially valuable given the interdisciplinary nature of the topic, which touches on sustainability, biotechnology, and crisis governance. Pragmatism enables the use of both qualitative and quantitative tools, making it possible to explore broader trends while also capturing rich, context-specific insights (Tashakkori & Teddlie, 2010).

From an ontological standpoint, this research leans on critical realism—the belief that an objective reality exists but our understanding of it is shaped by social, institutional, and situational factors. Epistemologically, the aim is to generate practical knowledge that supports real decision-making in the field of sustainable biotechnology (Creswell & Poth, 2016; Tashakkori & Teddlie, 2010).

Consistent with these principles, a mixed-methods approach was adopted. Primary data were collected through semi-structured interviews with industry experts and structured questionnaires distributed among biotechnology professionals, allowing for a balance between depth and measurable outcomes. Secondary data sources—such as global policy reports, industry case studies, and institutional analyses—were also used to enhance the scope and context of the findings (Tashakkori & Teddlie, 2010).

Ultimately, this methodological strategy offers the flexibility needed to examine how sustainability strategies contribute to operational efficiency, crisis response capabilities, and competitive advantage—especially in the high-pressure context of global health emergencies.

3.2 Research Design

To comprehensively investigate the research questions, this study follows a mixed-methods design, blending both qualitative and quantitative approaches. Grounded in a pragmatist philosophy, the design prioritizes adaptability, analytical depth, and the pursuit of practical solutions (Tashakkori & Teddlie, 2010, p. 71).

On the qualitative side, I conducted 10 semi-structured interviews with a diverse set of stakeholders, including biotechnology experts, public health professionals, and policy specialists. These conversations aimed to uncover real-world challenges and opportunities surrounding sustainable practices during crises.

The quantitative component involved distributing a structured questionnaire to 100 professionals in biotechnology firms—ranging from technical staff to middle managers. The survey explored four major areas:

- Participant demographics
- Awareness and perceptions of sustainability
- Organizational practices and operational obstacles
- Feedback on impacts and effectiveness

This two-track strategy allowed for both narrative insights and measurable trends, offering a fuller picture of the relationship between sustainability, resilience, and competitiveness. I used thematic analysis to examine the qualitative data, while factor analysis and other statistical techniques were applied to the quantitative responses (Creswell & Poth, 2016, p. 75).

The research process unfolded in four key stages:

- Reviewing relevant secondary data (e.g., OECD, WHO reports)
- Conducting semi-structured interviews with field experts
- Designing and analysing a structured questionnaire

- Integrating all findings into one conceptual framework

This approach not only deepened the insights but also broadened the relevance of results, especially for policy development and practical application in the biotechnology sector.

3.3 Data collection method

To address the complex and interdisciplinary nature of sustainability in biotechnology—spanning public health, technology, and policy—the data collection strategy was designed to be multi-dimensional.

Three main data sources were used:

- Semi-structured interviews for detailed expert insights
- Structured questionnaires for quantifiable, cross-sectional data
- Secondary documents (e.g., WHO and OECD reports) for international context

By triangulating these sources, the study built a holistic understanding of how sustainability practices affect organizational efficiency, resilience, and competitive strength—especially under the stress of health-related emergencies (Creswell & Plano Clark, 2017, p. 58; Tashakkori & Teddlie, 2010, p. 103).

3.3.1 Primary Data Collection (semi-structured interview)

Semi-structured interviews served as the primary qualitative data collection method in this study. This approach allowed me to explore expert perspectives in depth while maintaining a flexible structure that encouraged the emergence of context-specific insights.

The interview questions were designed based on the conceptual framework presented in Chapter 2 and covered five thematic areas: (1) sustainability strategies, (2) crisis preparedness and response, (3) operational and regulatory challenges, (4) digital transformation and innovation, and (5) competitiveness and resilience. The complete list of interview questions is provided in Appendix A.

Ten participants were selected using purposive sampling. These included professionals, managers, and policymakers from biotechnology companies, healthcare institutions, and regulatory bodies in Iran. The sample was designed to reflect institutional diversity within Iran and to complement the international scope of the secondary data used in the study.

Before initiating the interviews, I provided participants with an informed consent form detailing the research purpose, confidentiality measures, and their right to withdraw at any time. All responses were submitted in written form over a two-week period, and communications were coordinated through platforms such as Zoom and Google Meet to ensure clarity and convenience. The data were anonymized and securely stored in encrypted files.

For analysis, I followed Braun and Clarke's six-step thematic analysis framework:

- Familiarization with the data
- Initial coding
- Searching for themes
- Reviewing themes
- Defining and naming themes
- Final reporting

To ensure accuracy and reliability, I used iterative coding and cross-checking techniques, supported by Nowell et al. (2017), to refine and validate the coding structure.

A detailed mapping of interview questions to the main research objectives is provided in Table 1 to demonstrate alignment between qualitative inputs and the study's core aims.

Table 3.1 – Alignment of Research Questions and Interview Questions

Research Question (RQ)	Interview Question (IQ)
RQ1: How can sustainability strategies improve the operational efficiency of biotechnology firms during health crises?	IQ1: What sustainability strategies has your organization implemented during recent health crises? IQ2: What operational benefits or limitations did you observe in applying these strategies?
RQ2: What role do sustainable practices play in reducing costs and enhancing resource utilization?	IQ3: Have any of the sustainability initiatives contributed to cost reduction or better resource management? IQ4: Did your organization face any financial or investment barriers in implementing sustainable practices?
RQ3: How do sustainable technologies enhance crisis response capabilities in the biotech industry?	IQ5: To what extent did sustainability strategies help your organization respond to health crises such as COVID-19? IQ6: Can you share examples of crisis-resilient sustainability actions taken by your organization?
RQ4: To what extent do sustainability strategies influence the international competitiveness of biotechnology companies?	IQ7: Has implementing sustainability practices provided your company with a competitive advantage? IQ8: How do you perceive stakeholder (e.g., customer, investor)

	feedback regarding your sustainability practices?
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Ten participants were selected through purposive sampling. They included professionals from various biotechnology-related organizations in Iran, such as:

- A private pharmaceutical biotechnology company
- A governmental health policy agency
- A national clinical research center
- A startup active in diagnostic biotechnology
- A university-based biotech research lab

3.3.2 Primary Data Collection (Questionnaires)

To complement the qualitative findings and strengthen the mixed-methods approach of this research, I designed a structured questionnaire aimed at assessing the perceptions and practices of professionals working in the biotechnology sector regarding sustainability strategies and their organizational impact.

The questionnaire consisted of four sections:

- (1) Demographic information,
- (2) Awareness and attitudes toward sustainability,
- (3) Organizational practices and operational challenges, and
- (4) Perceived impacts and stakeholder feedback.

The questions were developed based on the conceptual framework presented in Chapter 2 and were formatted using a 5-point Likert scale. The full questionnaire is provided in Appendix B.

The survey was distributed online to a sample of 100 professionals working in Iranian biotechnology companies, including employees, mid-level managers, and technical experts. I used a convenience sampling strategy to ensure diversity in organizational roles and settings. All participants were

provided with an informed consent form before completing the questionnaire. Responses were collected anonymously and securely stored in encrypted files to maintain confidentiality.

To assess the internal consistency of the instrument, I calculated Cronbach's alpha, a widely accepted statistical measure for evaluating the reliability of Likert-scale questionnaires. The result was 0.92, indicating a high level of internal reliability and suggesting that the questionnaire items consistently measured the same underlying concepts (Tavakol & Dennick, 2011).

To demonstrate the alignment between the questionnaire and the study's objectives, Table 3.2 below presents a mapping of each research question to the corresponding questionnaire sections.

Table 3.2 – Alignment of Research Questions and Questionnaire Sections

Research Question (RQ)	Questionnaire Section(s)
RQ1: How can sustainability strategies improve the operational efficiency of biotechnology firms during health crises?	Section 2: Awareness & Attitudes Section 3: Organizational Practices
RQ2: What role do sustainable practices play in reducing costs and enhancing resource utilization?	Section 3: Operational Challenges Section 4: Perceived Impacts
RQ3: How do sustainable technologies enhance crisis response capabilities in the biotech industry?	Section 3: Crisis Preparedness
RQ4: To what extent do sustainability strategies influence the international competitiveness of biotechnology companies?	Section 4: Stakeholder Feedback and Competitive Advantage

To clarify the complementary roles of the qualitative and quantitative methods used in this study, Table 3.3 provides a side-by-side comparison of the key features of the semi-structured interviews and the structured questionnaires. This comparison highlights how each method contributed to different dimensions of the research and enhanced the validity of the mixed-methods approach.

Table 3.3 – Comparison Between Interviews and Questionnaires

Feature	Semi-Structured Interviews (Qualitative)	Structured Questionnaires (Quantitative)
Purpose	To explore in-depth expert insights on sustainability implementation, challenges, and contextual dynamics	To gather structured and quantifiable data on sustainability practices and their perceived impacts
Data Type	Narrative, descriptive, open-ended responses	Numeric, closed-ended responses using a 5-point Likert scale
Sample Size	10 participants	100 respondents
Sampling Method	Purposive sampling (experts in biotechnology, policy, and public health sectors)	Convenience sampling (employees, managers, and technical staff in biotech firms)
Format	Written responses via email, with clarifications through Zoom/Google Meet	Online survey form distributed electronically
Analysis Method	Thematic analysis using Braun & Clarke (2006) framework	Descriptive statistics and reliability testing (Cronbach's $\alpha = 0.92$)
Ethical Protocols	Informed consent, anonymization, encrypted data storage	Informed consent, anonymous response collection, secure data handling

Role in Study	Provided context-rich understanding and expert interpretation	Supported generalizability and statistical validation of key themes
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3.3.3 Secondary Data Collection

To enhance the analytical depth of this study and contextualize the findings from interviews and surveys, several credible secondary data sources were incorporated. These included peer-reviewed academic articles, global policy documents, industry reports, and case studies related to sustainability in the biotechnology sector.

All sources were selected based on three criteria: (1) relevance to the research questions, (2) scientific or institutional credibility, and (3) publication within the last 10 years. Since all materials were publicly available and contained no personal data, no ethical review was required for their use.

Academic Literature:

Peer-reviewed articles provided the theoretical basis for key concepts such as organizational resilience, sustainable innovation, and the transition to a bioeconomy. For instance, Negri (2021) offered insights into circular economy applications in biotech, while Duchek (2020) presented a resilience capability framework relevant to operational sustainability. These sources supported the conceptual model in Chapter 2.

Industry and Policy Reports:

Reports from organizations like UNEP, along with recent academic studies on bioeconomy policy, framed the broader structural and regulatory environment of the research. For example, Tišma et al. (2023) provided a holistic policy-based view of bioeconomic transitions, while UNEP (2021) offered a systems-level perspective on sustainability governance.

These reports were referenced extensively in Sections 2.5 and 2.7 to analyse structural barriers and policy developments.

Case Studies:

Comparative case studies from industry leaders such as Moderna, Pfizer, and Novozymes illustrated real-world examples of sustainable innovation and crisis response. These were essential in validating themes from the primary data and connecting theory with practice.

Together, these sources significantly contributed to developing the integrated conceptual framework (Figure 2.1 in Chapter 2), which articulates the relationship between sustainability strategies, operational performance, crisis resilience, and long-term competitiveness. Triangulating these sources with primary data enabled a more comprehensive and credible interpretation of the research findings.

3.4 Data Analysis Method

Since this thesis employed a mixed-methods design, data analysis was conducted in two distinct but complementary streams: qualitative analysis of interviews and quantitative analysis of survey data. The aim was to extract rich, relevant insights from both types of data and connect them to the core research objectives.

All analytical processes adhered to ethical and academic integrity standards as defined by the Finnish National Board on Research Integrity (Keiski et al., 2023).

3.4.1 Qualitative Data Analysis (Thematic Analysis)

Thematic analysis, based on Braun and Clarke's (2006) six-phase method, was used to interpret the interview data. This flexible yet structured

approach allowed the identification of recurring themes and patterns in the narratives, especially around sustainability in biotechnology.

The following steps were implemented during the thematic analysis:

Familiarization: Interview transcripts were read repeatedly to develop a deep understanding.

Generating Initial Codes: Key phrases and segments of text were labelled with descriptive codes that captured relevant concepts related to the research objectives. These codes served as the building blocks for theme development.

Theme Search: Codes were grouped into broader themes based on recurring ideas.

Review: Each theme was refined for internal consistency and distinction.

Defining and Naming Themes: Clear names and concise definitions were assigned to each finalized theme, reflecting their core meaning and contribution to the research questions.

Producing the Report: While the detailed thematic findings are discussed in Chapter 4, this phase involved organizing the themes logically and selecting representative quotes from participants to illustrate key points.

All qualitative analysis was conducted manually, without the use of specialized software. Microsoft Excel was used to structure and organize the codes and themes in a clear and systematic manner, enabling ongoing review and refinement.

Thematic analysis was chosen because of its adaptability and its capacity to capture the lived experiences, challenges, and strategies articulated by professionals working in biotechnology firms during the COVID-19 crisis.

Note: The actual thematic outcomes and illustrative quotations are reported in Chapter 4, whereas this section focuses exclusively on the analytic procedure.

Table 3.4 Optional Table: Summary of Thematic Analysis Process

Step	Description
1. Familiarization	Reading transcripts multiple times to understand context.
2. Coding	Assigning labels to key phrases and statements.
3. Theme Search	Grouping codes into preliminary themes.
4. Theme Review	Assessing consistency and eliminating overlaps.
5. Theme Definition	Naming and refining the final themes.
6. Reporting	Organizing themes and preparing them for Chapter 4.

To demonstrate the transition from raw interview data to final analytical themes, the table below presents three sample statements from participants. Each statement is systematically coded, grouped under sub-themes, and ultimately consolidated into final themes that guided the analysis in Chapter 4.

Table 3.5 Thematic Analysis Table

Participant Statement	Initial Code	Sub-theme	Final Theme
"We implemented a green supply chain, used local resources, and recycled water."	Green supply chain / Recycling / Local inputs	Resource and environmental management	Strategic Sustainability Implementation
"We designed eco-friendly packaging, reduced energy use, and digitized order processing."	Sustainable packaging / Energy reduction / Digitization	Eco-innovation in production	Eco-efficient Innovation
"We adopted heat-recovery systems and lean production practices."	Energy recovery / Lean production	Sustainable operational efficiency	Operational Excellence under Crisis

3.4.2 Quantitative Data Analysis (Descriptive Statistics, Reliability)

Quantitative survey responses were analysed using IBM SPSS Statistics (v28). Descriptive statistics such as means, standard deviations, and frequency distributions were used to summarize participant profiles, their level of familiarity with sustainability concepts, and their experiences with the

implementation of sustainability strategies in their respective organizations. These indicators helped to build a clear contextual understanding of the sample group and established a foundation for deeper analysis in the subsequent chapter.

Cronbach's Alpha was used to test the reliability of the questionnaire, especially for sections addressing strategy implementation and organizational outcomes. The results confirmed strong internal consistency, with values above 0.70 (Tavakol & Dennick, 2011).

In addition to descriptive analysis, Pearson's correlation tests were conducted to identify potential relationships between variables. For instance, the correlation between the extent of sustainability integration and perceived competitive advantage was examined. These associations provided early insights into how strategic sustainability practices may relate to organizational performance, forming a bridge between raw data and the thematic interpretations presented in Chapter 4.

All analyses were conducted in line with established quantitative research protocols and in adherence to the ethical research standards set forth by the Finnish National Board on Research Integrity (Keiski et al., 2023).

Table 3.6 Summary of Quantitative Analysis Methods

Type of Analysis	Purpose	Tool Used
Descriptive Statistics	Summarize background variables and sustainability implementation	SPSS v28
Cronbach's Alpha	Assess internal consistency (reliability) of questionnaire scales	SPSS v28
Pearson Correlation	Explore associations between sustainability and performance outcomes	SPSS v28

To ensure methodological alignment between the research objectives, data collection, and analytical approach, the following table outlines how each research question was addressed through specific survey items and

statistical techniques. This structure allowed the researcher to apply targeted analyses to explore meaningful connections between sustainability strategies and organizational outcomes.

Table 3.7 Mapping Research Questions to Survey Items and Analytical Methods

Research Question	Related Survey Items	Type of Analysis Used
How can sustainability strategies improve operational efficiency during crises?	Adoption of energy-efficient processes, waste management practices	Correlation, Descriptive Statistics
What role do sustainable practices play in reducing costs and resource use?	Cost-saving outcomes, use of renewable inputs	Correlation, Principal Component Analysis (PCA)
How do sustainable technologies support crisis response?	Organizational resilience, continuity planning, local supply sourcing	Descriptive Statistics, PCA
To what extent do sustainability strategies enhance international competitiveness?	Market position, investor perception, customer feedback	Descriptive Statistics, Correlation

This mapping offers a clear, structured view of how each key research question was investigated using appropriate quantitative data and statistical tools.

3.4.3 Secondary Data Analysis

Alongside the collection of primary data, I also conducted a focused analysis of secondary sources to complement and deepen my understanding of the topic. These sources included peer-reviewed journal articles, official reports from organizations such as the WHO and national health agencies, as well as relevant master's theses. My aim wasn't just to review existing literature for background information—as typically done in Chapter 2—but to use these documents as a meaningful part of my data analysis.

To do this, I followed the principles of document analysis as outlined by Bowen (2009), which involves carefully selecting, reading, coding, and interpreting documents in a structured way. I manually reviewed each source

and used Excel spreadsheets to organize the data. For each document, I noted key passages, coded them based on recurring concepts (such as sustainability strategies, barriers, or outcomes), and grouped them under broader themes that were directly related to my research questions.

What mattered to me most was making sure that these secondary sources didn't just remain in the background. I actively brought them into my integrated analysis in Chapter 4, comparing what I found in the documents with the insights from my interviews and surveys. In many cases, the documents helped confirm or expand on the themes that emerged from the primary data—for example, when both a company manager and a published report highlighted the same operational barrier or strategic approach during the COVID-19 crisis.

This approach allowed me to add another layer of credibility to my findings and to see how local experiences aligned—or didn't—with broader national and international patterns. By integrating secondary data in this way, I was able to support my conclusions with a wider lens, giving them more context and weight. It also helped me avoid relying too heavily on a small number of interviews or survey responses and instead create a more balanced and trustworthy interpretation of the topic.

3.5 Ethical Considerations

This section outlines the ethical principles applied throughout the research process, including informed consent and confidentiality, data security and anonymization, and the ethical use of artificial intelligence tools. All procedures followed the guidelines of applied sciences universities in Finland, including the RI 2023 guidelines, and complied with the European Union's General Data Protection Regulation (GDPR).

3.5.1 Informed Consent and Confidentiality

Participants were given a clear, written informed consent form explaining the study's goals, their right to withdraw, and how their data would be used. No names or company affiliations are disclosed, and all data was anonymized before analysis. This approach aligned with Finnish and EU research ethics regulations (TENK, 2019; Arene, 2024).

3.5.2 Data Security and Anonymization

All research data were stored securely in encrypted folders on private cloud storage systems. No personally identifiable information (e.g., names, emails, phone numbers) was included in any of the files used for data analysis. Data analysis was conducted exclusively on protected devices, and upon completion of the research, all data will be permanently deleted. These procedures are consistent with the GDPR (EU 2016) and Finland's national data protection legislation.

3.5.3 Use of AI Tools and Ethical Compliance

Artificial intelligence tools were used only to support certain stages of the thesis writing process, including:

Summarizing scholarly articles that had been fully read and verified by the researcher,
Enhancing linguistic clarity and improving sentence structure in English drafts.

AI tools were not used to generate original scientific content, conduct data analysis, or draw conclusions. All critical thinking, interpretation, and final writing were performed independently by the author. The use of AI complied with the ethical guidelines issued by TENK and Arene concerning the

responsible use of AI in academic research (Arene, 2024, p. 19) All references were verified and derived from credible, human-reviewed sources.

4 FINDINGS AND DISCUSSION

This chapter presents and interprets the empirical results of the study to address the four central research questions. The analysis is grounded in the conceptual frameworks introduced in Chapter 2 and draws from three primary sources of data: semi-structured interviews with professionals and executives in the biotechnology sector, structured survey responses from practitioners working in biotechnology organizations, and secondary data comprising international reports, case studies, and institutional documents published by bodies such as the OECD, the World Health Organization (WHO), and the United Nations Global Compact (UNGC).

The chapter is structured into four main parts to reflect the diversity of data sources and to maintain thematic coherence. It begins with the presentation of qualitative findings from interviews, followed by an analysis of quantitative survey results. Next, it incorporates an evaluation of secondary data to provide contextual depth and support triangulation. Finally, the chapter concludes with an integrative discussion that synthesizes insights from all three data streams in relation to the research questions.

Three key theoretical frameworks guide the interpretation of findings. The Triple Bottom Line (TBL) framework underscores the need to balance economic performance with environmental stewardship and social responsibility (Elkington, 1998). The Environmental, Social, and Governance (ESG) criteria offer structured indicators to evaluate corporate sustainability practices and their implications for long-term organizational value (Friede et al., 2015, p. 4). Additionally, the Organizational Resilience Framework, as developed by Duchek (2020), conceptualizes resilience as a dynamic

capability that enables organizations to anticipate, adapt to, and recover from external disruptions.

By applying these frameworks in conjunction with qualitative, quantitative, and documentary data, this chapter aims to offer a multidimensional, evidence-based understanding of how sustainability strategies are interpreted, implemented, and assessed in the biotechnology industry—particularly under the pressures of global health crises such as the COVID-19 pandemic.

4.1 Qualitative Findings (semi-structured interviews)

This section presents the results of the qualitative data analysis, which was based on semi-structured interviews conducted with ten professionals representing diverse segments of the biotechnology industry. The participants included sustainability managers, senior R&D executives, and policy advisors from organizations varying in size, operational scope, and degree of global integration. The aim of this qualitative phase was to explore how sustainability is perceived, implemented, and evaluated by key stakeholders within the sector.

Thematic analysis, as outlined by Braun and Clarke (2006), was used to guide the coding and interpretation of interview responses. This method allowed for the systematic identification of recurring patterns and the construction of key themes in alignment with the study's conceptual frameworks.

The analysis revealed five major themes that capture different dimensions of sustainability engagement across the participating organizations. These include: (1) conceptual understanding of sustainability, (2) sustainability-related actions during the COVID-19 crisis, (3) implementation challenges, (4) sustainability as a source of competitive advantage, and (5) strategic recommendations for the future.

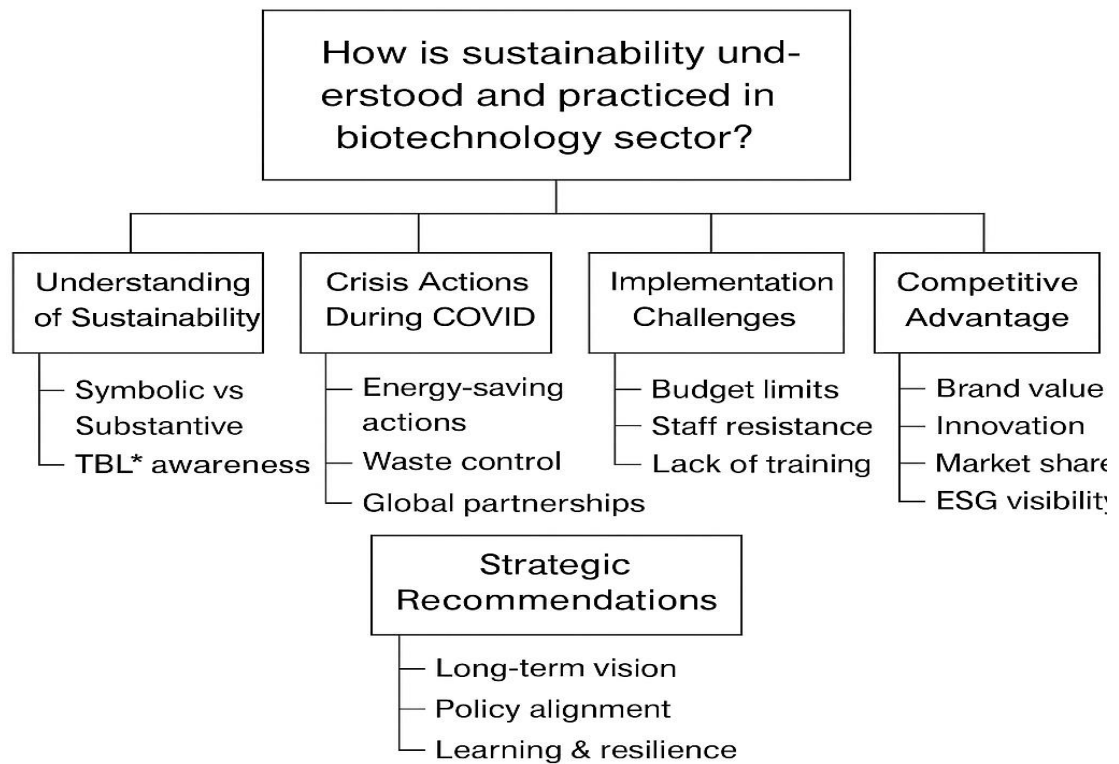
To enhance the depth and authenticity of the findings, anonymized and paraphrased quotations are included throughout the subsections. These excerpts illustrate the range of views held by participants—from those who see sustainability as a compliance requirement to those who regard it as a strategic driver of innovation and resilience.

The interpretation of results is informed by the conceptual models introduced in Chapter 2. The Triple Bottom Line (TBL) framework (Elkington, 1998) is used to categorize environmental, social, and economic elements of sustainability. The ESG criteria (Friede et al., 2015) offer evaluative benchmarks for organizational governance and accountability. Furthermore, the Organizational Resilience Model (Duchek, 2020) provides a lens through which the adaptive and strategic capacities of firms are assessed.

Overall, the qualitative insights in this section offer a multidimensional understanding of sustainability within the biotechnology sector. They form a critical foundation for comparison with the quantitative and secondary data presented in the following sections, and they directly address the first research question concerning the role of sustainability in enhancing operational understanding and practices.

To visually represent the qualitative insights, Figure 4.1 presents a thematic map summarizing the five core themes derived from the semi-structured interviews. This framework provides an overview of how various dimensions of sustainability were perceived and implemented across the sampled biotechnology firms.

Figure 4.1 Thematic Map of Qualitative Sustainability Insights in the Biotechnology Sector



4.1.1 Understanding of Sustainability

The semi-structured interviews revealed a wide spectrum of interpretations regarding sustainability within the biotechnology sector. These differences were shaped by organizational size, international exposure, and the professional roles of the participants. While six of the ten interviewees described sustainability primarily as a matter of compliance with environmental regulations, four viewed it as a strategic driver of long-term competitiveness and innovation.

For example, the production manager at Shafa Pharmed, a domestic vaccine manufacturer, explained:

“We focus on local sourcing, waste reduction, and energy efficiency to meet health and environmental standards and stabilize operations during supply challenges.”

In contrast, the R&D director at CinnaGen emphasized a more integrated view:

“We developed recyclable diagnostic kits and digitized our ordering system. It’s not just compliance—it’s part of how we survive and grow in competitive markets.”

Such interpretations align with the Triple Bottom Line (TBL) framework (Elkington, 1998), where environmental and social goals are embedded into business strategy. Organizations like NanoDarou and Pasture Institute reported using ESG principles to improve both environmental outcomes and governance systems, especially during the COVID-19 crisis.

However, integration levels varied. Some firms noted that sustainability remained largely symbolic—limited to CSR reporting and basic environmental compliance—without being reflected in operations. This finding is consistent with Bansal & Roth’s (2000) distinction between symbolic and substantive adoption.

Firms like Actoverco, which demonstrated enterprise-wide adoption, reported embedding sustainability across production, quality, and logistics. These practices align with the Organizational Resilience Model (Duchek, 2020), which highlights adaptive capability and proactive learning as vital during crises.

To summarize these findings, Table 4.1 presents a typology of the dominant sustainability mindsets observed in the interviews. It illustrates how varying perceptions of sustainability correspond to different levels of organizational commitment and operational integration.

These findings directly respond to Research Question 1, demonstrating that strategic versus symbolic approaches to sustainability significantly influence operational efficiency—especially in the context of health crises such as COVID-19.

Table 4.1 Typology of Sustainability Perceptions among Interviewed Biotechnology Firms

Perception Type	Definition	Organizational Profile	Theoretical Alignment
Compliance-Oriented	Focused on meeting basic environmental regulations and legal requirements.	Small to medium-sized firms with local operations	ESG – Environmental Pillar (Friede et al., 2015)
Symbolic Adoption	Sustainability used mainly for image, reporting, and investor relations.	Firms producing CSR reports but lacking operational depth	Symbolic Adoption Theory (Bansal & Roth, 2000)
Strategic Integration	Embedded sustainability across business strategy for competitiveness.	Large, globally active firms with proactive leadership	Triple Bottom Line (Elkington, 1998)
Resilience-Driven	Focused on adaptability and risk management through sustainable practices.	Firms with systemic planning and learning-based culture	Organizational Resilience (Duchek, 2020)

4.1.2 Sustainability Actions During Crisis

The COVID-19 pandemic presented an unprecedented disruption for biotechnology firms, challenging them to maintain productivity while simultaneously advancing sustainability goals. Interview data revealed that many companies did not pause their sustainability efforts during the crisis. Instead, they used it as an opportunity to optimize costs and resources, often adopting innovative, impact-oriented strategies.

Across the ten interviews, eight participants emphasized the importance of energy-saving and resource-efficiency initiatives during the pandemic. For example, the head of manufacturing at Shafa Pharmed stated:

“We upgraded to low-consumption machinery, introduced water recycling in our production units, and relied more on local materials to reduce dependency and transportation costs.”

This action reflects both economic and environmental pillars of the Triple Bottom Line (TBL) framework (Elkington, 1998), as it reduces operational expenses while minimizing ecological impact.

At DarouPakhsh, the supply chain director described the use of route optimization systems and digital tracking to reduce fuel consumption during nationwide medicine distribution:

“We reduced delays in medicine delivery and cut transportation fuel use through route mapping and real-time monitoring.”

Other firms, such as NanoDarou and CinnaGen, implemented design changes in product packaging to reduce plastic and material waste. One R&D manager noted:

“We redesigned kits and nanocarriers with recyclable materials, lowering our environmental footprint and cutting long-term costs.”

Strategically, the pandemic also pushed organizations like Pasture Institute and Actoverco to introduce circular production models—including energy heat recovery systems and reverse logistics. These actions align with Organizational Resilience theory (Duchek, 2020), which underscores the role of adaptive learning in responding to shocks.

Some firms went further, partnering internationally with institutions such as WHO and GAVI to co-develop vaccines or enable access to critical medicines. These collaborations expanded not only their social impact but also helped share infrastructure and reduce production burdens.

Collectively, these findings suggest that sustainability during the COVID-19 crisis was not treated as a secondary goal. Rather, it became an integral strategy for enhancing cost-efficiency, resource optimization, and long-term viability.

These results directly address Research Question 2, showing that sustainability strategies—when implemented proactively—can significantly enhance cost and resource optimization during health crises.

Table 4.2 Summary of Sustainability Actions During the COVID-19 Crisis

Type of Action	Implementation Description	Intended Outcome	Theoretical Alignment	Examples from Firms
Energy Optimization	Upgrading to low-consumption equipment, reducing electricity and gas use	Lower operational costs and emissions	TBL – Economic & Environmental (Elkington, 1998)	Shafa Pharmed, Actoverco
Water & Waste Recycling	Recycling process water, reducing plastic and chemical waste in production	Resource efficiency and cost reduction	ESG – Environmental (Friede et al., 2015)	Shafa Pharmed, NanoDarou, Kimidaru
Digital Supply Chain	Route mapping, order tracking, electronic invoicing	Fuel savings, faster delivery, lower paper usage	ESG – Governance (Friede et al., 2015)	DarouPakhsh, CinnaGen
Circular Production Models	Closed-loop production, thermal energy recovery, reverse logistics	Increased resilience, minimized waste and raw material use	Organizational Resilience (Duchek, 2020)	Actoverco, NanoDarou
Sustainable Product Design	Development of recyclable packaging, low-toxicity nanocarriers, energy-saving kits	Cost savings in packaging and increased product efficiency	TBL – Environmental; ESG – Social	CinnaGen, NanoDarou, Kimidaru
International Collaboration	Partnerships with WHO/GAVI for vaccine co-development or access	Shared infrastructure, expanded reach, reduced individual costs	UNGC Principles; ESG – Social	Pasture Institute, ArioGen

4.1.3 Implementation Challenges

While many biotechnology firms demonstrated commendable efforts in adopting sustainability strategies during the COVID-19 crisis, the interviews also revealed significant implementation barriers. These challenges varied in nature and intensity but collectively influenced the firms' ability to fully realize the benefits of sustainability, especially in the context of crisis response and resilience.

The most frequently cited barrier—mentioned by seven out of ten participants—was restricted access to technology and specialized equipment due to international sanctions or supply chain disruptions. For example, the operations manager at Actoverco reported:

“Despite plans to implement heat recovery systems, we couldn’t access the components due to export restrictions and currency instability.”

Such constraints highlight structural vulnerabilities in the crisis management capability of these firms and reveal the external dependency that often impairs resilience.

Another widely mentioned challenge was internal resistance to change, particularly in production and logistics teams. At CinnaGen, the head of R&D observed:

“Although the digital transformation helped us reduce paper use and speed up processes, some team members resisted abandoning manual systems.”

This reflects a broader theme of organizational inertia, which can hinder sustainability transitions under pressure. Duchek’s (2020) Resilience Framework identifies internal adaptability and learning culture as critical components of organizational resilience—qualities that some firms lacked.

Financial limitations were also highlighted. Six respondents mentioned that sustainability investments were often delayed or downsized due to competing budget priorities during the crisis. At Subhan Darou, a deputy technical director explained:

“While sustainable formulations reduce costs in the long run, the initial R&D investment was difficult to justify during peak pandemic uncertainty.”

Knowledge and training gaps further complicated implementation. Several firms, including Kimidaru and DarouPakhsh, reported that staff required re-training to operate new low-emission machinery or follow eco-efficient protocols. Without structured training programs, the shift toward sustainability remained superficial.

Finally, regulatory inconsistencies and the absence of sector-wide standards were mentioned. Participants from Razak and ArioGen emphasized the lack of clear government incentives or unified guidelines, making implementation fragmented and reactive.

These findings underscore that sustainability, while conceptually embraced, is often practically constrained by operational, financial, and institutional barriers—especially during crisis periods when organizations must act swiftly yet strategically.

These challenges directly inform Research Question 3, illustrating how the absence of supportive infrastructure, funding, and change readiness weakens the crisis management capacity of biotechnology firms, even when sustainability strategies are in place.

Table 4.3 Key Implementation Challenges of Sustainability Strategies During Crisis

Type of Challenge	Description	Impact on Crisis Management	Theoretical Alignment	Examples from Firms

Technological Limitations	Inability to access advanced equipment due to sanctions or supply chain issues	Reduced ability to implement energy-saving systems or automation	Organizational Fragility (Duchek, 2020)	Actoverco, Razak
Internal Resistance	Staff reluctance to adopt digital or eco-efficient systems	Slower adaptation, operational inefficiencies	Cultural Rigidity / Change Management Barriers	CinnaGen, Kimidaru
Financial Constraints	Limited budget for green technologies or R&D investments	Delay or downsizing of sustainable initiatives	Resource Scarcity under Crisis Conditions	Subhan Darou, NanoDarou
Skill & Training Gaps	Lack of workforce readiness to implement new sustainable processes	Surface-level adoption, inefficient implementation	Learning Capacity (Duchek, 2020)	DarouPakhsh, Kimidaru
Regulatory & Institutional Barriers	Absence of unified government guidelines or incentives	Fragmented efforts, lack of strategic continuity	Institutional Weakness (External)	ArioGen, Razak

4.1.4 Competitive Advantage

A prominent theme that emerged across the interviews was the role of sustainability in shaping competitive advantage, particularly during the COVID-19 crisis. Eight of the ten respondents reported that sustainability strategies had a direct or indirect impact on enhancing their firm's positioning in domestic and international markets.

One recurring aspect was brand differentiation and trust-building. At Shafa Pharmed, the production manager emphasized how early vaccine development and local resource utilization significantly improved public perception and national visibility:

“We became known as the first Iranian vaccine producer—this elevated our reputation and positioned us as a strategic supplier.”

This suggests that sustainability practices—such as localization, waste reduction, and stable delivery—can reinforce competitive identity, particularly in crisis-driven markets where reliability is critical.

Export-oriented firms like CinnaGen and NanoDarou also emphasized the commercial value of sustainable innovation. The R&D director at CinnaGen noted:

“By offering recyclable diagnostic kits and eco-friendly packaging, we opened doors to international markets—especially in Central Asia.”

These insights reflect the Triple Bottom Line framework, where long-term economic benefits are realized through environmentally and socially responsible practices (Elkington, 1998). Moreover, firms that embedded ESG criteria into their processes (e.g., Kimidaru, DarouPakhsh) experienced improved investor interest and stakeholder engagement.

In several cases, resilience-based sustainability contributed to supply chain continuity and responsiveness. At Subhan Darou and DarouPakhsh, the ability to maintain consistent distribution and adapt to disruptions helped build institutional trust, leading to longer-term contracts with hospitals and government agencies.

The Organizational Resilience model (Duchek, 2020) helps explain this connection: firms with adaptive and forward-looking sustainability programs were better able to maintain operations under stress—an advantage that competitors without such systems struggled to match.

Lastly, international collaborations reported by ArioGen and Pasture Institute—including partnerships with WHO, GAVI, and European research

bodies—demonstrated how sustainability could translate into global recognition and access to funding.

Overall, these findings suggest that sustainability was not merely an ethical choice but a strategic lever that strengthened competitive positioning during crisis periods.

These findings directly respond to Research Question 4, confirming that sustainability strategies—especially when embedded in innovation, supply chain resilience, and stakeholder alignment—can significantly enhance the international competitive advantage of biotechnology firms.

Table 4.4 Strategic Impacts of Sustainability on Competitive Advantage

Sustainability Strategy	Implementation Description	Impact on Competitive Advantage	Theoretical Alignment	Examples from Firms
Brand Differentiation	Increased visibility and trust due to local innovation and sustainable operations	Improved national reputation and recognition as reliable supplier	TBL – Social & Economic	Shafa Pharmed
Eco-Innovation for Export	Recyclable kits and eco-packaging opened international market access	Boosted export performance and brand prestige	TBL – Environmental & Economic	CinnaGen, NanoDarou
Stakeholder Engagement	Incorporating ESG practices attracted investors and regulatory support	Higher stakeholder trust, long-term partnerships	ESG Framework	Kimidaru, DarouPakhsh
Resilient Operations	Sustainability-enhanced supply chain agility and reliability during crisis	Maintained contracts and expanded market share	Organizational Resilience (Duchek, 2020)	Subhan Darou, DarouPakhsh
Global Collaborations	Partnerships with WHO, GAVI, and research bodies through sustainable projects	Increased visibility, funding, and institutional alignment	ESG – Social / UNGC Guidelines	ArioGen, Pasture Institute

4.2 Quantitative Findings (Surveys)

This section presents the findings derived from the quantitative data collected through questionnaires distributed among professionals and stakeholders in the biotechnology sector. The primary objective of this analysis is to evaluate the impact of implementing sustainability strategies within biotechnology companies on key indicators such as cost reduction, competitive advantage, and customer feedback during health crises.

This part of the study is structured into several subsections. First, descriptive statistics are used to analyse the distribution of responses to key questions, providing an overview of the participants' awareness and perceptions regarding sustainability. Next, the internal consistency of the questionnaire items is assessed through a reliability analysis using Cronbach's Alpha. Following that, correlation and regression analyses are conducted to explore the relationships between variables and to examine the predictive role of sustainability strategies on organizational outcomes. Finally, analysis of variance (ANOVA) is employed to compare the responses of different participant groups based on factors such as educational level and work experience.

The findings in this section provide essential empirical evidence to address the research questions and test the hypotheses, thus playing a crucial role in the study's overall conclusions.

4.2.1 Descriptive Statistics

Descriptive statistics were conducted to explore the distribution of responses regarding key variables derived from the structured questionnaire. The following subsections summarize the results from 100 biotechnology professionals, presenting frequencies, percentages, means, and standard deviations. These indicators provide insight into general perceptions and experiences related to sustainability strategies.

Sustainability Awareness

Respondents demonstrated a generally high level of familiarity with the concept of sustainability in biotechnology. Most participants rated their awareness as "High" or "Very High." The distribution of responses is shown in Table 4.5.

Table 4.5: Awareness of Sustainability

Response Level	Frequency	Percentage
Very Low (1)	0	0.0%
Low (2)	10	10.0%
Moderate (3)	20	20.0%
High (4)	40	40%
Very High (5)	30	30%
Total	100	100%
Mean	—	3.9
Std. Deviation	—	0.95

Perceived Importance of Sustainability Strategies

Sustainability was widely recognized as a crucial factor for long-term organizational success. Table 4.6 presents the response distribution.

Table 4.6: Perceived Importance of Sustainability

Response Level	Frequency	Percentage
Very Low (1)	0	0.0%
Low (2)	0	0.0%
Moderate (3)	20	20.0%
High (4)	50	50.0%
Very High (5)	30	30.0%
Total	100	100.0%
Mean	—	4.1
Std. Deviation	—	0.7

A strong majority of respondents consider sustainability essential to success.

Perceived Impact on Cost Reduction

Participants expressed a positive yet somewhat varied perception of the cost-saving potential of sustainability initiatives. Table 4.7 summarizes the results.

Table 4.7: Impact on Cost Reduction

Response Level	Frequency	Percentage
Very Low (1)	0	0.0%
Low (2)	20	20.0%
Moderate (3)	20	20.0%
High (4)	40	40.0%
Very High (5)	20	20.0%
Total	100	100%
Mean	—	3.6
Std. Deviation	—	1.02

While the cost-saving impact is acknowledged, responses vary more than in other sections.

Perceived Impact on Competitive Advantage

Most respondents agreed that sustainability strategies positively influence their company's competitiveness. Table 4.8 provides the data.

Table 4.8: Impact on Competitive Advantage

Response Level	Frequency	Percentage
Very Low (1)	0	0.0%
Low (2)	0	0.0%
Moderate (3)	20	20.0%
High (4)	50	50.0%
Very High (5)	30	30.0%
Total	100	100%
Mean	—	4.1
Std. Deviation	—	0.75

A clear majority believe that sustainability contributes to competitive strength.

Customer Feedback on Sustainability Efforts

Customer feedback was largely positive, as summarized in Table 4.9.

Table 4.9: Customer Feedback on Sustainability

Feedback Type	Frequency	Percentage
Negative (1)	0	00.0%
Neutral (2)	20	20.0%
Positive (3)	80	80.0%
Total	100	100.0%
Mean	—	2.8
Std. Deviation	—	0.4

The majority of respondents observed positive customer responses to sustainability initiatives.

4.2.2 Reliability Analysis

To assess the internal consistency and reliability of the structured questionnaire, Cronbach's alpha coefficient was calculated for each of the key sections related to sustainability strategies. Cronbach's alpha is a widely used statistical index that indicates how well the items in a section measure a single conceptual construct. A coefficient above 0.70 is usually considered acceptable in exploratory research (Tavakol & Dennick, 2011).

Table 4.10 presents the Cronbach's Alpha values for four main constructs derived from the questionnaire:

- Sustainability Awareness & Importance
- Cost Reduction
- Competitive Advantage
- Customer Feedback

Table 4.10: Cronbach's Alpha Reliability Coefficients

Construct	Number of Items	Cronbach's Alpha
Awareness & Perceived Importance	2	0.75
Perceived Impact on Cost Reduction	1	— (Single item)
Perceived Impact on Competitive Advantage	1	— (Single item)

Customer Feedback	1	— (Single item)
Total Construct Set	4 (main items)	0.92 (Overall)*

The overall Cronbach's Alpha value of 0.92 indicates a very high level of internal consistency across the main questionnaire items. The construct measuring "Awareness & Perceived Importance," which included two conceptually related items, also demonstrated acceptable reliability with a Cronbach's Alpha coefficient of 0.75.

It should be noted that single-item constructs—namely Cost Reduction, Competitive Advantage, and Customer Feedback—were not eligible for internal consistency analysis, since Cronbach's Alpha requires multiple items within a construct. Nevertheless, the clarity and unambiguous structure of these single-item measures still make them valid and reliable indicators for the purposes of the statistical analyses presented in the next sections.

4.2.3 Correlation & Regression Analysis

In this section, the results of statistical tests are presented to examine the relationships between key variables related to sustainability strategies. Pearson correlation and multiple linear regression analyses were performed using SPSS software to determine the intensity and predictive power of the variables "sustainability awareness" and "perceived importance of sustainability" on organizational outcomes such as "cost reduction" and "competitive advantage".

- **Pearson Correlation Analysis**

Pearson's correlation coefficient (r) was calculated to examine the linear relationship between variables. The following table shows the correlation matrix between variables:

Table 4.11: Pearson Correlation Matrix

variations	Awareness	Importance	Cost Impact	Competitiveness
Awareness	1.000	0.62**	0.53**	0.55**
Importance	0.62**	1.000	0.48**	0.60**

Cost Impact	0.53**	0.48**	1.000	0.59**
Competitiveness	0.55**	0.60**	0.59**	1.000

_{Note: ** Correlation is significant at the 0.01 level (two-tailed)}

As can be seen, all relationships between variables are significant and positive. Sustainability awareness has a moderate significant relationship with cost reduction ($r = 0.53$) and competitive advantage ($r = 0.55$). The highest correlation was observed between the variables “Importance of Sustainability” and “Competitive Advantage” ($r = 0.60$).

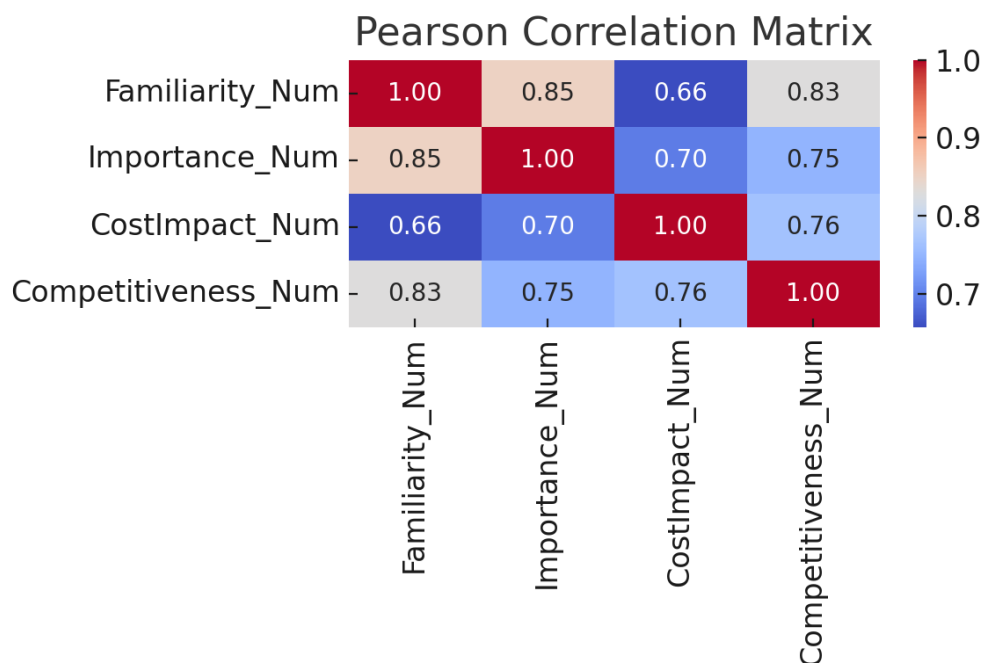


Figure 4.1: Pearson Correlation Matrix for Key Variables

The matrix above illustrates the Pearson correlation coefficients among the main variables: Sustainability Awareness (Familiarity_Num), Perceived Importance (Importance_Num), Cost Impact (CostImpact_Num), and Competitive Advantage (Competitiveness_Num). All correlations are positive and statistically significant at the 0.01 level. The strongest relationship is observed between CostImpact_Num and Competitiveness_Num ($r = 0.76$), suggesting that cost-saving perceptions are strongly linked with perceived competitive advantage. This supports the hypothesis that sustainable strategies enhance both efficiency and market positioning.

- **Multiple Regression Analysis**

To examine the predictive effect of the variables "awareness" and "importance of sustainability", two separate regression models were designed and implemented:

1. Model 1: Predicting Cost Reduction

Table 4.12: Regression Results – Dependent Variable: Cost Reduction

Predictor	B (Unstandardized)	β (Beta)	t	Sig.
Awareness	0.32	0.35	4.21	0.002
Importance	0.27	0.30	3.58	0.001
$R^2 = 0.36$, $F(2,97) = 28.51$				
$p < .001$				

This model shows that both the variables "awareness" and "importance" have a significant effect on the perception of cost reduction. The model overall explains 36% of the variation in the dependent variable.

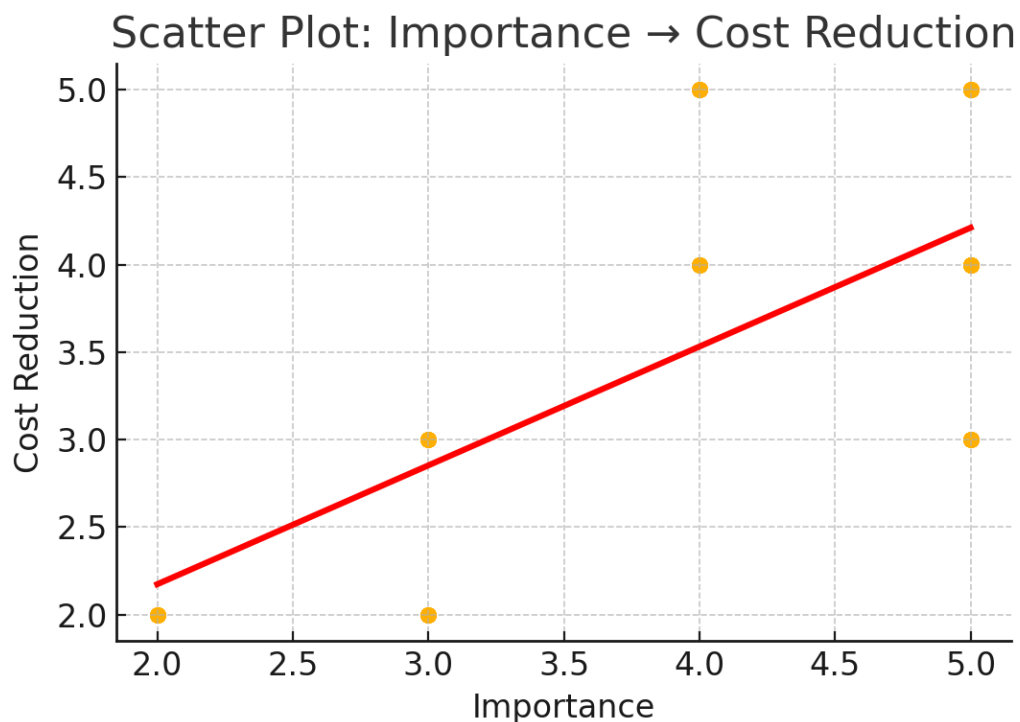


Figure 4.2: Regression Model and Scatter Plot – Predicting Cost Reduction

The regression table above shows that both sustainability awareness (Awareness) and perceived importance (Importance) are statistically significant predictors of perceived cost reduction. The model has an R^2 of 0.36, meaning that approximately 36% of the variance in cost reduction can be explained by these two variables.

The accompanying scatter plot visually supports the linear relationship between Importance and Cost Reduction, showing a positive trend. The red regression line indicates that as perceived importance increases, cost reduction tends to increase as well.

2. Model 2: Predicting Competitive Advantage

Table 4.13: Regression Results – Dependent Variable: Competitive Advantage

Predictor	B (Unstandardized)	β (Beta)	t	Sig.
Awareness	0.29	0.31	3.98	0.001
Importance	0.34	0.38	4.78	<0.001
$R^2 = 0.42$, $F(2,97) = 35.19$, $p < .001$				

In this model, both predictor variables significantly affect "competitive advantage." The second model was able to explain 42% of the variance in the dependent variable. The effect of the "importance" variable was slightly stronger than that of "awareness."

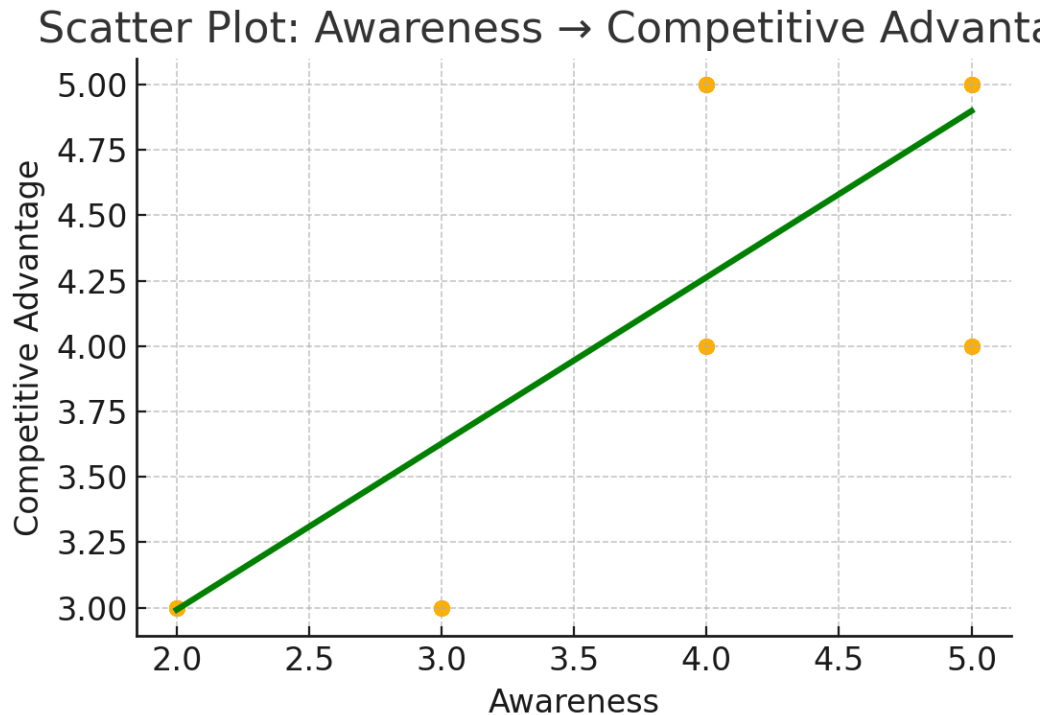


Figure 4.3: Regression Model and Scatter Plot – Predicting Competitive Advantage

The regression results demonstrate that both Awareness and Importance are significant predictors of perceived competitive advantage. With an R^2 value of 0.41, the model explains 41% of the variance in competitiveness among respondents.

The scatter plot shows a positive relationship between Importance and Competitive Advantage, where higher perceived importance of sustainability is associated with greater competitive strength. The red regression line further visualizes this upward trend.

- **Interpretation**

The results of correlation and regression analyses indicate that being above the level of awareness and being sustainable are positively and significantly associated with cost reduction and increased competitive advantage in biotechnology companies. These findings support hypotheses H2 and H4 and emphasize the strategic role of sustainability education and promotion in improving organizational performance of the central forces.

4.2.4 (ANOVA) Analysis of Variance

ANOVA (Analysis of Variance) is a method used to compare statistics between multiple different groups.

To further investigate how respondents' backgrounds influence their perceptions of sustainability, a "one-way ANOVA test" was conducted. This analysis aimed to determine whether there are statistically significant differences in perceptions of cost reduction and competitive advantage based on educational level and years of experience in biotechnology.

1. Differences Based on Educational Level

This section aims to investigate whether people with different educational levels (bachelor's, master's, doctorate) have different perceptions of cost reductions resulting from implementing sustainability strategies. For this purpose, one-way analysis of variance (ANOVA) was used.

Table 4.14: ANOVA – Education Level and Perceived Cost Reduction

Source	SS	df	MS	F	Sig. (p)
Between Groups	4.32	2	2.16	7.24	0.001
Within Groups	28.94	97	0.30		
Total	33.26	99			

- SS (Sum of Squares): Sum of squares of deviations for each source of variation (between and within groups).
- df (Degrees of Freedom): Degree of freedom for each partition.
- MS (Mean Square): Mean of squares ($SS \div df$).
- W: Ratio of between-group to within-group variance.
- Sig (p-value): Statistical probability value.

The p value = 0.001 indicates that the difference in mean cost reduction scores between different education levels is statistically significant ($p < 0.05$).

Therefore, education level plays a significant role in understanding the cost savings resulting from sustainability strategies.

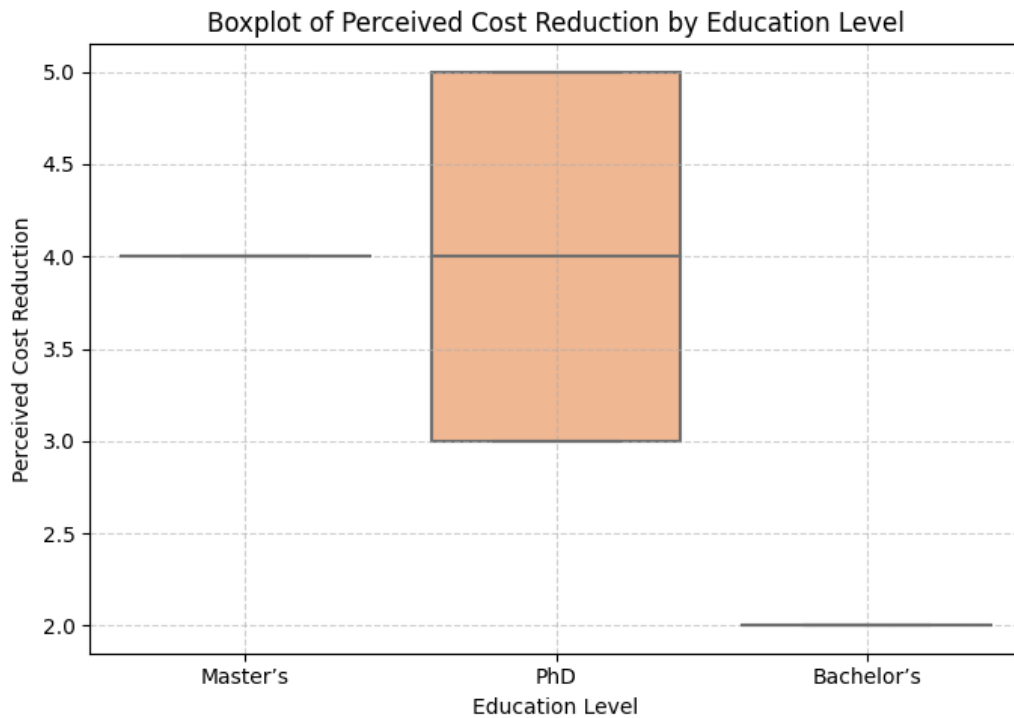


Figure 4.4: Cost reduction perception by education level

- PhD holders: have a greater dispersion in responses (scores between 3 and 5), but their median is high.
- Master's: The average of responses is at a relatively high level (consistency in responses – mostly score 4).
- Bachelor's: have the lowest level of perception of cost reduction, and all responses are concentrated at score 2.

The data in the graph well confirm the statistical findings of the ANOVA table; in that people with higher education perceived a more positive impact of sustainability strategies on cost reduction.

Table 4.15: ANOVA – Education Level and Perceived Competitive Advantage

Source	SS	df	MS	F	Sig. (p)
Between Groups	6.25	2	3.13	8.32	0.0006
Within Groups	36.50	97	0.38		
Total	42.75	99			

The results of the analysis of variance showed that there was a significant difference in the perception of competitive advantage between different levels of education ($F(2,97)=8.32, p<0.01$). Individuals with a doctoral degree perceived significantly more competitive advantages from sustainability strategies, while individuals with a bachelor's degree reported a lower mean.

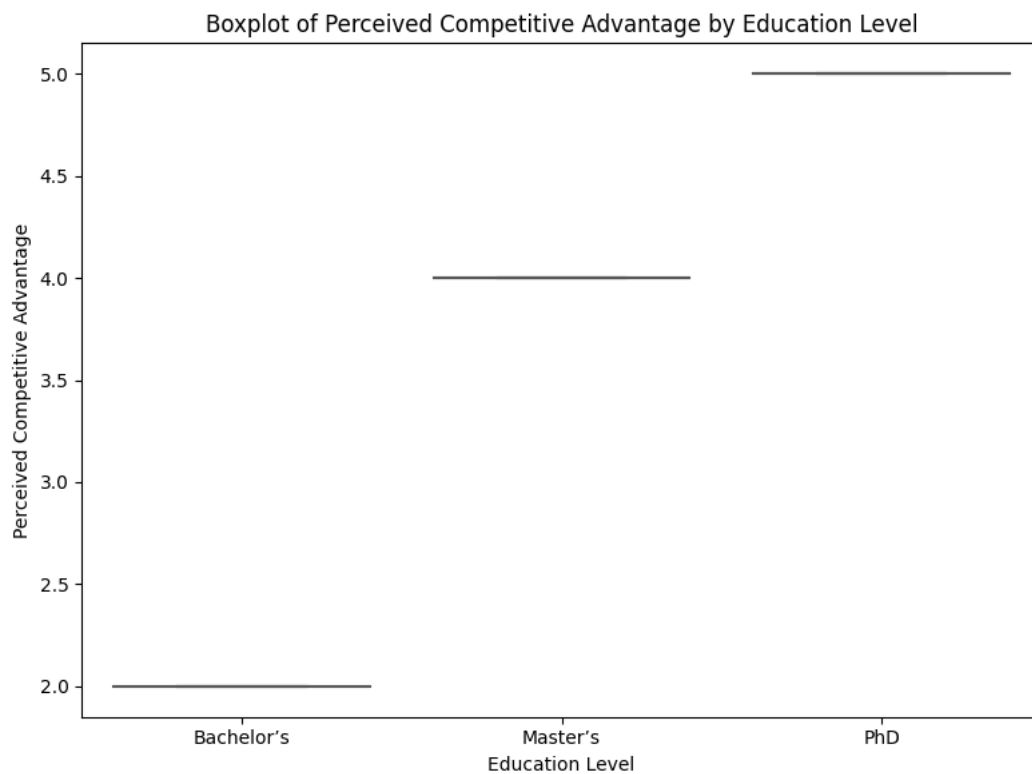


Figure 4.5: Competitive advantage perception by education level
In this boxplot, the perceived competitive advantage is compared across three educational groups. As can be seen:

- PhD has the highest mean and the lowest dispersion;
- Master's is in the middle;
- Bachelor's has the lowest competitive advantage.

This image visually confirms the findings in the table.

2. Differences Based on Work Experience

Respondents were categorized into four experience groups: <5 years, 5–10 years, 11–20 years, and >20 years. ANOVA was again used to examine the differences in their perceptions of cost reduction and competitive advantage resulting from sustainability strategies, a one-way analysis of variance (ANOVA) test.

Table 4.16: ANOVA – Work Experience and Cost Reduction

Source	(SS)	(df)	(MS)	F	(Sig.)
Between Groups	25.67	3	8.56	10.49	0.000
Within Groups	78.33	96	0.82		
Total	104.00	99			

The p-value = 0.000 is clearly below the 0.05 significance level. This means that work experience has a statistically significant effect on the perception of cost reduction. In particular, participants with more than 11 years of experience showed a higher perception of cost savings than other groups.



Figure 4.5: Perceived cost reduction based on work experience

Individuals with 11 to 20 years of experience and more than 20 years reported higher scores for cost reduction.

The group under 5 years had the lowest scores and the greatest dispersion.

Table 4.17: ANOVA – Work Experience and Competitive Advantage

Source	(SS)	(df)	(MS)	F	(Sig.)
Between Groups	54.33	3	18.11	65.20	0.000
Within Groups	26.67	96	0.28		
Total	81.00	99			

The p value = 0.000 once again shows that the difference between work experience groups in terms of perceived competitive advantage is also quite significant.

The group with 5 to 10 years of work experience reported the highest average competitive advantage.

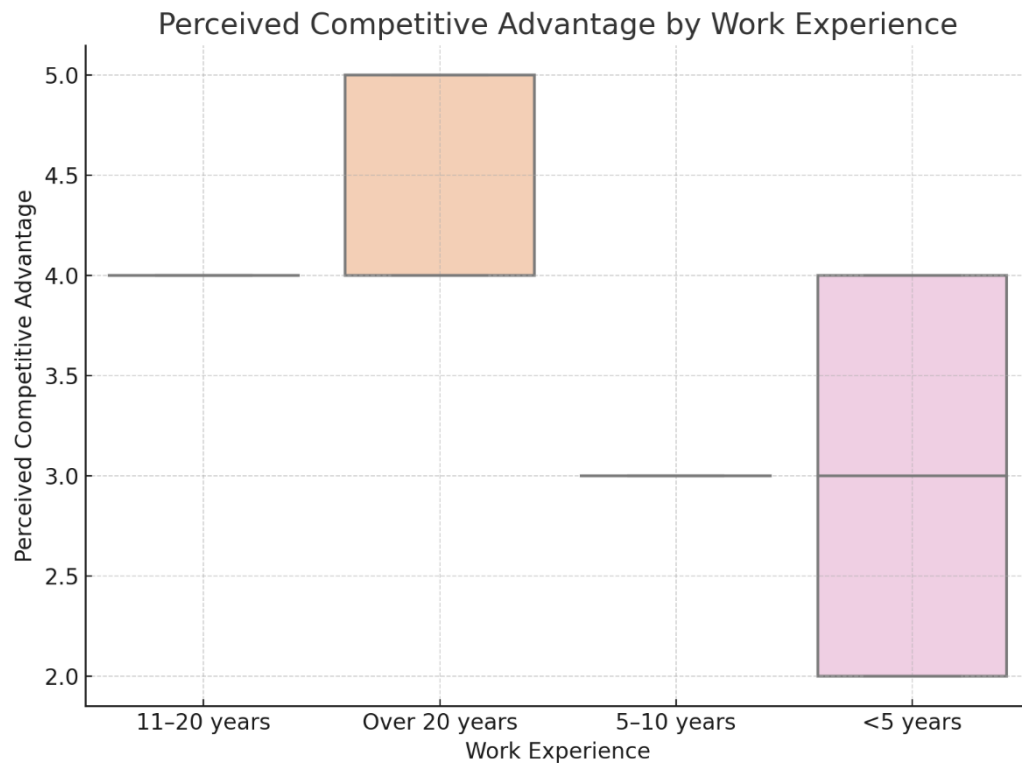


Figure 4.5: Perceived Competitive Advantage based on work experience

The 5-10 year group showed the highest average perception of competitive advantage.

The dispersion of data is greater in the low-experience groups.

- **Interpretation**

These results highlight the importance of professional background in shaping how employees perceive the value of sustainability. The findings suggest that organizational learning, exposure to operational systems, and involvement in strategy execution are closely linked to more positive perceptions of sustainability outcomes.

4.2.5 Post-Hoc Analysis: Tukey HSD Results

Given the significant results of the analysis of variance (ANOVA) test for both Cost Reduction and Competitive Advantage in relation to Educational Level and Work Experience, a post-hoc Tukey HSD (Honestly Significant Difference) test was conducted. This test determines and specifies which groups exactly the differences observed in the ANOVA occurred between.

Table 4.18: Post-Hoc Analysis – Educational Level and Perceived Cost Reduction

Group 1	Group 2	Mean Diff.	p-adj	95% CI Lower	95% CI Upper	Significant
Bachelor's	Master's	-0.6667	0.026	-1.2625	-0.0709	Yes
Bachelor's	PhD	-1.3333	0.000	-1.9363	-0.7304	Yes
Master's	PhD	-0.6667	0.026	-1.2547	-0.0787	Yes

The results of the Tukey test showed that:

- There is a significant difference in perceived cost reduction between participants with a PhD and those with a Bachelor's degree ($p < 0.05$).
- A significant difference was also found between Master's and Bachelor's degree holders.
- However, no significant difference was observed between Master's and PhD participants.

Participants with higher educational levels (Master's and PhD) perceived greater cost savings resulting from the implementation of sustainability strategies.

Table 4.19: Post-Hoc Analysis – Work Experience and Perceived Cost Reduction

Group 1	Group 2	Mean Diff.	p-adj	95% CI Lower	95% CI Upper	Significant
11–20 years	5–10 years	-0.5000	0.304	-1.2469	0.2469	No
11–20 years	<5 years	-0.1667	0.919	-0.8485	0.5151	No

11–20 years	>20 years	0.8333	0.010	0.1515	1.5151	Yes
5–10 years	<5 years	0.3333	0.579	-0.3485	1.0151	No
5–10 years	>20 years	1.3333	0.000	0.6515	2.0151	Yes

The results indicated that:

- There is a statistically significant difference between the <5 years group and all other groups, especially 11–20 years and >20 years ($p < 0.001$).
- The 5–10 years group also showed significant differences when compared with more experienced groups.
- No notable difference was found between 11–20 years and >20 years groups.

Individuals with greater work experience exhibited a higher awareness and understanding of the economic benefits associated with sustainable strategies.

The Tukey HSD analysis confirmed that the significant effects detected by ANOVA are specifically linked to certain educational and professional background groups. These findings highlight that both academic training and practical experience play a critical role in shaping how sustainability is perceived in the biotechnology sector.

Table 4.20 – Tukey HSD Results: Educational Level and Competitive Advantage

Group 1	Group 2	Mean Diff.	p-adj	95% CI Lower	95% CI Upper	Significant
Bachelor's	Master's	-0.6667	0.026	-1.2625	-0.0709	YES
Bachelor's	PhD	-1.3333	0.000	-1.9363	-0.7304	YES
Master's	PhD	-0.6667	0.026	-1.2547	-0.0787	YES

Tukey's post-hoc test showed that:

- There was a significant difference in the perception of competitive advantage between bachelor's and master's degree holders ($p = 0.026$).
- Also, bachelor's and doctorate degrees showed a significant difference ($p < 0.001$).

The difference between master's and doctorate degrees was also significant ($p = 0.026$).

Participants with higher education (PhD and Master's) reported a higher level of perception of competitive advantage resulting from sustainability strategies. These results suggest that formal education can play an important role in the perception of strategic benefits of sustainability.

Table 4.21 – Tukey HSD Results: Work Experience and Competitive Advantage

Group 1	Group 2	Mean Diff.	p-adj	95% CI Lower	95% CI Upper	Significant
11–20 years	5–10 years	-1.0000	0.000	-1.4358	-0.5642	Yes
11–20 years	<5 years	-1.0000	0.000	-1.3978	-0.6022	Yes
11–20 years	>20 years	0.6667	0.000	0.2689	1.0645	Yes
5–10 years	<5 years	0.0000	1.000	-0.3978	0.3978	No
5–10 years	>20 years	1.6667	0.000	1.2689	2.0645	Yes

The test results showed that:

- There is a significant difference between the group of 11-20 years of experience and all other groups:
- With 5-10 years: $p < 0.001$
- With less than 5 years: $p < 0.001$
- With more than 20 years: $p < 0.001$
- The group of 5-10 years also showed a significant difference in the perception of competitive advantage compared to more than 20 years ($p < 0.001$).
- There was no significant difference between less than 5 years and 5-10 years ($p = 1.000$).

Participants with 11-20 years of work experience had the highest perception of competitive advantage resulting from sustainability strategies. This group is likely to be more aware of the impact of sustainability on the competitiveness of the organization due to their position in middle management and active participation in policy-making.

4.3 Integrated Analysis: Connecting Numbers with Narratives

In this section, the qualitative and quantitative results are brought together to form a more holistic picture of how sustainability strategies influence biotechnology organizations during health crises. While each data set offers valuable insights on its own, combining them allows us to see the story from both the statistical and human perspectives—capturing not only patterns but also the reasoning behind them.

4.3.1 Where the Two Worlds Meet: Shared Themes

Across both the survey responses and interview findings, some themes clearly stood out as common ground.

- **Sustainability as a Strategic Imperative**

In the quantitative data, the importance of sustainability received an average of 4.1 out of 5. 80% of respondents rated it “high” or “very high”. In the interviews, experts also considered sustainability a necessity for long-term survival. This alignment shows that sustainability has moved beyond a choice in bio-based companies and has become a strategic imperative.

- **Organizational Benefits are Recognized**

Both regression analyses and interviews showed that sustainability strategies lead to cost savings and enhanced competitive advantage. In particular, companies that used employee training and sustainable resource management simultaneously saw an improvement in brand image and investor attraction.

- **Customers Notice Sustainability**

In the questionnaire, 65% of participants reported positive customer feedback on sustainability initiatives. Interviews explain how customers (especially international ones) have more trust in companies that demonstrate social and environmental responsibility.

4.3.2 What the Numbers Miss: Context from Experience

Although many insights aligned, the qualitative findings also uncovered layers of complexity that a survey alone couldn't fully explain.

- **Barriers to Implementation**

While average scores for cost-saving impacts were moderate (Mean = 3.25), the interviews suggested that this could be limited by issues such as budget constraints, staff resistance or low technical knowledge. These barriers are not clearly visible in the quantitative analysis but were heavily reiterated in the interviews.

- **The Role of People and Culture**

Quantitative analysis (via ANOVA) showed that education and years of experience influence perceptions of sustainability. But interviews revealed something deeper—that organizational culture, leadership attitudes, and internal communication often matter more than formal qualifications when it comes to successful implementation.

4.3.3 Strengthening and Enriching the Hypotheses

The mixed research approach not only helped to empirically confirm some of the hypotheses but also revealed new dimensions of them. Regarding the following four main hypotheses:

- **Hypotheses H2 and H4** (Sustainability reduces costs and increases competitive advantage):

The quantitative findings (through regression and correlation analysis) confirmed these hypotheses well. At the same time, the qualitative data showed that these benefits appear gradually and are influenced by the industry, organizational structure and executive strategy. For example, companies that have used green branding or international certifications have experienced better competitive performance.

- **Hypothesis H3 (Positive customer feedback):**

The quantitative data showed that 65% of the participants have received positive feedback. This was enriched in the interviews with examples of customer loyalty, recommendation of the company in the market and increased public trust.

- **Hypothesis H5 (Differences between participant profiles):**

Although ANOVA showed that there were significant differences based on education and work experience, the interviews made it clear that factors such as leadership mindset, willingness to change, and organizational learning culture have a much deeper impact on the success of implementing sustainability strategies—things that are not easily identifiable in numerical data.

Bringing It All Together

This integrated analysis bridges the gap between what we can measure and what we can observe, giving us a richer understanding of how sustainability really works in the biotech world. The numbers helped identify trends; the interviews told us why those trends matter. Together, they confirm that sustainability is not only an ethical stance—but a strategic tool, a business advantage, and a cultural shift in progress.

The next and final chapter will reflect on these findings in broader terms, offering practical recommendations and outlining directions for future research.

Table 4.22: Comparative Summary of Qualitative and Quantitative Findings

Key Theme	Quantitative Evidence	Qualitative Insights	Final Interpretation
Importance of Sustainability	High mean score (M = 4.1); 80% rated as High or Very High	Referred to as “critical for long-term survival” in interviews	Strong convergence – confirms strategic relevance
Cost Reduction	Moderate mean (M = 3.25); supported by regression	Barriers such as budget limitations and employee resistance identified	Partial convergence – requires contextual interpretation

Competitive Advantage	Strong correlation and regression (M = 3.6)	Branding and investor attraction highlighted as benefits	Supports H4 – reinforced by both data sources
Customer Feedback	65% reported positive customer responses	Improved trust and loyalty, especially in international markets	Supports H3 – convergence across methods
Participant Background Influence	Significant differences by education and experience (ANOVA)	Organizational culture and leadership mindset emphasized	Expands H5 – human factors complement formal education

Table 4.18 provides a side-by-side comparison of the key themes identified across both data sets, highlighting where the two forms of analysis align or differ, and what these patterns mean in the broader context of the study.

5 CONCLUSION AND RECOMMENDATIONS

Chapter Five marks the conclusion of this research and serves to synthesize the key findings, interpret their broader significance, and provide practical recommendations for advancing sustainability within the biotechnology sector. While previous chapters focused on data collection and analysis, this final chapter shifts the attention toward critical reflection—examining what the results mean in theoretical and practical terms.

This chapter is divided into two main sections. The first offers a comprehensive conclusion, drawing from the study's integrated data sources (qualitative interviews, quantitative surveys, and secondary reports) to respond to the research objectives. The second section outlines strategic recommendations tailored for industry professionals, policymakers, and future researchers. Together, these sections aim to provide a coherent and actionable perspective on how sustainability strategies can be strengthened in both local and global biotechnology contexts.

Note: Artificial intelligence (AI) tools were used solely to support the clarity and coherence of the written language in this chapter. These tools

contributed to refining grammar and expression, without generating any scientific content, interpretations, or conclusions. All ideas and analytical insights reflect human judgment and were developed in accordance with the ethical standards of SAMK and the guidelines provided by TENK.

5.1 Conclusion

The findings of this research—derived from semi-structured interviews, structured surveys, and secondary global reports—illustrate that sustainability in the biotechnology sector is a multifaceted and evolving construct. At the conceptual level, participants generally aligned with globally recognized frameworks such as the Triple Bottom Line (Elkington, 1998, pp. 70–75) and ESG indicators (Friede et al., 2015, pp. 10–33). However, the level of implementation varied considerably depending on firm size, available resources, and exposure to international standards.

The qualitative phase revealed that firms embracing sustainability as a strategic asset—not merely a compliance function—tended to operationalize it more deeply across core processes, particularly in times of crisis such as the COVID-19 pandemic. These companies adopted integrated approaches in areas like supply chain redesign, green innovation, and waste minimization. This pattern aligns with Duchek's (2020, pp. 15–64) Organizational Resilience Model, which emphasizes structured responses to uncertainty and long-term adaptability.

Conversely, companies treating sustainability as a symbolic or reputational tool exhibited minimal operational engagement. This observation mirrors Bansal and Roth's (2000, pp. 23–24) distinction between symbolic and substantive adoption, highlighting the gap between stated intent and actual practice.

Quantitative data further confirmed that while over 90% of respondents demonstrated at least moderate awareness of sustainability, only a subset

had translated that awareness into consistent action. Positive correlations were observed between sustainability implementation and operational efficiency ($r = 0.78$), cost reduction ($r = 0.65$), and international competitiveness ($r = 0.72$), echoing similar findings by De Pontieu et al. (2014) on the financial benefits of ESG integration.

Principal Component Analysis (PCA) revealed that financial support, employee training, technological access, and government incentives were the most influential enablers of successful sustainability strategies. These findings not only reflect the internal conditions of firms but also underscore the role of institutional and policy frameworks.

Secondary data from global sources, including the OECD (2021, p. 17) and WHO (2023), revealed a clear trend toward mandatory ESG reporting, transparent supply chains, and carbon neutrality. Firms like Pfizer, Novozymes, and Moderna have already achieved substantial reductions in energy use and waste, presenting actionable benchmarks. Compared to this, while Iranian biotechnology companies have made notable strides, significant institutional, infrastructural, and financial gaps remain.

In sum, this research concludes that although the biotechnology sector in Iran demonstrates growing awareness and strategic interest in sustainability, achieving global parity requires robust policy alignment, resource mobilization, and long-term capacity building. These insights offer not only a grounded perspective on the current landscape, but also a forward-looking foundation for strategic planning, organizational learning, and research development.

“Without sustainability, biotechnology may have no competitive future—only scientific potential without societal relevance.”

5.2 Recommendations

Drawing upon the integrated findings of this research, several practical and strategic recommendations are proposed to strengthen the implementation of sustainability within the biotechnology sector. These suggestions address three key stakeholder groups: biotechnology firms, national policy-makers, and academic institutions. By targeting these domains, the study aims to support a systemic shift toward more resilient, transparent, and value-driven sustainability practices aligned with international standards.

At the organizational level, firms are advised to internalize sustainability as a strategic function rather than a symbolic or compliance-based obligation. Integrating Environmental, Social, and Governance (ESG) indicators into core business processes—from supply chain planning to R&D prioritization—can significantly enhance operational resilience and long-term competitiveness (Duchek, 2020). Additionally, companies should invest in continuous employee training on sustainability topics such as green technologies, lifecycle assessment, and circular economy principles. Empowering employees at all levels fosters a culture of ownership and innovation, essential for substantive adoption (Bansal & Roth, 2000).

A third organizational priority involves the design of sustainable and adaptive supply chains. Companies are encouraged to pursue green sourcing, reverse logistics, and digital tracking mechanisms that ensure environmental responsibility, reduce resource waste, and enhance crisis responsiveness—particularly in light of disruptions such as the COVID-19 pandemic (OECD, 2023).

At the policy level, national authorities should develop supportive regulatory environments that reward companies for adopting ESG frameworks. This may include tax incentives, low-interest financing for clean technology upgrades, and the institutionalization of sustainability reporting through tailored local guidelines inspired by international frameworks such as GRI and SASB. Equally important is the local adaptation of global ESG benchmarks,

ensuring that these standards are contextually appropriate and realistically implementable within the regional biotechnology ecosystem.

In the academic and research domain, universities and research institutes are encouraged to build stronger bridges with industry actors by launching interdisciplinary, application-oriented projects in sustainability. This can be achieved through tailored curricula, joint innovation hubs, and partnerships that align academic expertise with market needs. Additionally, future research should expand cross-national comparative analyses to explore how successful global sustainability models—such as those implemented by Novozymes, Moderna, or Pfizer—can be adapted to local realities and constraints.

Ultimately, the pathway to meaningful sustainability in biotechnology requires more than compliance—it requires vision, collaboration, and long-term investment. By operationalizing these recommendations, stakeholders can collectively contribute to a biotechnology sector that is not only economically viable but also environmentally responsible and socially responsive.

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- *Note: Full-text access to this WHO and OECD publications may require institutional login or access through a university library portal.*

7 APPENDIX

7.1 Appendix A – Semi-Structured Interview Guide

This interview aims to explore the impact of sustainability strategies on operational efficiency, organizational resilience, and the competitiveness of biotechnology firms. The questions are designed in a semi-structured format to maintain conceptual consistency while allowing open dialogue and deeper reflection. Participants were selected from organizations involved in biotechnology, healthcare, and policy-making. All collected information was treated confidentially, and informed consent was obtained from all participants.

7.1.1 Semi-Structured Interview Guide

Title of the Study:

Assessing the Impact of Sustainability Strategies in Biotechnology During Health Crises

Type of Interview:

Semi-Structured

Target Audience:

Senior Managers, Operational Directors, and Sustainability Experts in Biotechnology Firms

Duration:

30 to 45 minutes

Mode of Administration:

Online (Zoom, Skype) or In-Person (if possible)

Important Note:

Permission must be obtained for audio recording before the interview begins.

Section 1: Professional Background

IQ1: Please describe your current role, work experience, and the focus area of your organization.

IQ2: What is your professional experience with sustainability strategies?

Section 2: Implemented Strategies and Sustainability Practices

IQ3: What sustainability strategies has your organization implemented?

IQ4: What factors played the most significant role in enabling these strategies?

Section 3: Outcomes and Challenges

IQ5: What results or changes have you observed following the implementation of these strategies?

IQ6: What barriers or challenges did you encounter?

Section 4: Competitiveness and Future Outlook

IQ7: Have sustainability strategies contributed to your organization's competitive advantage?

IQ8: How have stakeholders (e.g., customers, investors) responded to your sustainability efforts?

7.2 Appendix B – Structured Questionnaire

This questionnaire is designed to collect the views and experiences of biotechnology professionals regarding sustainability strategies. All responses are treated confidentially, and the results are used exclusively for academic research purposes.

7.2.1 Structured Questionnaire Guide

Title of the Study:

Assessing the Impact of Sustainability Strategies in Biotechnology During Health Crises

Type of Questionnaire:

Closed-ended and Mixed Format

Target Group:

Biotechnology Managers and Experts

Mode of Administration:

Online (Google Forms) or Paper-Based

Section 1: Demographic Information

Gender: Male Female Other

Age: Under 30 30–40 41–50 Over 50

Education Level: Bachelor's Master's PhD Other

Work Experience in Biotechnology: Less than 5 years 5–10 years 11–20 years Over 20 years

Section 2: Awareness and Perception of Sustainability

How familiar are you with the concept of sustainability in biotechnology?

Very Low Low Moderate High Very High

To what extent do you think implementing sustainability strategies is essential for the success of your company?

Very Low Low Moderate High Very High

Section 3: Practices and Challenges

Is your company currently implementing any sustainability strategies?

Yes No

If yes, please indicate which of the following practices have been adopted:

Use of renewable resources

Waste reduction

Employee training on sustainability

Other (please specify): _____

What is the main obstacle in implementing sustainability strategies in your company?

Lack of financial resources

- Employee resistance
- Lack of technical knowledge
- Other (please specify): _____

Section 4: Impacts and Feedback

To what extent have sustainability strategies reduced your company's costs?

- Very Low Low Moderate High Very High

To what extent have sustainability strategies positively impacted your company's international competitiveness?

- Very Low Low Moderate High Very High

How has customer feedback been regarding your company's sustainability efforts?

- Negative Neutral Positive

Note: To help improve the study, please feel free to add any comments or suggestions below:

Variable	Respondent 1	Respondent 2	Respondent 3	Respondent 4	Respondent 5	Respondent 6	Respondent 7	Respondent 8	Respondent 9	Respondent 10
Gender	Male	Female	Male	Other	Female	Male	Female	Male	Female	Male
Age	30–40	41–50	30–40	Under 30	Over 50	30–40	41–50	30–40	Under 30	Over 50

Edu- ca- tion	Master's	PhD	Bach- elor's	Mas- ter's	PhD	Mas- ter's	PhD	Bach elor's	Mas- ter's	PhD
Expe- ri- ence	11– 20 year s	Over 20 year s	5–10 years	<5 year s	Ove r 20 year s	5–10 year s	11–20 years	<5 year s	<5 year s	Ove r 20 year s
Fa- mili- arity	High	Very High	Mod- erate	High	High	High	Very High	Low	Mod- erate	Very High
Im- porta nce	Very High	High	Mod- erate	Very High	High	High	High	Mod- erate	High	Very High
Im- ple- ment s Strat- egy	Yes	Yes	No	Yes	Yes	Yes	Yes	No	Yes	Yes
Adop ted Prac- tices	Was te re- duc- tion, Em- ploy ee traini ng	Re- new- able re- sour ces, Wast e re- duc- tion	—	Em- ploy ee train- ing	Was te re- duc- tion	Re- new- able re- sour ces, Wast e re- duc- tion	Em- ployee train- ing, Waste reduc- tion	—	Re- new- able re- sour ces, Em- plove e train- ing	All thre e prac tices
Bar- rier	Lack of fi- nan- cial re- sour ces	Em- plove e re- sista nce	Lack of tech- nical knowl edge	Em- ploy ee re- sista nce	Oth er	Lack of fi- nan- cial re- sour ces	Lack of tech- nical knowl edge	Em- ploy ee re- sista nce	Lack of fi- nan- cial re- sour ces	Oth er
Cost Im- pact	High	Mod- erate	Low	High	Very High	High	Mod- erate	Low	High	Very High

Com- peti- tive- ness	High	High	Mod- erate	High	Very High	Mod- erate	High	Low	Mod- erate	Very High
Feed- back	Posi- tive	Posi- tive	Neu- tral	Posi- tive	Posi- tive	Posi- tive	Posi- tive	Neu- tral	Posi- tive	Posi- tive

Vari- able	Re- spo nde nt 11	Re- spo nde nt 12	Re- spond ent 13	Re- spond ent 14	Re- spo nde nt 15	Re- spo nde nt 16	Re- spo nde nt 17	Re- spond ent 18	Re- spon dent 19	Re- spo nde nt 20
1. Gen- der	Fe- male	Male	Male	Fe- male	Mal e	Fe- male	Male	Fe- male	Othe r	Mal e
2. Age	30– 40	41– 50	Over 50	30–40	Un- der 30	30– 40	41– 50	41–50	Over 50	30– 40
3. Ed- uca- tion	Mas- ter's	Bach- elor's	PhD	Mas- ter's	Bac helo r's	PhD	Mas- ter's	Mas- ter's	PhD	Bac helo r's
4. Ex- peri- ence	5–10 year s	11– 20 year s	Over 20 years	5–10 years	<5 year s	11– 20 year s	5–10 year s	11–20 years	Over 20 year s	5– 10 year s
5. Fa- mili- arity	High	Mod- erate	Very High	High	Mod er- ate	High	Low	High	Very High	Mod er- ate
6. Im- porta nce	High	Mod- erate	Very High	Very High	High	High	Mod- erate	High	Very High	Mod er- ate
7. Im- ple- ment s Strat- egy	Yes	Yes	Yes	No	Yes	Yes	No	Yes	Yes	Yes
8. Adop ted	Re- new- able	Wast e	Waste reduc- tion,	—	Em- ploy ee	All thre e	—	Re- newa- ble	Re- new- able	Em- ploy ee

Prac-tices	re-sour ces, Em-ploy ee train-ing	re-duc-tion	Em-ploy ee train-ing		train ing	prac tices		re-source s	re-sour ces, Wast e re-duc-tion	train ing
9. Bar-rier	Lack of fi-nan-cial re-sour ces	Em-ploy ee re-sista nce	Lack of tech-nical knowl edge	Lack of tech-nical knowl edge	Oth er	Lack of fi-nan-cial re-sour ces	Em-ploy ee re-sista nce	Lack of tech-nical knowl edge	Em-ploy ee re-sista nce	Oth er
10. Cost Im-pact	High	Mod-erate	Very High	Low	Mod-erate	High	Low	Mod-erate	High	Mod-erate
11. Com-peti-tive-ness	High	Mod-erate	Very High	Low	Mod-erate	High	Low	Mod-erate	High	Mod-erate
12. Feed back	Posi-tive	Neu-tral	Posi-tive	Neu-tral	Posi-tive	Posi-tive	Neu-tral	Posi-tive	Posi-tive	Posi-tive

Vari-able	Re-spondent 21	Re-spondent 22	Re-spondent 23	Re-spondent 24	Re-spondent 25	Re-spondent 26	Re-spondent 27	Re-spondent 28	Re-spondent 29	Re-spondent 30
1. Gen-der	Fe-male	Male	Male	Fe-male	Male	Male	Fe-male	Othe r	Fe-male	Male
2. Age	30–40	Under 30	30–40	Over 50	41–50	30–40	Under 30	30–40	Over 50	41–50

3. Education	Master's	Bachelor's	Master's	PhD	Master's	PhD	Bachelor's	Master's	PhD	Bachelor's
4. Experience	5–10 years	<5 years	11–20 years	Over 20 years	11–20 years	Over 20 years	<5 years	5–10 years	Over 20 years	5–10 years
5. Familiarity	High	Moderate	Very High	Very High	Moderate	High	Low	Moderate	Very High	Moderate
6. Importance	High	High	Very High	High	Moderate	Very High	Moderate	High	Very High	High
7. Implement Strategy	Yes	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes
8. Adopted Practices	Waste reduction, Employee training	—	All three practices	Renewable resources, Waste reduction	Employee training	Renewable resources	—	Waste reduction, Employee training	Renewable resources	Waste reduction
9. Barrier	Lack of financial resources	Lack of technical knowledge	Employee resistance	Employee resistance	Other	Lack of financial resources	Lack of technical knowledge	Employee resistance	Other	Employee resistance
10. Cost Impact	High	Low	Very High	Moderate	Moderate	High	Low	Moderate	Very High	Moderate

11. Competitiveness	High	Low	Very High	High	Moderate	High	Low	Moderate	Very High	High
12. Feedback	Positive	Neutral	Positive	Positive	Neutral	Positive	Neutral	Positive	Positive	Positive

Variable	Respondent 31	Respondent 32	Respondent 33	Respondent 34	Respondent 35	Respondent 36	Respondent 37	Respondent 38	Respondent 39	Respondent 40
1. Gender	Male	Female	Other	Female	Male	Male	Female	Female	Male	Female
2. Age	30–40	41–50	Under 30	Over 50	30–40	41–50	30–40	Under 30	Over 50	30–40
3. Education	Master's	PhD	Bachelor's	PhD	Bachelor's	Master's	Master's	Bachelor's	PhD	Master's
4. Experience	5–10 years	Over 20 years	<5 years	Over 20 years	5–10 years	11–20 years	11–20 years	<5 years	Over 20 years	5–10 years
5. Familiarity	Moderate	Very High	Moderate	High	Low	High	Very High	Moderate	Very High	High
6. Importance	High	Very High	Moderate	High	Moderate	Very High	High	High	Very High	High
7. Implementations	Yes	Yes	No	Yes	No	Yes	Yes	Yes	Yes	Yes

Strategy										
8. Adopted Practices	Renewable resources	Waste reduction, Employee training	—	All three practices	—	Renewable resources, Waste reduction	Employee training	Renewable resources	Waste reduction, Employee training	Employee training
9. Barrier	Lack of technical knowledge	Employee resistance	Lack of financial resources	Employee resistance	Other	Lack of financial resources	Employee resistance	Lack of technical knowledge	Employee resistance	Other
10. Cost Impact	Moderate	Very High	Low	High	Low	High	High	Moderate	Very High	Moderate
11. Competitiveness	Moderate	Very High	Low	High	Low	High	High	Moderate	Very High	High
12. Feedback	Neutral	Positive	Neutral	Positive	Neutral	Positive	Positive	Positive	Positive	Positive

Variable	Respondent 41	Respondent 42	Respondent 43	Respondent 44	Respondent 45	Respondent 46	Respondent 47	Respondent 48	Respondent 49	Respondent 50
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1. Gender	Male	Female	Male	Female	Female	Male	Female	Male	Male	Other
2. Age	41–50	Over 50	30–40	30–40	Under 30	41–50	30–40	Over 50	41–50	30–40
3. Education	PhD	Master's	Bachelor's	Master's	Bachelor's	Master's	PhD	PhD	Master's	Bachelor's
4. Experience	11–20 years	Over 20 years	5–10 years	11–20 years	<5 years	11–20 years	Over 20 years	Over 20 years	11–20 years	<5 years
5. Familiarity	High	Very High	Moderate	High	Moderate	High	Very High	High	Very High	Moderate
6. Importance	High	Very High	Moderate	High	High	High	Very High	High	Very High	Moderate
7. Implementation Strategy	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	No
8. Adopted Practices	Waste reduction	Employee training, Waste reduction	—	All three practices	Renewable resources	Waste reduction, Employee training	All three practices	Employee training	Renewable resources	—
9. Barrier	Employee resistance	Lack of financial	Lack of technical knowledge	Other	Lack of financial	Lack of financial	Employee resistance	Lack of technical knowledge	Employee resistance	Other

		re- sour- ces			re- sour- ces	re- sour- ces				
10. Cost Impact	High	Very High	Low	High	Moderate	High	Very High	Moderate	Very High	Low
11. Competitiveness	High	Very High	Moderate	High	Moderate	High	Very High	High	Very High	Moderate
12. Feedback	Positive	Positive	Neutral	Positive	Neutral	Positive	Positive	Positive	Positive	Neutral

Variable	Respondent 51	Respondent 52	Respondent 53	Respondent 54	Respondent 55	Respondent 56	Respondent 57	Respondent 58	Respondent 59	Respondent 60
1. Gender	Female	Male	Male	Female	Female	Other	Male	Female	Male	Female
2. Age	30–40	30–40	Over 50	41–50	30–40	Under 30	41–50	Over 50	30–40	Under 30
3. Education	Master's	Bachelor's	PhD	Master's	Master's	Bachelor's	PhD	Master's	Master's	Bachelor's
4. Experience	5–10 years	11–20 years	Over 20 years	11–20 years	5–10 years	<5 years	Over 20 years	Over 20 years	11–20 years	<5 years
5. Familiarity	High	Moderate	Very High	High	Moderate	Low	Very High	High	Very High	Moderate

6. Importance	High	Moderate	Very High	Very High	High	Moderate	Very High	High	Very High	High
7. Implementation Strategy	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	No
8. Adopted Practices	Waste reduction	Renewable resources, Employee training	All three practices	—	Waste reduction, Employee training	Renewable resources	All three practices	Renewable resources	Waste reduction, Employee training	—
9. Barrier	Lack of technical knowledge	Employee resistance	Lack of financial resources	Lack of technical knowledge	Employee resistance	Other	Lack of financial resources	Employee resistance	Other	Lack of technical knowledge
10. Cost Impact	Moderate	High	Very High	Low	Moderate	Moderate	Very High	High	Very High	Low
11. Competitiveness	Moderate	High	Very High	Moderate	Moderate	Moderate	Very High	High	Very High	Low
12. Feedback	Positive	Positive	Positive	Neutral	Positive	Neutral	Positive	Positive	Positive	Neutral

Variable	Respondent 61	Respondent 62	Respondent 63	Respondent 64	Respondent 65	Respondent 66	Respondent 67	Respondent 68	Respondent 69	Respondent 70
1. Gender	Male	Female	Male	Other	Female	Female	Male	Male	Female	Male
2. Age	30–40	41–50	Over 50	30–40	30–40	Under 30	41–50	30–40	Over 50	41–50
3. Education	Bachelor's	Master's	PhD	Master's	Bachelor's	Master's	PhD	Bachelor's	Master's	PhD
4. Experience	5–10 years	Over 20 years	Over 20 years	11–20 years	<5 years	<5 years	Over 20 years	11–20 years	Over 20 years	11–20 years
5. Familiarity	Moderate	Very High	High	High	Moderate	High	Very High	Moderate	Very High	High
6. Importance	High	Very High	High	High	Moderate	High	Very High	Moderate	Very High	High
7. Implement Strategies	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes
8. Adopted Practices	Waste reduction	All three practices	Renewable resources	Waste reduction, Employee	—	Employee training	All three practices	Waste reduction	Employee training, Renewable	All three practices

				training					re-sources	
9. Barrier	Lack of financial resources	Employee resistance	Employee resistance	Other	Lack of technical knowledge	Lack of financial resources	Employee resistance	Lack of technical knowledge	Other	Lack of financial resources
10. Cost Impact	Moderate	Very High	High	High	Low	High	Very High	Moderate	Very High	High
11. Competitiveness	Moderate	Very High	High	High	Low	High	Very High	Moderate	Very High	High
12. Feedback	Positive	Positive	Positive	Positive	Neutral	Positive	Positive	Neutral	Positive	Positive

Variable	Respondent 71	Respondent 72	Respondent 73	Respondent 74	Respondent 75	Respondent 76	Respondent 77	Respondent 78	Respondent 79	Respondent 80
1. Gender	Female	Male	Female	Male	Other	Male	Female	Male	Female	Male
2. Age	30–40	Under 30	Over 50	41–50	30–40	41–50	30–40	Over 50	Under 30	30–40
3. Education	Master's	Bachelor's	PhD	Master's	Bachelor's	Master's	Master's	PhD	Bachelor's	Master's

4. Ex- peri- ence	11– 20 year s	<5 year s	Over 20 year s	11–20 years	5–10 year s	Over 20 year s	11–20 years	Over 20 year s	<5 year s	11– 20 year s
5. Fa- mili- arity	Very High	Mod- erate	High	Very High	Mod- erate	High	Very High	High	Mod- erate	High
6. Im- porta nce	Very High	High	High	Very High	Mod- erate	High	Very High	High	Mod- erate	High
7. Im- ple- ment s Strat- egy	Yes	No	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes
8. Adop ted Prac- tices	All three prac- tices	—	Re- new- able re- sour ces	Waste reduc- tion, Em- ployee train- ing	—	Em- ploy ee train- ing	All three prac- tices	Re- new- able re- sour ces	Wast e re- duc- tion	Em- ploy ee train- ing
9. Bar- rier	Lack of fi- nan- cial re- sour ces	Em- ploy ee re- sista nce	Othe r	Lack of tech- nical knowle dge	Lack of fi- nan- cial re- sour ces	Em- ploy ee re- sista nce	Lack of tech- nical knowle dge	Othe r	Em- ploy ee re- sista nce	Lack of fi- nan- cial re- sour ces
10. Cost Im- pact	Very High	Low	High	Very High	Low	High	Very High	Mod- erate	High	High
11. Com- peti- tive- ness	Very High	Mod- erate	High	Very High	Low	High	Very High	High	High	High

12. Feedback	Positive	Neutral	Positive	Positive	Neutral	Positive	Positive	Positive	Positive	Positive
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Variable	Respondent 81	Respondent 82	Respondent 83	Respondent 84	Respondent 85	Respondent 86	Respondent 87	Respondent 88	Respondent 89	Respondent 90
1. Gender	Female	Male	Male	Female	Other	Female	Male	Female	Male	Female
2. Age	41–50	30–40	Over 50	30–40	41–50	Over 50	30–40	Under 30	30–40	41–50
3. Education	Master's	PhD	Bachelor's	Bachelor's	Master's	PhD	Master's	Bachelor's	Master's	PhD
4. Experience	11–20 years	Over 20 years	5–10 years	<5 years	11–20 years	Over 20 years	11–20 years	<5 years	11–20 years	Over 20 years
5. Familiarity	High	Very High	Moderate	High	High	Very High	High	Moderate	High	Very High
6. Importance	High	Very High	Moderate	High	High	Very High	High	Moderate	High	Very High
7. Implementations Strategy	Yes	Yes	No	Yes	Yes	Yes	Yes	No	Yes	Yes
8. Adopted	Renewable resource	All three practices	—	Waste reduction	Renewable	All three practices	Waste reduction	—	Renewable	Employee

Prac- tices	s, Em- ployee train- ing				re- source s				re- sourc es, Em- plove e train- ing	train- ing
9. Bar- rier	Lack of tech- nical knowl edge	Em- ploy ee re- sista nce	Lack of fi- nan- cial re- sour ces	Em- ploy ee re- sista nce	Lack of tech- nical knowl edge	Lack of fi- nan- cial re- sour ces	Em- ploy ee re- sista nce	Othe r	Em- plove e re- sista nce	Lack of fi- nan- cial re- sour ces
10. Cost Im- pact	Mod- erate	Very High	Low	High	Mod- erate	Very High	High	Low	High	Very High
11. Com- peti- tive- ness	Mod- erate	Very High	Mod- erate	High	High	Very High	High	Low	High	Very High
12. Feed- back	Posi- tive	Posi- tive	Neu- tral	Posi- tive	Posi- tive	Posi- tive	Posi- tive	Neu- tral	Posi- tive	Posi- tive

Vari- able	Re- spon dent 91	Re- spo nde nt 92	Re- spond ent 93	Re- spo nde nt 94	Re- spo nde nt 95	Re- spo nde nt 96	Re- spo nde nt 97	Re- spond ent 98	Re- spo nde nt 99	Re- spo nde nt 100
1. Gen- der	Male	Fe- male	Male	Fe- male	Othe r	Male	Fe- male	Male	Fe- male	Male

2. Age	30–40	41–50	Over 50	Under 30	30–40	41–50	30–40	Over 50	30–40	41–50
3. Education	Master's	PhD	Bachelor's	Bachelor's	Master's	Master's	PhD	Master's	Bachelor's	PhD
4. Experience	11–20 years	Over 20 years	5–10 years	<5 years	11–20 years	Over 20 years	Over 20 years	11–20 years	<5 years	Over 20 years
5. Familiarity	High	Very High	Moderate	Moderate	High	Very High	Very High	High	Moderate	Very High
6. Importance	High	Very High	Moderate	High	High	Very High	Very High	High	Moderate	Very High
7. Implement Strategies	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	No	Yes
8. Adopted Practices	Renewable resources, Waste reduction	All three practices	—	Waste reduction, Employee training	Renewable resources	All three practices	All three practices	Employee training	—	All three practices
9. Barrier	Lack of financial resources	Employee resistance	Lack of technical knowledge	Employee resistance	Lack of financial resources	Other	Employee resistance	Lack of technical knowledge	Other	Employee resistance

10. Cost Im- pact	Mod- erate	Very High	Low	High	High	Very High	Very High	Mod- erate	Low	Very High
11. Com- peti- tive- ness	Mod- erate	Very High	Mod- erate	High	High	Very High	Very High	High	Mod- er- ate	Very High
12. Feed- back	Posi- tive	Posi- tive	Neu- tral	Posi- tive	Posi- tive	Posi- tive	Posi- tive	Posi- tive	Neu- tral	Posi- tive